Pesticide Reducing Instruments
– An Interdisciplinary Analysis of effectiveness and optimality[1]

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Abstract

In the paper we combine several analytical tools in search of an effective pesticide reduction instrument and an optimal application of such an instrument. The tools under consideration are a CGE model used for evaluating the cost and to calculate general economic and sectoral consequences. The CGE model is linked to an agricultural sector model calculating the optimal use of land and application of pesticides. The agricultural sector model is then linked to a biological agent based simulation model (ABM) calculating changes in the population of a key species of farmland bird, due to changes in production and landscape. The results from the agricultural sector model are also used in a Bayesian network evaluation of pesticide usage and the leaching of pesticides to ground water.

In this combined model framework three scenarios are analyzed. All three scenarios are constructed such that they result in the same welfare implication (measured by national consumption in the CGE model). The scenarios are: 1) pesticide taxes resulting in a 25 percent overall reduction; 2) use of unsprayed field margins, resulting in the same welfare loss as in scenario 1; and finally 3) increased conversion to organic farming also resulting in the same welfare loss as in scenario 1.

Biological and geological results from the first part of our analysis allow us to select the most cost-effective instrument of those analysed for improving bio-diversity and securing drinking water. We proceed by including valuation studies of increased bio-diversity and secure water resources which thus contribute to a cost-benefit analysis. Furthermore, we address the question of optimal application of the selected instrument by calculation of the total abatement cost and benefit curves. From these curves we can then deduce the marginal benefit and cost curves, which allow us to determine the optimal instrument application.

Results suggest that Denmark could benefit from adaptation of unsprayed field margins and further that the optimal application of such margins should exceeds 20 percent of the total agricultural area.

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[1] Paper prepared for the 8th Annual Conference on Global Economic Analysis, June 9 - 11, 2005. Lübeck, Germany.

1. **Introduction**

For decades the concerns about the impact of modern agriculture's use of pesticides have been one of the most debated issues within Danish environmental politics. The agricultural sector accounts for 80 percent of the total pesticide usage in Denmark. The use of pesticides has contributed on a large scale to increased production and lower product prices. However, there are also negative environmental consequences of the use of pesticides. There is a risk that pesticides will pollute water resources (drinking water and ground water resources), pesticide usage is also expected to have a negative impact on the level of biodiversity as well as possible negative health effects.

Several action plans have aimed at reducing the use of pesticides. The fist was introduced in 1986 with the specific target of cutting both the pesticide treatment frequency (TFI) and active substance by 50 per cent. An evaluation of the plan concluded that treatment frequency was unchanged while active substance was reduced by 36 percent, but this was mostly due to introduction of new low dosage products. Therefore a pesticide tax was introduced in 1996 and subsequently doubled in 1998 resulting in a value tax of approximately 50 percent of the wholesale value.

In 1999 the Bichel Committee (Bichel Committee 1999) analysed legal, health and cost issues related to pesticide usage. Among other scenarios the committee analysed the consequences of a complete ban on pesticides. The works of the Bichel committee lead to the Pesticide Action Plan II in 2000 (Danish Ministry of Environment and Energy and the Ministry of Food, Agriculture and Fisheries 2000). The target in Pesticide Action Plan II was that the pesticide frequency index should be below 2.0 by 2002 (from 2.45 in 1999), the instrument used to achieve this target was; education, advice to farmers, specific targets for pesticide usage in different crops, and the layout of 20.000 hectare pesticide free buffer zones around lakes and alongside watercourses.

The latest and third action plan was passed in 2003 (Ministry of Environment and Ministry of Food Agriculture and Fisheries 2003). In this action plan the current situation is evaluated; the pesticide treatment frequency has fallen to 2.04 and buffer zones along watercourses and lakes are 8.000 hectares. The action plan set new targets for the development until 2009; the pesticide frequency index is targeted at 1.7 through increased advice to farmers, the plan also included 25.000 hectare buffer zones alongside targeted watercourses and lakes and advice on handling pesticides.

In the first action plan, targets were set with limited knowledge of the environmental effects and calculation of costs. The later action plans did include cost estimates to society of achieving a given reduction, but there have not yet been an economic evaluation of whether the total environmental benefits exceed the economic cost for achieving the goals. That is, a real social cost-benefit analysis including estimates of the monetary value of the environmental benefits has not been carried out.

This paper sets up a model framework that allows us to asses some of the main environmental benefits and to compare them with the social cost. The model framework combines several analytical tools; a CGE model used for evaluating the cost and calculating general economic and sector consequences. This CGE model is linked to an agricultural sector model calculating the optimal use of land, and the agricultural sector model is then linked to a biological agent based simulation model (ABM) calculating changes in the population of a key species of farmland bird, caused by changes in production and landscape. The results from the agricultural sector model are also used in evaluation of pesticide usage and the leaching of pesticides to the ground water.

We apply this model framework in search of an effective pesticide instrument and an optimal application of such an instrument by analysing three different scenarios:

1. Pesticide taxes resulting in a 25 percent overall reduction;
2. Use of unsprayed field margins, resulting in the same welfare loss as in scenario 1;
3. Increased conversion to organic farming also resulting in the same welfare loss as in scenario 1.

The remainder of this paper is organized into three sections: section 2 deals with the applied model framework and the linkage of the different models; in section 3 results are analysed to find the most effective instrument and optimal application of this instrument, section 4 concludes.

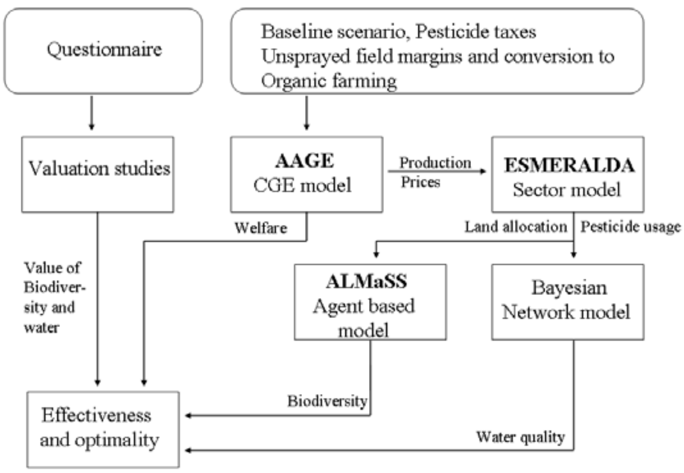
2. The model framework applied

This analysis focuses on reducing pesticide usage in Danish agriculture, which is the main user of pesticides in Denmark. The analysed instruments have different consequences for income, production, biodiversity, water quality etc. No single model addresses all these very different indicators. Hence, an integrated model framework has been constructed from different existing models that are in use in Denmark.

The models included in this framework are; a CGE model of the Danish economy; an econometric model of Danish agriculture; a biological agent-based simulation model of biodiversity in landscapes; a geological/hydrological assessment of pesticide leaching to groundwater using a Bayesian network analysis. All scenarios analysed are constructed to result in uniform welfare impacts approximated by national consumption. Results for biodiversity and groundwater in all scenarios are compared in terms of monetary values found through an economic valuation study of biodiversity and existing literature of valuation studies related to water issues. This final step allows for addressing the question of effectiveness and optimal application of an analysed instrument.

The combined model framework is illustrated in figure 2.1. with indication of how the models are linked.

Figure 2.1 The applied model framework



The following section 2.1- 2.5 contains short description of each model/tool in the framework.

2.1 AAGE (Agricultural **A**pplied **G**eneral **E**quilibrium Model of the Danish Economy)
AAGE (Frandsen 1995 et. al.; Adams 2000) is a dynamic general equilibrium model, but for the purpose of this analysis, the model was closed in a comparative-static fashion why we limit the model description to address the core comparative static nature of the model.

There are five types of agents in the AAGE model: industries, capital creators, households, governments, and foreigners. The current database of the model identifies 68 industries producing 76 commodities. For each industry there is an associated capital creator. The capital creators each produce units of capital that are specific to the associated industry. There is a single representative household and a single government sector. Finally, there are foreigners, whose behaviour is summarised by export demand curves for Danish products, and by supply curves for imports.

AAGE determines supplies and demands of commodities through optimising behaviour of agents in competitive markets. Optimising behaviour also determines industry demands for labour and capital.

The assumption of competitive markets implies equality between the producers' price and the marginal cost in each industry. Demand is assumed to equal supply in all markets other than the labour market (where excess supply conditions can hold). The government intervenes in markets by imposing sales taxes on commodities. This places wedges between the prices paid by purchasers and prices received by the producers. The model recognises margins (e.g. retail trade and freight) that are required for each market transaction (the movement of a commodity from the producer to the purchaser). The costs of the margins are included in purchasers' prices.

AAGE recognises two broad categories of inputs: intermediate inputs and primary factors. Firms in each industry are assumed to choose the mix of inputs, which minimises the costs of production for their level of output. They are constrained in their choice of inputs by nested production technologies (see appendix B). For the land-using industries (see appendix A), AAGE specifies nested substitutions between:

(a) capital, labour, energy and herbicides (CLEH);
(b) land, fertiliser and insecticides (LFI);
(c) CLEH and LFI (CLEHLFI); and
(d) CLEHLFI and an aggregate of remaining intermediate inputs

For non-land using industries, substitution is allowed between capital, labour and energy (CLE) and between CLE and aggregate non-energy intermediate inputs.

The representative household buys bundles of goods to maximise a utility function subject to a household expenditure constraint. The bundles are combinations of imported and domestic goods.

Capital creators for each industry combine inputs to form units of capital. In choosing these inputs, they minimise costs subject to technologies similar to that used for current production; the only difference being that they do not use primary factors. The use of primary factors in capital creation is recognised through inputs of the construction commodity.

The government demands commodities. In AAGE, there are several ways of handling these demands, including: (i) endogenously, by a rule such as moving government expenditures with household consumption expenditure or with domestic absorption; (ii) endogenously, as an instrument which varies to accommodate an exogenously determined target such as a required level of government deficit; and (iii) exogenously. In this paper both (iii) and (i) are used. In the baseline projection, government demands are exogenous while in the scenario analysis that changes in government demand follow household consumption expenditures.

Two categories of exports are defined: traditional, which are the main exported commodities, and non-traditional. Traditional export commodities face individual downward-sloping foreign demand schedules. The commodity composition of aggregate non-traditional exports is treated as a Leontief aggregate. Total demand is related to the average price via a single downward-sloping foreign demand schedule.

For all industries, AAGE includes the standard Armington specification for imported and domestically produced inputs. This assumes that users of a given commodity regard the domestic and the imported varieties of this commodity as imperfect substitutes. The Armington assumption is also used in input demands for industry investment and in household demands for consumption.

2.2 ESMERALDA (**E**conometric **S**ector **M**odel for **E**valuating **R**esource **A**pplication and **L**and use in **D**anish **A**griculture)

ESMERALDA (Jensen et al., 2001) describes production, input demands, land allocation, livestock density and various economic and environmentally relevant variables on representative Danish farms, and subsequently in the Danish agricultural sector at relevant levels of aggregation. These variables are assumed to be functions of the economic conditions facing the farms, including agricultural prices, economic support schemes, quantitative regulations etc. A basic assumption underlying the model's behavioural description is that farmers exhibit economic optimisation behaviour, which means that farmers allocate production to the lines of production with the highest economic return.

The model covers 15 lines of agricultural production and 11 agricultural outputs, including 7 cash crops, 2 cattle sectors, pigs and poultry. Along with these outputs, the model determines demands for 7 variable inputs in the short run. In the long run, the model determines changes in activity levels (land allocation and livestock density), input of capital and derived effects of outputs and demands for short-run variable inputs. Based on changes in prices, quantities etc., a number of economic variables can be determined: output value, variable costs, gross margin etc.

The main principle in the ESMERALDA model is to determine economic behaviour on a number of (approximately 2000) representative Danish farms, and subsequently aggregate these farm-level results to the relevant level or type of aggregation, e.g. the national, regional or municipal level or various typological farm aggregates. The economic behaviour at farm level includes determination of input composition, production intensity in individual lines of production as well as activity levels (numbers of hectares or animals) in each line of production. In each of these stages, the behavioural adjustments (e.g. adjustments to price changes) are determined by econometrically estimated behavioural parameters (e.g. price elasticities). Specifically, 8 sets of behavioural parameters have been estimated, representing 8 main farm types (part-time farms and full-time crop, cattle and pig farms on loamy and sandy soil, respectively). To each farm in the model, the most relevant of these 8 sets of parameters is attached. Behavioural parameters of the model are estimated econometrically using anonymous farm account data from 1000-2000 Danish farms per year in the period 1973/74 to 1997/98. These data comprise land use, livestock herds, labour and capital input, output revenues from different agricultural products and variable input costs at farm level.

In ESMERALDA, the allocation of agricultural area is determined by the development in relative economic returns in different crop sectors. It is assumed that the economic return in cattle production is channelled to the returns in roughage production (fodder beets, grass in rotation, permanent grasslands and silage cereals). On the other hand, the economic return to pig production is assumed not to affect the relative economic returns between different crops. Adjustments in land use is described in a pair wise nesting structure with corresponding farm-type dependent elasticities of transformation (part time farms and full time crop, cattle and pig farms on clay and sandy soils, respectively). See Jensen et al. (2001) for more description of the mechanisms.

Aggregation of farm results is carried out by means of an aggregation matrix, which contains aggregation factors for each model farm to each of the relevant aggregates. Hence, the aggregation matrix represents the farm structure related to the considered grouping of farms. The aggregation matrix is assumed to be independent of the economic conditions. This assumption might be considered as a restrictive one. However, a study by Wiborg et al. (1997) indicates that developments in the Danish farm structure seem to have been fairly unaffected by observed changes in prices and regulations.

In its present version, the model can be used for economic analysis of changed conditions in the Danish agricultural sector, e.g. price changes or restrictions on the production behaviour. The “bottom-up” approach of the model yields the opportunity to distinguish economic effects between different farm types, in different regions etc.

2.3 ALMaSS (Animal, Landscape and Man Simulation System)

An extension of the ALMaSS system (Topping et al., 2003), ToxImpact, together with a modified version of the skylark model described by Topping & Odderskær (2004) were used for these simulations. The properties of the model system are briefly described below.

The model consists of two separate but interacting models, a landscape simulation and the skylark model. The skylark model is an agent-based model describing skylark behaviour as a set of states linked by transitions, requiring the landscape simulation to act as a data server. The full model is described by Topping & Odderskær (2004) and unless noted below the values for parameters in the model are taken from Topping & Odderskær (2004). Hence, only the key differences between the agent-based model and the implementations of more traditional models are briefly described here.

The model is spatially explicit with a spatial resolution of $1m^2$ and a total landscape of 10 x 10 km^2 is modelled. Each vegetated landscape element is modelled separately with vegetation height, green- and total-biomass, and insect biomass sub-models, each driven by day-degree relationships.

A landscape element may be subject to management by man. Fields and linear habitats are managed in this way by mowing or other agricultural activities. These activities interact with the vegetation and insect models altering their values (e.g. insecticide spraying reduces insect abundance by 80% on the field where it is sprayed, insect abundance recovers back to pre-spray levels over a three-week period).

Individual farms manage crop rotations, and all fields are assigned to farm units. Fields are managed following crop husbandry plans designed to closely simulate the real management of each crop modelled in terms of logical and temporal relationships between agricultural operations. Any agricultural activity on a field is recorded and this information is available to any skylark in the simulation. These managements include the use of normal insecticides, herbicides, fungicides and growth regulators as the default.

Breeding skylarks are spatially located within the landscape and have a 250m-radius home range from which to find food. The location is dependent upon territory quality, which is expressed in terms of vegetation structure.

Development of chicks and eggs utilises the ambient temperature and the period of time the female spends incubating to determine the development rate of the eggs. Incubation time is determined by the time required for the female to fulfil her daily energy budget, which in turn depends on food availability and accessibility within the home range of the bird. Likewise, nestling growth and survival is determined by the rate of food supply by both parents. The energy balance of the nestlings determines their growth, and birds with negative growth rates for two consecutive days are assumed to die. The time to nest leaving is determined by the size of the nestling, and hence slower developing birds will leave the nest later. Nestlings that do not reach fledging weight after 14 days are assumed to die. Fledglings follow the same rules as nestlings, but gradually become self-sufficient, finding a linearly increasing proportion of their own food daily until total independency at 30 days old.

The spatial nature of the model permits explicit foraging behaviour to be modelled. Insect biomass is modelled explicitly for each vegetated element in the landscape, and the availability of insects is determined by the structure of the vegetation (see below).

Over-wintering mortality is modelled as a probabilistic mortality for the individual varying each year and being evenly distributed between 0.3 and 0.7. Other mortalities modelled explicitly are a daily probability of predation for all stages during the breeding season, estimated from Odderskær et al, (1997), and estimates of direct mortalities resulting from agricultural operations such as mechanical weeding.

In order to be able to handle the application of a pesticide to local areas at different times of the year and to model its fate, the landscape model incorporates a pesticide module. The pesticide module is responsible for ensuring that when a pesticide is sprayed in a landscape element, each 1 m^2 unit of that element has a pre-determined amount of pesticide residue deposited upon it. Twenty-four hours after application, the concentration of each 1-m^2 area is re-evaluated based on an estimated rate of decline. If a subsequent application were to occur in the same landscape element, the pesticide concentration is the sum of the new application residue and that remaining from the previous application. Once the concentration of residue is below 0.00001 mg kg-1 m^2, it is assumed to be zero to avoid infinitesimal calculations.

The pesticide module is also capable of simulating drift into neighbouring elements by a specified relationship relating the proportion of applied rate deposited to the distance from source. The minimum grid size for resolution of drift in the model was 4m, hence the amount applied to each grid cell was determined by taking the mean proportion for the whole grid cell.

Nest location is a critical part of the skylark's behaviour since the availability of nesting locations will determine the suitability of a territory. ALMaSS used vegetation height alone to determine nest site quality (Topping & Odderskær, 2004), however this has since been extended to use a combination of height and vegetation density to reflect the fact that skylarks can nest in relatively tall, but open crops. Both vegetation height and density has to comply with certain values for a nest location to be valid. The vegetation density is defined as the vegetation biomass in g dry matter m^2 divided by the height of the vegetation

Similarly the evaluation of an area by the male skylark for its suitability as territory also incorporates the density measure applied to vegetation by incorporating a relationship that has the property of penalising habitats with dense uniform vegetation.

Vegetation density is also used in addition to height to determine the hindrance factor associated with foraging in tall dense vegetation. Vegetation is assumed totally accessible if less than 30cm tall and with a density of 15 or less, above this the hindrance function calculates a hindrance factor rapidly decreases accessibility for vegetation. The hindrance factor calculated in this way is multiplied by the insect food biomass present at that location to determine the effective available biomass for the skylark.

There are a number of other constraints to nest location, also present in the original model. These are that the nest may not be within 50m of very tall structures (>3m), and must be inside the territory (not the home range). The search pattern determining the placement of the nest is a spiral search pattern starting at the centre of the territory and spiralling outwards. Hence, if suitable nest locations occur closer to the territory centre they will be selected over those in the periphery.

It should also be remembered that this selection will be time-specific. This is because the vegetation structure is changing on a daily basis, hence what would be a viable selection in May (e.g. in winter wheat), may no longer be viable in June. In this way the breeding window of Schläpfer (1988) is explicitly incorporated in the model.

2.4 Geological/hydrological assessment

The geological assessment uses a Bayesian network to asses the probability of pesticides being present in dinking water and also in the entire subsoil water resource (Henriksen et. al. 2004).

The strength of the Bayesian network is that very different assessments can be comprised within the framework; model results, monitoring results, assessment from expert's etc. In the process of setting up a Bayesian network relevant variables have to be chosen together with relevant states of each variable and links have to be defined (relationships between variables).

Using the network for analysis is the process of changing the states of one or several variables where after a new set of probabilities is calculated for each variable in the network. For this project the key variables are the probabilities of finding pesticides in concentration higher than the threshold limit in drinking water and in the subsoil water resource.

2.5 Economic valuation of biodiversity and groundwater

In order to compare the social costs of the different policy instruments with the economic values of the environmental benefits, it is necessary to obtain monetary estimates of the value of the environmental improvements. Several economic valuation methods have been developed over recent decades. These methods have been widely adopted in several countries, but so far only a modest number of valuation studies have been carried out in Denmark. Several international studies indicate that the (hypothetical) valuation methods yield upward-biased estimates of the willingness to pay for environmental improvements, List and Gallet (2001). Because of this apparent upward bias, the merits of the hypothetical valuation methods have been questioned. However, it should be taken into account that all decisions on environmental policy indirectly reflect implicit values of the environmental benefits compared to the social costs. In a valuation study the values are explicitly measured, which may increase the transparency of the decision process and ensure consistency in the decisions across sectors and over time.

In order to take into account some of the environmental gains from pesticide regulation, a valuation study has been carried out in order to estimate the value of increased biodiversity in rural areas, as indicated by a change in the population of birds in rural areas. The contingent ranking method was applied in this study (Bjørner et al. 2004).

A number of international studies have provided valuation estimates related to drinking water or groundwater contamination, e.g. values for ensuring that the level of drinking water and groundwater contamination does not exceed threshold limits. Results of these international studies have been applied in the analysis in order to provide a rough measure of the value of reducing pesticides in the drinking water.

3. Applying the model framework

In this section results from the analysis are presented and explained. First, we deal with the baseline focusing briefly on selected results until 2015. We proceed in 3.2 with a presentation of the three scenarios before proceeding with the analysis of results from all the models used in the combined framework. In section 3.3, we combine the model results with economic valuation studies trying to address effectiveness and cost-benefit issues. Furthermore, the economic evaluation allows us to address optimality in instrument usage

3.1 Baseline scenario

A baseline is constructed for the CGE model to introduce all ongoing policy developments and known shocks to the economy so as to ensure that the policy shocks are undertaken in an economy where all known developments and shocks are accounted for.

- The baseline scenario takes departure in current trends in economic growth, productivity etc. Developments in international markets are projected using an international economic model (GTAP), taking into account the effects of the EU enlargement from May 2004. The

baseline includes: Public consumption shock with actual development from 1995 to 2003, thereafter an annual increase of one percent per annum is assumed.
- Prices in foreign trade from GTAP model simulations; this also introduces effects of the enlargement of the European Union.
- Labour productivity, annual growth
  - assumed between 2.5 – 6 percent in agriculture
  - assumed 2.2 in manufacturing and 2.1 in services
- 2003 reform of the CAP
  - Intervention price cut for butter and skimmed milk powder
  - Compensatory payments to the dairy quota
  - Increase in the dairy quota
  - Full decoupling of hectare premium
  - Partly decoupling of animal premium
  - Modulation of direct support
- Action Plan for the Aquatic Environment III
  - Phosphorus taxes – Revenues return to the agricultural sector
  - Reducing area with high production intensity – Compensation payments to land
  - Late crops requirements tightened
  - Manure utilisation requirements tightened
- Pesticide taxes introduce in the 1995 – 2003 period

The return to capital is assumed to be determined by the rate of return on the world market and this rate of return is assumed to remain fixed throughout all scenarios. Total employment is assumed exogenous and with fixed rate of return, capital is determined on the factor frontier thus effectively determine GDP from the supply-side. With capital determined on the supply side investment are also determined. Fixing the trade balance as a fraction of GDP finally determines national consumption (public and private consumption).

In the baseline scenario, public consumption is assumed truly exogenous while in the pesticide reduction scenarios public and private consumption are linked together and therefore effectively determined by the trade balance requirement.

3.1.1 Results

The assumed changes in productivity lead to an increase in effective labour units throughout the baseline period and consequently to a total increase in GDP of 53.8 percent or an average of 2.2 percent per year. The growth leads to an increase in capital stock of 51.9 percent (2.1 percent per year).

With assumed shocks to import and export prices the domestic price level is determined to ensure that the trade balance as a fraction of GDP remains fixed. A decrease in the terms of trade ensures this and hence real exports grow faster than real imports. With the trade balance determined and investment effectively determined by capital growth, national consumption is determined, and since we have an exogenous assumption on public consumption, growth in private consumption can be determined at 2.5 percent per year.

Table 3.1 Macroeconomic impacts of baseline 1995 – 2015 as calculated by AAGE				
	1995-level	Baseline		
	Bill. DKK.	Bill. DKK. 2003	Percent	Anual pct.
Real GDP	1037.7	558.8	53.8	2.2
Real private consumption	511.1	321.8	63.0	2.5
Real public consumption	260.3	81.6	31.3	1.4
Real investments	189.3	93.9	49.6	2.0
Real stocks	39.3	0.0	0.0	0.0
Real exports	296.0	176.4	59.6	2.4
Real imports	258.2	104.3	40.4	1.7
Real capital stock			51.9	2.1
Welfare	771.4	405.3	52.5	2.1

The baseline scenario implies some changes in the agricultural sector, due to changes in foreign and domestic demands as well as changes in the supply conditions caused by e.g. environmental regulations and reforms of the Common Agricultural Policy. These changes are used in the linkage (prices and production) from AAGE to the ESMERALDA model resulting in a baseline projection for aggregate use of land as shown in Table 3.2.

Table 3.2 Land use as calculated by ESMERALDA		
1000 ha	Basis 2002	Baseline projection
Wheat	602	619
Other grains	910	789
Peas	41	7
Rapeseed	67	10
Seeds for sowing	68	68
Potatoes	14	9
Sugar beets	58	60
Other cash crops	13	13
Fodder beets	9	9
Grass, rotation	178	194
Perm. grass	180	175
Silage cereals	233	285
Fallow	226	180
Total area	2.599	2.419

The cultivated area will be reduced by 180.000 hectares in the baseline projection, due to increased demand for land for other purposes (e.g. urban growth and afforestation). The reduction in cultivated area mainly takes place for “other grains” and rapeseed, due to the decoupling of agricultural support as a result of the 2003 reform of the Common Agricultural Policy. The area with roughage is increased. The latter effect is however due to some uncertainty, as it depends on the final implementation of the reform, which allows some flexibility for member states to maintain some degree of coupling between production and subsidy payments.

Table 3.3 Average treatment frequency index as calculated by ESMERALDA		
Standard doses per hectare	Basis 2002	Baseline projection
Herbicides	0,96	0,93
Fungicides	0,45	0,59
Insecticides	0,26	0,24
Growth regulators	0,20	0,18
Total	1,87	1,93

This shift in land allocation, including an increase in wheat area, leads to an increase in the average treatment frequency index (TFI), as far as the use of fungicides is concerned, cf. table 4.3.

ESMERALDA results for average TFI (table 3.3) and land use for 9 farm types and 17 crops (aggregated in table 3.2) are fed into ALMaSS thus predicting the future skylark population. Results are shown in table 3.4.

The baseline scenario results in a stable population of skylarks. The maximum population size was predicted to be approximately 150 birds per square kilometre. The average size of the floating population was 21%, meaning that in mid-May there was an average of 21% of adults that were not involved in breeding. This figure will also include those birds that have not yet started but will breed, and those which have just abandoned breeding (e.g. in winter crops), so it is likely to be an over-estimate. However, a figure of 21% represents a large buffer against poor breeding years and indicates a healthy population. In the baseline, the number of chicks per breeding female is calculated to 2.61. This figure is defined as the mean of the total annual output of young surviving to day 18 divided by the number of females which attempted breeding.

Table 3.4 Baseline skylark population as calculated by ALMaSS.

Population Mean	14997
Floating Population Proportion	0.21
No. Chicks per breeding female	2.61

As was the case with the biodiversity, the geological assessment is also linked to the combined model framework through results from ESMERALDA for allocation of land and pesticide treatments. Uncertainty exists in the relation between pesticide TFI and pesticide leaching. In the analysis a linear relation between the two is assumed, however considering two alternative assumptions; an S-curved relation and crop specific linear relationship.

Table 3.5 Baseline water results, percent contaminated water

	Linear	S-curve	Crop specific
Drinking water	8.10	6.90	5.50
Subsoil water	14.44	12.2	9.1

In the baseline the likelihood of finding pesticide in drinking water is estimated to 8.1 percent being lower under either of the two alternative assumptions. The probability of finding pesticides in the subsoil water resource is calculated to 14 percent also being assessed a little lower when using the two alternative specifications.

3.2 Scenarios

At all analytical levels the scenarios are measured against the baseline in the year 2015. The scenarios are:

1. Pesticide taxes resulting in a 25 percent overall reduction;
2. Use of unsprayed field margins, resulting in the same welfare loss as in scenario 1;
3. Increased conversion to organic farming also resulting in the same welfare loss as in scenario 1.

Following figure 2.1 we start out by evaluating the macroeconomic impacts of a pesticide tax resulting in a 25 percent reduction in overall pesticide use. Then we proceed to calculate the size of unsprayed field margins, by solving for change in land productivity that will result in the same welfare loss as in scenario 1. Combining this productivity result with actual productivity loss on unsprayed fields allow for calculating the actual size of field margins. Finally, in scenario 3 subsidies to organic farmers are used to encourage conversion. It turns out that due to numerical problems subsidies alone can not achieve a sufficient conversion to achieve the welfare loss calculated in scenario 1. Therefore the subsidies are supplemented with movements in domestic and foreign demand schedules. This means that the necessary welfare loss is achieved through movement of land into a less productive use, but also that no actual policy recommendation can be drawn from this scenario and that one should be careful not to draw to definite conclusion.

Results for production and prices for agricultural products are then fed into the ESMERALDA model. The key variables from ESMERALDA in this frame work are the variables that are linked to the biodiversity model (ALMaSS) and the geological assessment, namely pesticide TFI and allocation of land on each farm type covered by ESMERALDA.

In all three scenarios, ALMaSS is fed with results from ESMERALDA. Furthermore, in scenario 2 the unsprayed field margins are implemented by allocating a 5m margin around all crop boundaries. In the organic scenario the area of organic farming in the landscape is increased in concordance with results from the CGE model (25 percent increase).

For the geological assessment no other changes are applied than those from ESMERALDA. That is, allocation of land and pesticide frequency indexes. This implies that the consequence of increased organic farming is assumed to be explained by aggregated reduction in the pesticide usage.

3.2.1 Scenarios results

We proceed by analysing results from the three scenarios in a top down fashion starting with macroeconomic implications as well as sector results for productions and prices.

As mentioned earlier, the pesticide reduction scenarios are compared by scaling the considered regulation instruments to the extent that their effects on economic welfare are equal to the welfare loss incurred by a general pesticide tax targeting a 25 per cent decrease in total pesticide use. This results in a decrease in total welfare by 862.1 million DKK.

In the pesticide tax scenario, the introduced taxes reduce competitiveness in agriculture, thus reducing the demand for land, labour and capital resulting in a downward pressure on the economic return to these factors. Since land is used only in agriculture it is not surprising to see the large effect on the price of agricultural land.

Except for international trade the macroeconomic effects in scenario 2 (unsprayed field margins) are similar to the tax scenario. The reason for the difference in trade is the way export is modelled. A large fraction of the Danish export is described by a common export function, this export is termed non-traditional export and the commodity composition of this aggregate is treated as a Leontief aggregate, where total demand is related to the average price of the aggregate via a single downward-sloping demand schedule.

In the tax scenario, relative large price increases of a few agricultural products in the group of non-traditional exports lead to an increased average price of non-traditional exports and consequently a decrease in export volumes. With unsprayed field margins, price increases of agricultural products in the group of non-traditional export commodities are more modest and are outweighed by decreased prices of other commodities in the aggregate, thus leading to a decrease in the average price and an increase in the export volume.

Table 3.6 Macroeconomic impact 2015, measured in 2003 currency

	Baseline	Pesticide taxes		Unsprayed field margins		Organic farming	
	Billion DKK	Million DKK	Percent	Million DKK	Percent	Million DKK	Percent
Real GDP	1899.8	-799.0	-0.04	-703.4	-0.04	-789.1	-0.04
Real private consumption	991.1	-611.2	-0.06	-611.2	-0.06	-611.2	-0.06
Real public consumption	406.8	-250.9	-0.06	-250.9	-0.06	-250.9	-0.06
Real investments	337.0	7.1	0.00	-112.5	-0.03	236.2	0.07
Real stocks	46.7	0.0	0.00	0.0	0.00	0.0	0.00
Real exports	562.2	-59.7	-0.01	642.7	0.11	-320.8	-0.06
Real imports	431.5	-245.0	-0.06	313.2	0.07	-181.7	-0.04
Real capital stock			-0.05		-0.04		0.01
Welfare		-862.1	-0.06	-862.2	-0.06	-862.1	-0.06
GDP deflator			-0.11		-0.08		-0.01
Consumer price index			-0.08		-0.06		-0.01
Price of investment goods			-0.10		-0.06		-0.01
Consumer real wage			-0.19		-0.12		-0.02
Price of agricultural land			-7.05		-1.26		0.99

The pesticide tax will increase unit cost in sectors using land, and hence reduce the production level and demand for land, labour and capital in these sectors. In the long run, prices of these factors must fall and most for land since this factor is fully and only used in agriculture.

The immediate effect of introducing lower productivity of land (unsprayed field margins) reduces effective input of land and thus results in lower production, ceteris paribus. This results in an increase in unit cost and thus a need for a production adjustment.

Industries can also be indirectly affected by the introduced instruments through higher input prices for intermediate inputs produced by sectors directly affected by the policy instrument. The final result for these industries is a weighted result of increased prices for some intermediates and the lowered factor prices of primary factors.

Industries not affected negatively by the policy instrument (directly or indirectly) face lower factor prices and are thus able to expand production at lower unit cost. Individual industry results are generally a result of changed factor priced and the intensity of use of these factors in each industry.

The first striking result of the pesticide tax is the relatively large decrease in horticultural production. The reason is that horticulture uses very little land compared to other sectors. When the taxes result in decreased land price, land intensive sectors have the ability to maintain their competitiveness. On the other hand, horticulture faces the pesticide tax, but at the same time the land price reduction has very little effect on the sector’s profitability.

The introduced taxes benefit pig production even though there is an increase in the price of cereals (a major input). The reason is that the lover factor prices dominate the effect on unit cost.

Table 3.7 Impacts on agricultural production and exports, per cent

	Pesticide tax		Unsprayed field margins		Organic	
	Production	Price	Production	Price	Production	Price
Cereals	-1.59	0.11	-9.01	0.60	-0.21	0.93
Rapeseed	-0.48	4.28	-0.21	0.04	-9.58	0.81
Potatoes	-2.43	7.80	0.13	-0.09	-0.36	-0.19
Sugar beets	0.00	-0.40	0.00	0.23	0.00	-8.44
Roughage	0.00	0.40	0.00	-0.06	2.33	1.63
Beef	-0.05	0.10	0.00	0.02	-3.87	3.74
Milk	0.00	-0.04	0.00	0.04	0.00	2.39
Pork	0.22	-0.08	-0.22	0.19	-0.78	0.25
Poultry	0.12	-0.13	0.00	0.08	5.69	-0.23
Furred animals	0.19	-0.10	0.08	-0.03	0.06	0.04
Horticulture	-9.69	1.85	0.36	-0.05	3.27	-0.06

In contrast to the tax scenarios, horticulture increases its production (0.36 percent) with unsprayed field margins. This effect arises because horticulture is the agricultural sector with the lowest share of land in production. At the same time, horticulture does not use any input from the other land using sectors, therefore it gains from lower price of capital and labour.

Pig production, not directly affected by the shock, looses because of an increased price of cereals, which dominates the price decreases of factor inputs, in contrast to the tax scenarios. The major looser in this scenario is production of cereals due to its relatively high usage of land.

The AAGE model does not include field margins directly. In order to mimic such margins, these are translated into an average change in the productivity of land. To translate results from this scenario back into an actual usage of field margins requires some assumptions. Total crop production falls by 2.87 percent. The average productivity loss with pesticide free production is approximately 20 percent (Frandsen and Jacobsen, 1999; Ørum, 1999) Assuming unchanged productivity on land not in the field margins, the fraction of land in the margins can be calculated as

$$
\begin{aligned}
&0.9713 = \beta \times 0.8 + (1-\beta) \times 1 \Rightarrow \\
&0.0287 = (1-0.8) \times \beta \Rightarrow \\
&\beta = 0.1435
\end{aligned}
$$

That is at least 14.35 percent of total land should be allocated as unsprayed field margins. This fraction increases with increased productivity of land outside the margins and with the ability to change productivity inside the field margins, provided the assumption that the associated welfare loss should equal that from the tax scenario.

Feeding the production and price results from AAGE into ESMERALDA allows for calculation of detailed farm type specific land allocation and for calculating the TFI. The consequences of the pesticide reduction scenarios for aggregate land use are displayed in table 3.8.

A tax on pesticides will strike relatively hard on the economic returns to wheat production, because wheat is relatively intensive in pesticides. Hence, the pesticide tax will lead to a change in the composition of grain production – from wheat towards grains with lower pesticide intensity, mainly spring barley. The increase in potato area may seem surprising, as potatoes are relatively intensive in pesticides, especially fungicides. However, the tax induces a price increase for potatoes, which makes the loss of economic returns to land in potato production relatively lower than for other crops[2].

Table 3.8 Land use, 1.000 hectare

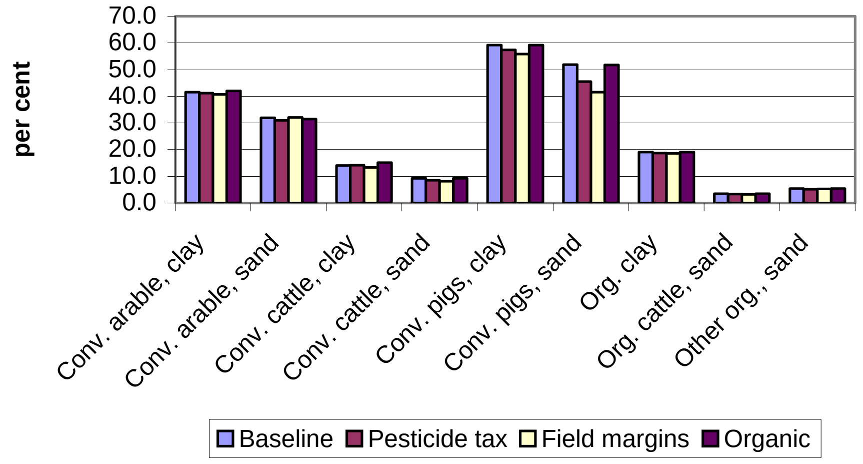
	Baseline projection	Pesticide tax	Pest.-free buffer zones	Organic
Wheat	619	571	540	607
Other grains	789	819	873	784
Peas	7	9	7	7
Rapeseed	10	13	11	10
Seeds for sowing	68	68	67	67
Potatoes	9	24	7	9
Sugar beets	60	59	61	58
Other cash crops	13	13	13	13
Fodder beets	9	8	9	9
Grass. rotation	194	194	194	205
Perm. grass	175	175	175	177
Silage cereals	285	286	285	294
Fallow	180	181	180	181
Total area	2.419	2.419	2.419	2.419

Introduction of pesticide-free buffer zones will also have relatively large consequences for the economic returns to land in wheat production, due to the high pesticide intensity in wheat production. It will thus become less attractive to cultivate wheat, compared with other grains, if a share of the area should be cultivated without using pesticides. This leads to a change in the composition of grain area.

Figure 3.1 illustrate selected land use effects of the pesticide reduction scenarios for winter cereals on different farm types. In general, the major differences across scenarios occur on pig farms, and to a lesser extent on cattle farms, whereas the impacts for arable farms are quite similar across scenarios. Land use on organic farms is not affected significantly by the pesticide reduction measures, as these measures only affect farms using pesticides.

[2] It should be mentioned that this finding is subject to some uncertainty, as there is some deviation in the potato area effect in the two models.

Figure 3.2 Winter cereals. per cent of area grown on different farm types



The pesticide tax scenario leads to a reduction in the total pesticide quantity of 26 per cent (table 3.9), which is mainly a result of the target reduction of this scenario. The decrease is larger for herbicides and insecticides than for fungicides, which is related to the above-mentioned increase in potato area.

Introduction of unsprayed field margins lead to a lower reduction in the average treatment frequency index, because 14 per cent of the cultivated area is not treated with pesticides and because the intervention leads to re-allocation of the cultivated area, cf. above. Compared with the baseline scenario, the pesticide quantity is reduced by 19 per cent (table 3.9).

Table 3.9 Index for pesticide quantity (baseline = 1.00)

	Baseline	Pesticide tax	Unsprayed field margins	Organic
Herbicides	1.00	0.69	0.80	0.90
Fungicides	1.00	0.80	0.82	0.98
Insecticides	1.00	0.66	0.88	0.94
Growth regulators	1.00	0.89	0.77	0.88
Total	1.00	0.74	0.81	0.93

Feeding the ALMaSS model with detailed results for land allocation and change in pesticide application allows us to asses the impacts on skylark population in all three scenarios. The baseline scenario resulted in a stable population of skylarks with a maximum population size predicted to be approximately 150 birds per square kilometre.

In all scenarios a stable population of skylarks was achieved. Within a scenario, population levels were relatively constant resulting in narrow confidence limits to the mean population size despite the relatively low number of replicates.

The organic scenario did not significantly affect the skylark population. The reason is clearly that the increase of 25% in organic farming gives less than 2 percentage points increase in the total area of land under organic farming. Hence with the current level of replication, this difference is not detectable. In the cases of general pesticide tax scenarios, the proportion of non-breeders on May 15th decreased, indicating that the average population surplus was lower than baseline for these scenarios. These impacts are caused by a combination of two factors, namely changes in crops grown and the fact that by not spraying, tramlines are not opened, denying the birds access to food resources in the crop. By contrast, the unsprayed field margins scenario leads to an increased population size, increased floating population and increased number of chicks per female compared to all other scenarios. This is clearly due to the assumptions that these margins have ample food (see Chiverton & Sotherton, 1991) and have a structure which does not impede access for nesting or foraging.

Table 3.10 Skylarks in the baseline and policy scenario

	Baseline	Pesticide tax	Unsprayed field margins	Organic[2]
Population Mean	14997	14264	16555	15236
Floating population proportion[1]	0.21	0.12	0.25	0.17
Number of chicks per breeding female	2.61	2.37	2.77	2.47
Population size relative change to baseline	N/A	0.95	1.10	1.02

1) Floating population proportion is the mean proportion of adults not breeding on May 15th.
2) At the 95% confidence interval baseline results overlap with results from the organic scenario and the organic scenario can not be considered different from the baseline.

As was the case with the biodiversity the geological assessment is also linked to the combined model framework through results from ESMERALDA (allocation of land and pesticide treatment). Here we use results based on the assumption of a linear relationship between pesticide treatment frequency and pesticide leaching. In the baseline scenario, the likelihood of finding pesticides in drinking water and in the ground water resource was estimated to 8 percent and 14 percent respectively.

Positive effects are found in all three scenarios, although only modest effects are found in the organic scenario. Unsprayed field margins seem to be very effective in relation to reducing the probability of finding pesticides in drinking water above the limits. The probability is cut in half to 4 compared to the baseline. Looking at ground water resources, the effect is more modest - the probability of finding pesticide is calculated to 13 as compared to 14 in the baseline. A pesticide tax also affects water quality positively and, compared to the baseline, the probability of finding pesticide in both drinking and subsoil water is affected relatively alike.

Table 3.11 Contamination probability

	Baseline	Pesticide tax	Unsprayed field margins	Organic
Drinking water	8.10	6.50	4.00	7.80
Subsoil water	14.44	11.56	13.22	14.00

We can now sum up the results so far for an evaluation of the effectiveness of each instrument. In table 3.12 main findings from the combined model framework are listed.

Table 3.12 Main findings for baseline and policy deviations

	Baseline	Pesticide tax	Unsprayed field margins	Organic
		---------- Percentage change as compared to baseline ---------		
National consumption	1397.9 bill. DKK.	-0.06	-0.06	-0.06
Biodiversity	150 skylarks per square kilometre	-4.9	10.4	1.6
Probability that pesticides in drinking water exceeds the threshold	8.1 percent above the limit	-19.8	-50.6	-3.7
Probability that pesticides in ground water resource exceeds the threshold	14.4 above the limit	-20.0	-8.5	-3.1

All three scenarios are associated with the same cost measured by national consumption. The organic farming scenario does not seem to be competitive as a policy instrument measured by the three indicators. With regard to biodiversity we could not conclude that this scenario is different from baseline and with regard to water quality, effects seem small compared to the two other scenarios.

It is somehow unclear whether pesticide taxes or unsprayed field margins are doing best. With regard to biodiversity the field margins are clearly doing best by increasing the skylark population by 10 percent while with pesticide taxes the skylark population actually decreases.

With respect to drinking water the margins scenarios also win by lowering the probability of finding contaminated water by 50 percent. But the conclusion is reversed with respect to ground water where, compared to the baseline, the percentage change in the probability of finding contaminated ground water is more than twice as high in the tax scenario as in the scenario with unsprayed field margins.

To select between using pesticide taxes and unsprayed field margins as instruments for pesticide reduction would require a weighted sum of the three indicators such that we could make a final conclusion to which instrument is the most effective. Economic valuation studies of the three indicators would allow us to add up the three indicators to address the effectiveness issue. Furthermore, since valuation studies put monetary values to these non-marketed environmental goods it can also allow us to address the question whether the environmental benefits from the analysed instruments exceed the economic cost of achieving environmental goals. These questions are addressed in the next section where valuation studies are included in the analysis.

3.3 Accessing benefits in search of an effective instrument

Using economic valuation studies allows us to calculate the economic value of increased biodiversity and a lower probability of ground- and drinking water contamination. This analysis will allow us to conclude, whether regulation in addition to that already in use is appropriate. Furthermore, we can also assess, which of the considered instruments is the most appropriate to use. Having found the appropriate instrument we continue by trying to evaluate the optimal application of the selected instrument.

There exist many valuation studies of biodiversity and water quality and in relation to this project a contingent ranking study has been carried out Bjørner et. al (2004). In that study, the value of biodiversity related to changed use of pesticides in agriculture was estimated. The population of birds in arable land was used as an indicator of biodiversity. The study found an annual willingness to pay between 213-230 DKK per household for a one percent increase in the population of birds. For evaluating the benefit of increased biodiversity we use an average of 222 DDK per household.

A review of the international literature indicates that a value of 900 DKK per household for ground water within the threshold limit is a reasonable estimate (Danish Economic Council, 2004). In the literature different hypothetical scenarios are used in the valuation; preserve the entire ground water resource within the threshold limit or preserve drinking water within the threshold limit. It is doubtful whether the respondents in these studies have distinguished between the ground water resources or that ground water that is used for recovery of drinking water. This makes it difficult to determine whether the value should be attached to changes in the quality of drinking water, the ground water resources or both. The valuation studies in the included literature are based on stated preferences, which can include both use values and non-use values like existence values. We have therefore chosen to attach the 900 DKK to ground water that are used for preservation of drinking water within the threshold limit.

The benefit values in table 3.13 are calculated by taking the percentage change in the probability of finding drinking water in excess of the threshold limit and taking the same percentage of 900 DKK. and multiplying that figure with the number of households in Denmark (2.9 mill.). Pesticide taxes are expected to reduce the probability 19.8 percent (table 3.12), the value per family is thus 178 DKK and for the country as a whole 516 mill. DKK. The value of increased biodiversity is calculated simply by multiplying the percentage change in table 3.12 by 222 DK which was the above mentioned value attached to a one percent change in farmland bird population above and finally multiplied by the number of households. The calculations in table 3.13 are done in a comparative static fashion, assuming that the cost of implementing the policies falls within the year it is implemented, benefits from increased biodiversity are also assessed to fall within the first couple of years. Benefits from increased water quality on the other hand fall within a longer time span, why discounting in principle should take place, but the length of this time span is very uncertain so this discounting has been omitted.

Table 3.13 Cost-benefit assessment, mill DKK.

	Pesticide tax	Unsprayed field margins	Organic
Economy wide costs	-862	-862	-862
Benefit:			
Drinking water	516	1321	97
Biodiversity	-3118	6628	1017
Benefit (hypothetical bias 3):			
Drinking water	172	440	32
Biodiversity	-1039	2209	339
Total	-3465	7087	251
Total (hypothetical bias 3)	-1730	1788	-491

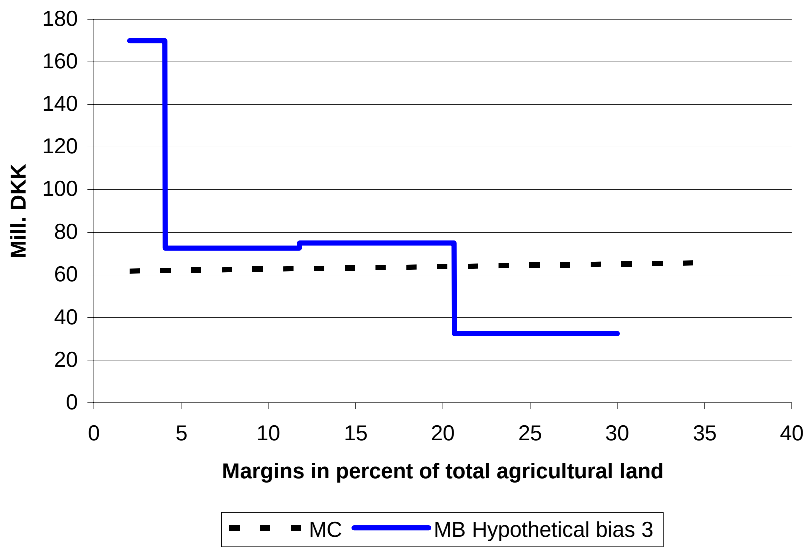
By construction, the cost in all three scenarios is 862 mill. DKK. The negative effect on biodiversity in the pesticide tax scenario results in the total deficit of 3.5 bill DKK effectively ruling taxes out as an instrument under consideration. The positive impact on both water quality and biodiversity results in benefits in excess of cost with a total surplus 251 mill. DKK in the organic farming scenario. But of the three scenarios analysed there, is no doubt that unsprayed field margins is by far the best strategy, with costs of 862 mill DKK society gets benefit from better quality of water valued at 1.3 bill. DKK and 6.6 bill DKK from increased biodiversity resulting in a total excess 7.1 bill DKK.

Using monetary values for physical non-marketed environmental goods thus allow us to select the unsprayed field margins scenario as the clearly most effective. But furthermore, it seems that implementing field margins will yield benefits to society that by far outweighs the cost of implementing these margins.

As mentioned in section 2.5 above, several studies indicate that the (hypothetical) valuation methods yield upward-biased estimates of the willingness to pay for environmental improvements, List and Gallet (2001) finds that the hypothetical willingness to pay is on average 3 times higher than the actual. We have included results adjusting for this “hypothetical bias” in table 3.13 and find that the conclusion still holds; unsprayed field margins are the most effective of the instruments analyzed and furthermore this instrument yields positive net benefits to society.

Running several model simulations with varying sizes of field margins would allow us to construct total cost- and benefit curves and ´hence also marginal cost- and benefit curves, and subsequently to calculate the optimal size of field margins by equating marginal cost with marginal benefit. It has been possible to do this exercise with the AAGE model and the ALMaSS models, not including the geological assessment. Thus, this analysis will result in a minor underestimate of the optimal degree of intervention, i.e. the optimal size of the field margins.

Figure 3.2 Optimal application of field margins



The assessment of biodiversity impact with ALMaSS within the analysed interval was done with margins that were both unsprayed and unfertilized. Testing with the model has indicated that the effects are roughly half when fertilising is allowed in the margins zone; this has been used to construct the benefit curve. Future revision of this paper will be based on simulations with only unsprayed field margins.

The marginal cost- and benefit curves intersect where approximately 21 percent of the total agricultural land is allocated to unsprayed field margins (figure 3.2). This corresponds roughly to 10 meters margin around each field. The calculation has been done with a hypothetical bias of 3, without the biases the two curves do not intersect within the interval analysed.

4. Conclusion

In this paper we set up a multidisciplinary model framework comprising very different models - economic, biological and geological models based on very different foundations; general equilibrium, econometric, agent-based and Bayesian network model. The model framework allows us not only to address economic cost of policy instruments, but the inclusion of biological, geological and valuation studies allows us to address effectiveness, cost-benefit assessments and optimality in instrument usage.

The established model framework is used for evaluating three types of instruments to reduce pesticide use in Danish agriculture: pesticide tax, unsprayed field margins and increased conversion to organic farming. It should be noted that the analysis does not rule out the existence of potentially more cost-effective instruments to improve biodiversity or ground-water quality.

Results suggest that Denmark could benefit from adaptation of unsprayed field margins increasing both the level of biodiversity and quality of water resources. The main contribution on the benefit side stems from biodiversity, but the estimated value of improved drinking water protection is also significant. According to the analysis, conversion to organic farming also yields benefits exceeding costs, but these net benefits are by far lower than those in the field margin scenario. On the other hand, the estimated benefits of pesticide taxes are negative. Hence, increased pesticide taxes or conversion to organic farming must be considered inferior to field margins. These results are highly sensitive to the economic valuation of the considered benefits. Adjusting for hypothetical bias in the benefit valuation does not alter the overall conclusions, but reduces the net benefits of the considered scenarios considerably.

There is room for improvements, though. The linkage between the individual models used for cost assessments can be improved in terms of better correspondence between behavioural descriptions in the models. Also, biodiversity is represented by one species (skylark), but a more complete picture of biodiversity could be obtained by considering more indicators of biodiversity, including e.g. possible effects and value of changes in wild plants, insects, mammals and health effects. Inclusion of these is however not expected to change the qualitative conclusions. Furthermore, the estimation of benefits could be improved by including a spatial dimension in the scenario effects on production, pesticide intensity and land use. Despite these potential improvements, the results presented above – and the ranking of the regulation instruments - are considered to be valid.

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