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AGRICULTURAL UNIVERSITY OF SZCZECIN
FACULTY OF ECONOMICS AND ORGANIZATION OF FOOD ECONOMY

MODELLING OF ECONOMY IN SPECIALLY PROTECTED REGIONS

Proceedings of the international conference held on 9-11 june 1994 in Drawno, Poland

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RISK MANAGEMENT IN ECONOMIC-ECOLOGICAL MODELLING IN REGION

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Introduction

The growing awareness of environmental problems has stimulated much research in economics and ecology over the last three decades. At the same time, both in economics and in ecology mathematical modeling approaches have increasingly become more important. The pioneer work of *Lotka (1920)* and *Volterra (1931)* in population ecology, of *Linderman (1942)* at the ecosystem level, and of *Tinbergen (1956)* in economics, has been followed by extensive efforts to obtain more insight into the complexities of the real world by means of statistical, econometric, and analytical modeling techniques. In the last 15 years academic researchers as well as policy analysts became increasingly aware of the limitations of monodisciplinary modeling. A series of attempts was undertaken which aimed at the improvement of the existing models.

In the 1960s studies on environmental and resources economics started to be published *(Barnett and Morse, 1963; Ridker, 1967; Kneese et al., 1969).* In the 1970s both these new subdisciplines of economics proliferated *(Maler, 1974; Krutilla and Fisher, 1975; Pearce, 1976; Nijkamp, 1977; Kneese, 1977).*

Special attention to the relationship between economic growth and environmental constraints and impacts was given by *Barkley* and *Seckler (1972)*, and *Hueting (1974).* The economics of pollution effects, environmental damage, improvement, and control was addressed by *Victor (1972), Maler* and *Wyzga (1976), Smith (1976), Freeman (1979).*

Resource economics in the 1970s has concentrated of minerals and fuel resources, the so-called nonrenewables *(Herfindahl* and *Kneese, 1974; Pearce, 1975; Pearce* and *Walter, 1977).* Renewable economics has received most of its attention under traditional names such as agricultural, forestry, and fisheries economics *(Ciriacy-Wantrup, 1968; Fisher, 1977; Smith, 1978).* Several books were published in these areas calling for renewed attention to the problems of depleting stocks and especially to the problems in developing countries.

The global community has become increasingly linked by common issues, problems and needs. Many of the simple, single - discipline problems that plagued efforts to increase crop yields in the 1960s and 1970s - which was the urgent issue during that period to avert hunger in many continents - have been tackled and many have seen resolution. In the 1990s and in the next century, problems that require urgent attention, such as global climate change, declining yield potential and environmental degradation, are more complex in nature and the search for their solutions has necessitated more focussed yet inter-disciplinary efforts. Organized thinking about future farming requires forecasting of the implications of alternative ways to farm and to develop agriculture. System thinking and simulation are indispensable tools for such integration and interpolation.

The *Pearson, Brandt* and *Brundtland Report (1987)*, which popularized the concept of sustainable development, also contributed to the term 'sustainable agriculture'. The debate over this concept may be explained by the impasse confronting conventional forms of agriculture in developing as well as developed countries, which takes the form of ever more acute environmental problems and more rapid soil degradation. For agricultural development programmes, solving these problems involves taking into account more complex objectives than those set by conventional agriculture. The development and promotion of this new form of agriculture requires major efforts in the areas of research and training, and also the revamping of agricultural programmes and policies that influence the decisions made by farmers. Its success will depend as well on the worldwide creation of institutions that can manage the international trade in agricultural products in such a way as to favour the promotion of sustainable agriculture and the alleviation of rural poverty.

The Maastricht treaty includes a commitment to 'sustainable and noninflationary' growth respecting the environment. What this means is that the environment will be placed on an equal footing with economic growth.

Agricultural models

Models are built for agriculture and included or related fields, such as plant production, animal husbandry, soil sciences, water management, and so forth, for very different purposes. Selection of particular model is usually determined by the problem investigated.

A considerable part of the models describes the interaction between production and ecological conditions. This is obvious, for environmental conditions have an important effect on the level of agriculture. Depending on how far the possibilities of utilization of ecological conditions are connected to the investigation of economic problems, there is a shift in stress from the ecological to the economic side.

The impact of ecological conditions on the production is not yet very well known. At the same time, however, they have more and more important role in agricultural planning. So-called biomass programs were initiated in many countries of the world. Their aim is not only to determine the conditions to increase the production, but to secure the balance of the production and environment as well. The ecological character of models selected for this chapter is justified by the above considerations. The three models are, at the same time, good complements to one another.

The first model examines the possibilities of plant production setting out from an ecological basis. The second one describes how to adjust production to ecological conditions taking into account the dynamic impacts of production on the environment. Results of the first model could serve as inputs to the second.

The third model is related to pest management making possible joint analysis of ecological and economic parameters. Such types of models can be used in planning the long-range structure of plant production very well.

Methodologies of the models applied in agriculture follow the nature of the problems examined and since the problems are heterogeneous, the methodologies are very diversified. Recently, dynamic, control-type models have become increasingly general to describe these phenomena. This is reflected in the models to be described. I can say about their methodology, that the first model uses simulation, the second one multipurpose optimization, while the third one can be considered as a control model.

Multiseasonal management of an agricultural pest

Pest management is a set of activities in agricultural production aimed at keeping pest populations or injury within economically and socially acceptable loss level. Management implies both knowledge and intervention. One important concept that has found much application in modern pest management is that of **Integrated Pest Management** (**IPM**; *Stern at al., 1957*), which stresses the rational use of a combination of pest control techniques while enhancing the role of natural regulatory mechanism to produce an economically and socially acceptable yield with no adverse effect on the environment *(Teng, 1991a)*. Pest management is complex, involving many components (e.g. pest, crop, beneficial organisms, non-target organism) and with man's production-oriented interventions (such as ploughing, pesticides) superimposed on a variable, physical environment (e.g. weather). The scientific basis for pest management was initially based on single-factor and single-pest studies which expanded to multiple-factor, multiple-pest studies and strategies. This coincided with actual demonstrations of how system components were linked, and how to manage one pest without due regard to other pests, was to invite problems. In the early years of pest management, mathematical modelling and even computer simulation were attempted *(Watt, 1962)* although without explicit recognition of the influence of a conceptual base which was later called **the systems approach.**

This study is concerned with the multiseasonal crop-pest management problem. The main result is that the timing of the application of pesticide can be used to control buildup of resistance and that the intensity of the application can be used to control the crop yield. These results make possible to establish optimal production-protection policies.

The model system is based on the submodel for the pest and crop dynamics. The goal of the pest model is, given the fractions of resistant and susceptible pests in the population at year n and the spraying strategy in year n, to find the respective fractions in year $n + 1$. Population dynamics and relatively simple genetics are included in the pest submodel.

The submodel for the crop dynamics has the following goal: given the pest populations at the start of year n, and a spraying strategy in year n, what is the yield of crop in year n? Using this submodel we can also determine the optimal strategy within a single season.

The three primary parameters in the application of a pesticide in a given season are the number of applications, the timing of the applications, and the intensity of the applications.

The model system is built up step by step. The first one is the so-called age-independent model, in which pesticide susceptibility and crop consumption are independent of age. In this model it is assumed that all pests are susceptible to the pesticide, the pest population does not reach its carrying capacity before the end of the season, and as a consequence, the growth rate of the pest population is independent of the value C, the crop.

The second model incorporates age dependence in both susceptibility to the pesticide and consumption of the crop. The resistant and the susceptible pests are divided into two groups:

young and old.

The mathematical description contains the dynamic model of the crop-pest system. A multiseasonal economic optimization problem is to choose a spraying strategy over **N** seasons to maximize the profit from the crop harvest.

This simplification is possible since the conclusion was that very simple age and genetic structure in the model gives results which are qualitatively the same and quantitatively close to those obtained using a more complex model.

The model comprises a set of differential equations describing the dynamic of the pest population:

$$\frac{dy_k}{dt} = \rho_k \cdot \alpha_k + \mu_k(n)I(t) - \nu \cdot y_k - [(\omega_y s(t;n)/e_{y_k} + s(t;n)) + \overline{\sigma}] \cdot yk$$

$$\frac{d \cdot \alpha_k}{dt} = \nu y_k - [(\omega \cdot u \cdot b \cdot \alpha \cdot s(t;n)/e_{\alpha_k} + s(t;n)) + \overline{\nu}]\alpha_k, \qquad k = R, S$$

where:

R - resistant subpopulations,

S - susceptible subpopulations,

$\mathbf{y}_k(\mathbf{0,n}) = \alpha_k(\mathbf{0,n}) = \mathbf{0}.$

The parameters **I(t)** are the immigration rate, ρ_k is the birth rate, and γ measures the turnover rate from young to adult.

The equation for the crop is:

$$\frac{dc}{dt} = r_c c - \nu = [x_R + x_S]$$

$$\mathbf{c(0,n) = C_0},$$

where $\mathbf{y}_k$ **(t;n) a** α_k **(t;n)** are the young and adult pest populations, which are divided into resistant and susceptible subpopulations:

$$x_k(t;n) = y_k(t;n) + \alpha_k(t;n),$$

c is the measure of the crop, the continuous variable **t**, 0<=t<=T, represents intraseasonal time,the discrete variable **n**, 0 <=n <= N, represents seasonal time.

$$\sigma(t) = \frac{\omega_y \cdot s(t)}{e_y + s(t)} + \sigma$$

$$\nu(t) = \frac{\omega_\alpha \cdot s(t)}{e_\alpha + s(t)} + \nu$$

The parameters ω_y and ω_α measure the maximal effect of the pesticide on the population. The parameters e_y and e_α measure the necessary dose to obtain a given pest kill ratio. The parameters $\bar{\sigma}$ and $\bar{\nu}$ represent natural mortality.

$$\mu_k = x_k(T;n-1)/[x_R(T;n-1) + x_S(T;n-1)]$$

$$\mu(1) = \rho_0$$

$$\mathbf{I(t)=I_0\ (1 - I_c\ t/T)}$$

where function S(t;n) is equal:

$$S(t;n) = \begin{cases} \eta & ;t_s \leq t \leq t_s + \delta \\ 0 & ;\text{otherwise} \end{cases}$$

for a single dose of pesticide applied at time t_s. The control variables for this problem are the variables t_S and η.

The multiseason economic optimization problem is to choose a spraying strategy η[(n),t_s(n)], n = 1,...,N, to maximize the profit function **J**, subject to the appropriate dynamics as given.

The profit function is:

$$J = \sum_{n=1}^{N} \alpha^{n-1}[c(T;n) - c_p\eta(n)] \tag{0.1}$$

where **c(T;n)** is the crop biomass in year n at the end of the season,

$$\alpha = (1-\nu)^{-1}$$

where ν is the discount rate, and c_p is the relative cost per unit of pesticide. This problem can be solved by the method of dynamic programming.

Applying systems techniques in tactical and strategic pest management

Pest or pest-crop model find little application for pest management unless they are used within the context of the socio-economic factors influencing the considered system and are adapted to the application domain. Models do not necessarily have to be used in their entirety for pest management: their outputs such as yield loss threshold, or simplified versions of detailed models requiring fewer inputs, may suffice and be practical.

Rationalization of pesticide use

This has been accomplished in several ways. Simplified pest models or simplified decision rules from crop-pest models with economic values assigned to their outputs have been used for managing sugarbeet Cercospora leafspot *(Shane et al., 1985)*, sweet corn common rust (Teng, 1987), wheat diseases *(Zadoks, 1984, 1989)*, and rice blast *(Surin et al., 1991)*. Detailed simulation models have been used to design strategies for insecticide use *(Heong, 1990)* and predict disease epidemics *(Teng et al., 1978)*.

Detailed, sophisticated simulation models are poor, or of no help, in the development of a pest management programme: they require too much information, and their output is too sophisticated *(Zadoks, 1989)*. Simplified simulation models - models that retain only the essentials of detailed ones, and have been tested for their robustness - on the contrary, may prove valuable tools, for example, in rationalizing the use of fungicides *(Teng et al., 1978)*. Complex or simplified pest models, when coupled to crop models, may also be used to generate iso-loss curves which show various combinations of pest intensity or injury and crop age that result in the same yield loss. These curves may than be used in a scouting program in pest management, in which preset levels of acceptable loss are used to decide on the timing of control measures. Pest management programs in the future will probably take the form of a series of interlinked decision rules, or simple models, each representing one pest sub-system of the considered crop system. The coefficients or parameters of this multiple decision support system would be functions of the cropping practices, and could be altered in relation to the recommendation domain (i.e. the combination of farm economic context and agro-ecological zones) where the output of the decision support system would be applicable. If such an architecture was to be considered, the linkage between the decision support system and the recommendation domains would play a considerable role. The development of extrapolation methodologies that can simultaneously handle agroecological and economic factors involved in decision-making in agriculture, such as geographic information system **(GIS)**, may play a key role in helping to define these multi-attribute recommendation domains.

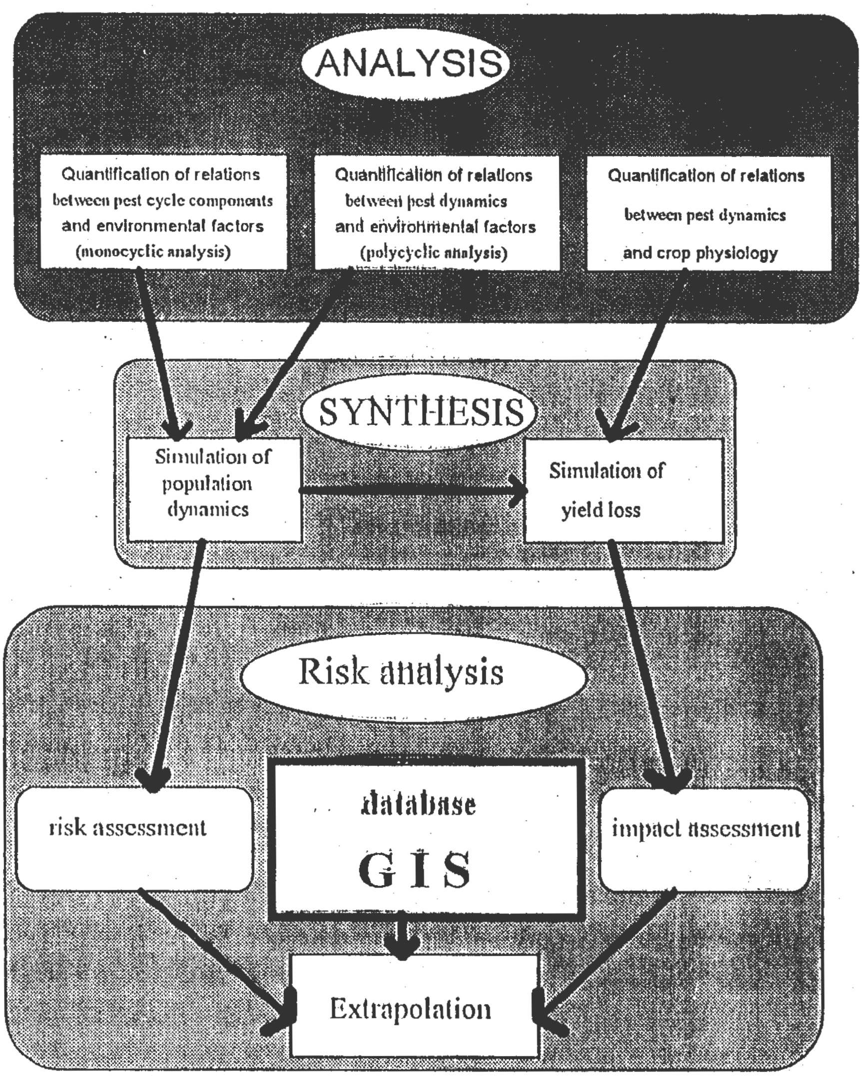

Fig 1. Schematic showing suggested step in using models for risk analysis.

Risk analysis

One exciting new use of models is for analyzing the risk associated with the introduction of exotic pests into ecosystem in which they have not previously been known to exist. *Yang et al. (1991)* have demonstrated the feasibility of the approach with a soybean rust model, SOYRUST, which when run with continental USA weather data predicted potential areas for epidemics. The authors further linked model disease estimates to a soybean crop model and determined potential losses attributable to rust epidemic. Their approach is, however, a simplistic one, and I propose a generic approach, as illustrated in Fig. 1, in which models of different complexities may be used to estimate the needed disease and yield effects.

Andow et al. (1989) used a potato model to estimate the benefits from reduction of yield losses if non-ice nucleating bacteria, produced through bioengineering, were released into the environment. The methodology they used resulted in probability curves for yield losses with different release scenarios and allowed an evaluation of the value of the technology. The work illustrates an important application of models to assess situations where actual field work on a pest is not possible because of concern for potential hazards, and simulation appears to be ideal tool for exploring the options *(Teng, 1991b)*.

Pest management information systems

Kenmore et al. (1985) described three different types of 'IPM program pathologies: political, social, and perceptual. Each of these pathologies is a cause of failures of IPM programmes. Considerable attention is being paid to the conditions under which an IPM program can be adopted by farmers, and be successful. The farmer's behavior and reaction toward risk have been studied in a number of instances. Many authors consider that, among farming communities, there is a much higher proportion of insurers *(Mumford, 1981)* - who would prevent risk at any cost - than of investors - who keep profit as the main goal. The proportion however, varies considerably depending on the farm size, the investments in the crops, and the production objectives *(Kenmore etal., 1985)*. It seems therefore that the farmer's perception and attitude towards risk are related to the production situation, taken in its broadest sense.

Because the presence of several pest constraints is the rule rather than the exception, the adoption of an IPM program by farmers is often linked with its potential to address several pests at the same time *(Zadoks, 1989)*. Examples of IPM programs involving a number of pests differing in their nature are few; The Michigan state IPM program *(CIPM, 1983)*, the EPIPRE program for control of pests and diseases in wheat *(Zadoks, 1984)*, and the BLITECAT program *(MacKenzie, 1981)* are frequently quoted examples. Although the principles for developing pest management information system appears to be low and one reason may be that the technology is still ahead of the need. In developing countries, computer-based pest management is a long way from realization even in the more advanced of such countries in Asia.

A modification to the concept of using detailed pest simulation models in an information system is to incorporate the simplified outputs of simulations (such as expected crop losses caused by specific pest populations) into an information system. This was done in New Zealand for barley leaf rust *(Thornton and Dent, 1984)*, and although the technology was sound, farmer adoption has been low.

Every effort should therefore be spent to develop a pest management programme in close contact with farming communities. *(Kenmore et al., 1985)*. This system approach must incorporate strong social sciences inputs, and allow characterization of production objectives, farmers' perception of pest injuries and losses, farmers needs', and farmers' means to implement the IPM programme.

Concluding remarks

The systems approach is now more relevant and important than at any previous time because of increasing realization of the inter-relatedness between components and fragile ecosystems. For agricultural development, and more specifically, for an accelerated adoption of the systems approach in pest management, a toolkit may have to be developed for countries in order to reduce the lag time between generation of global principles and development of site-specific management tools. To generate this toolkit, I propose that an international collaborative effort for harmonization be developed, involving advanced laboratories, national programs and international organizations. This collaborative effort could facilitate the sharing of models, the harmonization of model design, the collection of common data sets for model validation, and most importantly, facilitate the application of models or their outputs to solve specific problems of agricultural development.

With the demands on oceanic fisheries and grasslands now commonly exceeding sustainable yields, the world's population is heavily dependent on croplands to satisfy future food needs

(Brown et al., 1992). Eliminating hunger among an estimated 900 million people and providing for nearly 3000 million more by the year 2000 will require pushing the current world grain harvest of 1700 Mt to some 2700 Mt. With little prospect of expanding the cultivated area, satisfying future food needs depends on raising the productivity of existing cropland. This can be achieved through multiple cropping, intercropping and transplanting; land reform; expanding the irrigated area and using water more efficiently; increased use of fertilizers in some regions; greater nutrient recycling; greater environmental protection to reduce erosion and declines in soil fertility; more sustainable production patterns; increased agroforestry; greater use of biological pest control and integrated pest management; and biotechnology developments. Changes in attitudes can also help reduce hunger through more moderate levels of livestock product consumption, population control and greater environmental awareness.

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