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The Municipality Approach in Regional Agricultural Models: Improving Accuracy in Environmental Analyses

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Abstract

This paper shows the benefits of using municipalities as decision units in economic models and the key role of Positive Mathematical Programming (PMP) as the underlying calibration method. The difficulty in using the municipality level for analysis stems largely from the fact that data on costs of production cannot be obtained from secondary sources at this level. This problem can be overcome by using PMP. The economic component of an interdisciplinary project which deals with the analysis of the effects of agricultural land use on soil erosion and nitrate concentration in the infiltration water along with an introduction to PMP is presented. The results indicate that the municipality approach used in the economic model facilitates the mutual interchange of economic and ecological data within the interdisciplinary project as it eases the necessary process of translating economic model results into the - relatively smaller - spatial units examined by natural scientists. When the model is used as an independent economic-ecological model the use of municipalities rather than the whole region as smallest spatial units facilitates the inclusion of ecological functions such as the erosion and nitrate concentration functions because the aggregation bias that stems from using average values of relevant natural parameters can be reduced. In addition, these ecological equations can be used as environmental constraints by assigning an upper boundary to each of the two indicators which makes it possible to search for the necessary adaptations to achieve certain environmental quality standards at minimal costs. We conclude that the municipality approach combined with Positive Mathematical Programming as a necessary methodological prerequisite is a promising approach to modeling causal linkages between agricultural land use and the environment either in the form of independent economic-ecological models or as components in interdisciplinary research projects.

Introduction

Causal linkages between agriculture and the environment have often been addressed and examined in depth since the 1970's. Economic agricultural production models are a widely used tool in this field. The scale on which these studies were executed ranges from single plots (Jarosch 1990) and farms (Krayl 1993) to landscapes, as in the British NELUP project (see, for example, O'Callaghan 1995), and sectors, as done in the German RAUMIS project (see, for example, Weingarten 1995). Since the scale of farm models is relatively small it is possible to gather primary data and achieve a high degree of precision which is especially important for linking them to ecological models in interdisciplinary projects. On the other hand, such detailed approaches cannot be used to study larger regions or even agricultural sectors because the procurement of primary data would lead to exorbitant costs. Therefore, the availability of secondary data is an important prerequisite for building large-scale models.

However, secondary data is usually only available for relatively large spatial units which consequently leads to a low degree of spatial resolution in most economic regional and sector models. In the RAUMIS project, as well as in several other regional models (see, for example, Paeffgen 1994 and Braun 1995) counties were chosen as spatial units. In the NELUP project the whole region under investigation (the catchment of the river Tyne which comprises 3000 km^2) was modeled as a single farm (Moxey et al. 1995). Depending on how inhomogeneous the spatial units are, an aggregation bias arises which not only directly influences the results of the economic model but also indirectly the results of the ecological models as they use economic model results as input parameters. Besides, natural sciences tend to look at spots or very small spatial units which makes it necessary for the success of interdisciplinary projects to agree upon a spatial unit of analysis which is small enough to facilitate a reasonable degree of spatial precision but big enough to ensure the availability of secondary data where economists and natural scientists can agree (Moxey and White 1998).

Therefore, a new approach was chosen in the currently ongoing large-scale interdisciplinary project "Regional-Scale Models for a Sustainable Use of Landscapes in Baden-Württemberg"[2] in that municipalities were chosen as decision units in the economic component[3]. The project focuses on strategies to reduce soil erosion and nitrate leaching and studies the corresponding socio-economic preconditions and effects in the agricultural sector. The use of municipalities as smallest spatial units in the economic component of the project represents a middle course between the commonly used county level in most economic models and the 100 m * 100 m (1 hectare) grids which were defined as smallest spatial units in the natural science components of the interdisciplinary project. The municipality approach has two benefits with respect to the application of the economic model in environmental studies. In interdisciplinary, models it helps to reduce the differences in the size of the spatial units used by economists as opposed to those used by natural scientists. This eases the necessary process of translating economic model results for land use on the municipality level into smaller spatial units such as the grids of 1 hectare. If the economic model is not used as part of an interdisciplinary study but rather as an independent economic-ecological model, the municipality approach facilitates the use of parameters related to natural characteristics of the area of investigation as the aggregation bias coming along with the necessity to use average values of these natural parameters can be diminished compared to a county level approach.

The problem that arises with the municipality approach is that many economically relevant data is not available at the municipality level from secondary sources. While land use and livestock data are available for each municipality, variable costs of production cannot be obtained with this amount of precision. However, this lack of information can be compensated by using a calibration method called positive mathematical programming (PMP) that can be applied in cases of limited information in economic modeling.

This paper shows the benefits of using municipalities as decision units in economic models and the key role of PMP. Therefore, the economic component of the interdisciplinary project along with an introduction to PMP is presented in the following sections. This includes a

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[2] This project is carried out at the Universities of Stuttgart and Hohenheim, Germany. It is financially supported by the Volkswagen-Stiftung.

[3] The municipality level approach is also applied in a regional model by Kächele and Dabbert (1995). However, the study had to rely on data which is usually not available at the municipality level and which limits the study's transferability significantly.

description of the model structure as well as a presentation of selected results and further potential applications in socio-economic and interdisciplinary environmental studies.

The Economic Component of the Interdisciplinary Project

Model goals and concept

The model should be able to serve as a tool to support agricultural policy decisions emphasizing environmental aspects according to the goals of the interdisciplinary project of which it is a part. More specifically, the economic component is supposed to predict land use changes induced by changing political and socio-economic conditions. The interdisciplinary character of the research project allows designing policies aimed at improving environmental quality with respect to soil erosion and nitrate leaching in the region of investigation not only from a fiscal or economic point of view (e.g., fiscal or structural aspects of environmental policy programs) but also from an ecological point of view. The latter could be done by elaborating suggestions for critical levels of soil erosion and nitrate leaching and imposing them as constraints to the economic model.

As outlined previously the region under investigation, the Kraichgau region, which forms part of the federal state of Baden-Württemberg in Southern Germany, is not treated as a single economic unit. Rather the total area, which comprises 2,200 km^2, is divided into 29 municipalities with 3000 to 6000 ha of farmland each. Within each of the 29 model regions a whole range of production activities is defined. They include 10 cropping activities, fallow land, 3 forage production activities, and 11 livestock activities.

In order for the economic model to be used as an independent economic-ecological model for environmental analysis it was amended by various ecological elements. Regarding soil erosion, the cropping and forage production activities are further distinguished into 3 production alternatives, each including conventional drilling, mulch drilling and catch crop growing associated with the respective main crop. This distinction allows not only accounting for the significantly differing effects on soil erosion caused by each of the production alternatives but also to specifically include the prevailing agro-environmental program in Baden-Württemberg. This so-called MEKA program grants subsidies to farmers who switch from conventional farming to mulch drilling and catch crop growing. Regarding nitrate leaching, the model had to be endowed with a mechanism which allows for a variation of the nitrogen fertilization intensity. This was achieved by including a quadratic yield response function with yield depending on the nitrogen application level. The inclusion of these elements facilitates the addition of ecological constraint functions to the model. Soil erosion is calculated using the Universal Soil Loss Equation (Wishmeier and Smith 1978, Schwertmann et al. 1987). Nitrate leaching is derived by calculating the nitrogen fertilizer balance and implementing the balance value into another equation in order to obtain a value for nitrate concentration in the infiltration water.

Mathematical structure

The objective variable is total gross margin ($\prod$) which is defined as the difference between revenue and variable production costs (c). Revenue equals market price (p) times production output (Y) and may be supplemented by different kinds of subsidies and premiums (prem). The objective value depends on cropping acreage and livestock numbers. These production activities are represented by a variable X which, according to the degree of differentiation outlined in the previous section, is defined over 3 dimensions including the range of municipalities (r), production activity categories (i) and production alternatives in each category (v)[4]. The objective function (1) is maximized[5] subject to a number of technical constraints ((2) to (7)), environmental equations ((8) to (9))[6], and the yield response function (10)[7]:

$$\max! \Pi_r = \sum_i \sum_v \left(p_i * Y_{i,r} + prem_{i,v} - c_{i,v} \right) * X_{i,v,r} \qquad (1)^8$$

subject to

(land constraint) $$\sum_{ic} \sum_v X_{ic,v,r} \le l_r \qquad (2)$$

(stable constraints) $$X_{il,r} \le s_{il,r} * 1.1 \qquad (3)$$

(fodder constraints forage) $$\sum_{il} (X_{il,r} * req_{il}) \le \sum_{if} \sum_v X_{if,v,r} * y_{if,r} \qquad (4)$$

(fodder constraints cereals) $$\sum_{il} (X_{il,r} * req_{il}) + sell_{ice,r} \le \sum_{ice} \sum_v X_{ice,v,r} * Y_{ice,r} \qquad (5)$$

(replacement constraints) $$X_{il,r} * need_{il} + sell_{il,r} \le X_{il,r} * prod_{il} + purch_{il,r} \qquad (6)$$

(calibration constraints) $$\sum_v X_{i,v,r} \le \sum_v \hat{x}_{i,v,r} \qquad (7)$$

$$X_{ic,v,r} \le \hat{x}_{ic,v,r} \qquad (7a)$$

(soil erosion equation) $$erosion_r = \frac{\sum_{ic} \sum_v (X_{ic,v,r} * cfac_{ic,v})}{l_r} * lsfac_r * rfac_r * kfac_r * pfac_r \qquad (8)$$

(nitrate equation) $$nitrate_r = \frac{bal_r}{inf_r} \qquad (9)$$

(yield response function) $$Y_{ic,r} = ay_{ic,r} * N^2_{ic,r} + by_{ic,r} * N_{ic,r} * cy_{ic,r} \qquad (10)$$

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[4] The distinction between production alternatives is only made for cropping activities.
[5] The optimization routine used is GAMS/MINOS.
[6] The environmental equations are intentionally not called constraints for they do not affecting the activity levels X in the base year. However, while they are only used for reporting purposes initially, they can be used in scenario runs to impose upper boundaries on erosion, nitrate and stocking rate thus becoming constraints.
[7] Upper case letters are used for variables and lower case letters are used for parameters in this paper.
[8] Yield is a variable for cash crops and a parameter for forage crops and livestock activities.

where the symbols mean

ic, il, if, ice:	subsets of i for crops, livestock, forage production and cereals
l, s:	total land and total stable capacities
req:	livestock energy requirements
need, prod:	requirements and production of replacement animals
purch, sell:	purchase and sale of productive inputs and outputs
$\hat{x}$:	observed output (cropping acreage and livestock numbers) in base period
c-, ls-, r-, k-, pfac:	c-, ls-, r-, k-, and p-factors of the universal soil loss equation
bal:	nitrogen balance as difference between nitrogen fertilization and actual uptake
inf:	infiltration water
N:	nitrogen fertilization
ay, by, cy:	yield function coefficients as estimated following Krayl (1993)

Data

The model base period is 1995. This represents the latest year in which a complete land use survey was carried out. Several sources were used to receive the necessary data. Land use, livestock numbers[9], input and output prices, forage crop and livestock yield data were taken from publications by the state bureau of the census (Statistisches Landesamt Baden-Württemberg 1994, 1995). Information on the level of conventional and mulch drilling as well as catch crop growing was obtained from the state ministry of agriculture (Landesamt für Flurneuordnung 1995). In order to estimate quadratic yield functions maximum yields and corresponding nitrogen fertilization had to be obtained for in several extension offices within the region of investigation. Data on soil type, precipitation, inclination, and infiltration water to be used in the ecological equations was obtained from colleagues in the interdisciplinary project. Several other sources were used to obtain information on production costs, labor requirements (Frede and Dabbert 1998), fodder requirements, and nutrient contents of forage crops (Deutsche Landwirtschafts-Gesellschaft 1992). Data on nutrient uptake of crops were taken from a preliminary version of the German fertilization directive. Most data were available on the municipality level. However, some parameters had to be assumed equal in each of the 29 municipalities due to a lack of further information. Among these are prices and variable production costs.

The Concept of Positive Mathematical Programming (PMP)

The following brief introduction to PMP aims at demonstrating the use of this calibration method as a tool to be used in economic models that are part of interdisciplinary projects which study the effects of land use on the environment. By omitting strict calibration constraints and replacing them by non-linear cost functions PMP helps to improve the model's flexibility in the calculation of scenarios. Since the non-linear cost functions take observed

[9] Since livestock numbers are only surveyed in even-numbered years a match with land use data was impossible. Livestock numbers were taken from the 1994 survey.

land use patterns into account a highly differentiated cost structure within a region can be obtained. The degree of spatial differentiation which can be achieved by using PMP is only limited by the degree of differentiation to which land use data is available. In Germany, land use data is regularly surveyed for each municipality for statistical purposes which is why municipalities were chosen as decision units in the economic model. While increasing the models flexibility is a general advantage of PMP, achieving a high level of spatial resolution is especially important when data related to natural conditions such as soil, climate and topography are to be included.

PMP was originally developed by Howitt (Howitt 1995). The concept of PMP will be explained here with the help of a simple model with two production activities (X_1, X_2) and one limiting factor (land). If gross margin (GM) was formulated in a linear fashion total gross margin (TGM) of the firm would be[10]

$$TGM = \sum_i GM_i = (p_i y_i - c_i)X_i \qquad (11)$$

Marginal cost (MC_i) would be equal to average cost (AC_i) and be c_i. One of the main problems with linear models which makes the inclusion of calibration constraints necessary, is the overspecialization of the results. By this it is meant that the solution vector X_i does not cover all of the activities which have been observed in the base period. In the simple model the more profitable activity would be realized until the land capacity limit has been reached whereas the less profitable one would not be realized. In case this optimal solution does not concur with actual observations in the base period, the more profitable activity must be artificially limited to the value that is observable in the base period. For this purpose, calibration constraints must be introduced. However, since these constraints are - in contrast to the general constraints such as the total land constraint - often only valid in the base period, the model's adaptability to altered parameters in the calculation of scenarios is adversely affected. The reason for the necessity to make use of calibration constraints lies in the linear specification of the gross margin function.

There are several reasons for decreasing marginal returns when the acreage of a crop is increased in an economic unit be it a single farm, a municipality, region or sector. These reasons include agronomic aspects, differences in the soil quality, allocation of labor, and an increasing risk. Despite the difficulties in exactly measuring these costs the diversity of observed crop allocations prove the existence of additional costs not covered by the linear cost term c[11]. Therefore, if it was possible to find a mathematical way to explicitly account for increasing marginal costs the calibration constraints could be omitted. Since in this case marginal costs would be dependent on the acreage of the crop, the total cost function and consequently the gross margin function of the crop would become non-linear. Among several possibilities to specify a new cost function (Paris 1993) the quadratic function is used in this model. Total gross margin hence becomes

[10] For simplicity, any subsidies and premiums are ignored.

[11] The term "revealed efficiency" has been introduced to describe the existence of hidden costs of production which are expressed by observed crop allocations (Arfini and Paris 1995).

$$TGM = \sum_i GM_i = (p_i y_i) X_i - 0.5 \gamma_i X_i^2 \quad (12)$$

Marginal cost (MC_i) for a given crop would now be $\gamma_i X_i$ where an increasing effect of the crop acreage on production costs becomes obvious. The question remains how the PMP cost function coefficients γ_i are to be obtained. Considering the goal of the non-linear cost functions the values of γ_i must ensure that the base period model results be equivalent to the actually observed crop allocation. This can be achieved when MC_i equals MR_i for each crop at the actually observed acreage of the crop. Since the value of the marginal product (VMP_i) of land becomes 0 for all crops the condition that the VMP_i of land be equal for all activities in the optimal solution is automatically fulfilled. A procedure to calculate the γ_i coefficients using duality was developed by Paris (Paris 1993). It can be demonstrated with the help of figure 1.

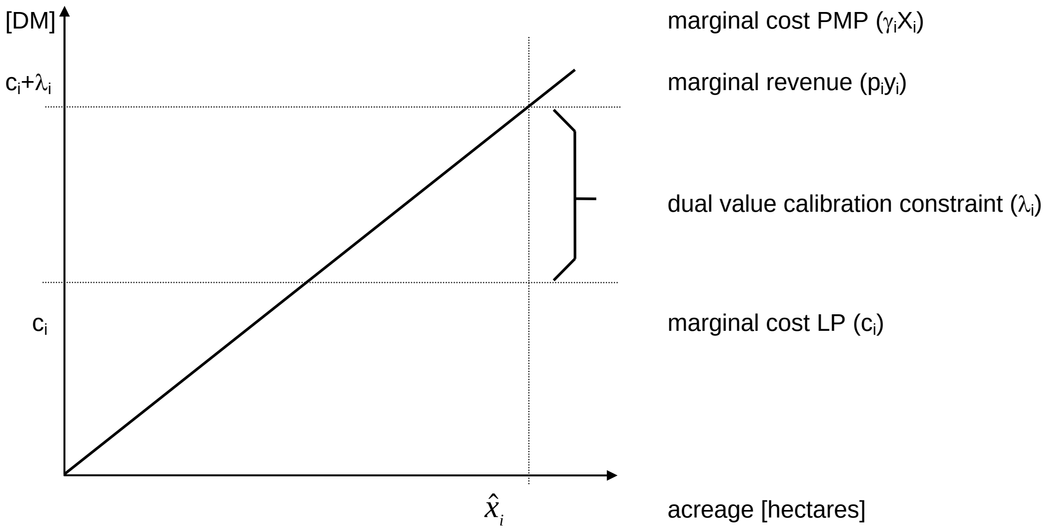

Figure 1 Derivation of the PMP Marginal Cost Function

Source: Original Diagram

If the PMP marginal cost function is of the form such that at the observed acreage of crop X_i, $\hat{x}_i$, MC_i equals MR_i as shown in figure 1, the model will calibrate exactly because at $\hat{x}_i$ any further increase of the acreage of this crop will lead to negative returns. In order for the marginal cost function to be equal to MR_i at $\hat{x}_i$, the γ_i coefficients have to be calculated as follows:

$$MC_i = MR_i = \gamma_i \hat{x}_i = \lambda_i + c_i \quad (13)$$

where λ_i represents the dual value of the calibration constraints of the crops X_i which would have to be used if the model was linear. Equation (13) therefore becomes

$$\gamma_i = \frac{\lambda_i + c_i}{\hat{x}_i} \quad (14)$$

Since the calculation of the γ_i coefficients requires dual values of a previous model with a linear objective function PMP becomes a three-stage process (Howitt 1995). In the first step, the programming model with linear objective function is run. In our case it is the linear programming model defined in section 2 under the subheading *mathematical structure*. In a second step the resulting dual values λ_i are then used to calculate the γ_i coefficients of the PMP cost function which becomes part of a new quadratic objective function. The resulting quadratic optimization problem is finally solved in the third step.

The principal concept of PMP can be extended to more complex models including cash crops, livestock and forage production. As shown in the economic model described above yield response functions and different management strategies for cash crops can also be included in PMP models.

Selected Model Results and Potential Applications in Environmental Analyses

In order to show the potential of the municipality approach and the key role of PMP some selected results of the economic model are presented. In the first part the PMP cost functions generated for each municipality and selected results of base period crop allocations are presented. These results serve as an example of the degree of spatial resolution of the model and its benefits in interdisciplinary projects. In the second part it is shown how the inclusion of ecological equations facilitates the application of the economic model as an independent economic-ecological model.

PMP cost functions

As mentioned in section 2, variable production costs had to be assumed equal for all 29 municipalities in the linear model. It is a common problem in agricultural economics research that detailed cost data are hard to obtain (Arfini and Paris 1995). However, PMP allows to using actual crop and livestock allocations as a proxy for hidden production costs. Since land use and livestock data are available for each municipality distinct cost functions can be calculated for each municipality, too. Table 1 shows for winter wheat the unique linear marginal cost term c (MC_{LP}) and the PMP marginal cost terms γX (MC_{PMP}) for each of the 29 municipalities of the Kraichgau region[12]. It also contains the γ- and $\hat{x}$-values with which the PMP marginal costs were calculated. Finally, the PMP average cost terms (AC_{PMP}) are included in order to compare the values to the LP cost value.

The numbers show significant differences in variable production costs between municipalities calculated with PMP. One could argue that it is hard to justify that within a relatively homogeneous region such big differences occur. However, there are many factors which may contribute to these deviations if we take into consideration that several farms within the municipalities are treated as one single economic unit. The resulting γ coefficients indicate that the Kraichgau region is obviously not as homogenous as thought at first sight. The aggregation of single farms to the municipality level leads to different structural situations between municipalities which in turn influence costs of production.

[12] For simplicity, the index i in the mathematical notations is omitted in this section.

Crop and livestock allocation

Traditionally, economic production models are intended to calculate input use, output and profit. Given the scope of the economic model as part of an interdisciplinary project to study the effects of different land use patterns on the environment, the model concept is primarily focused on predicting land use changes and changes in total gross margin. Stable capacity use, labor use and nitrogen fertilization are also calculated. Output is calculated in terms of crop acreage and livestock numbers. In addition, yields are endogenously calculated for cash crops. However, only crop acreage and livestock numbers can be used for calibration and validated since only for these items is base period data available. In principle, other parameters such as stable capacity, labor and nitrogen input as well as optimal yield and total gross margin or even environmental variables could be used for calibration and consequently be validated if data was available.

PMP ensures an exact calibration of the model within rounding errors. Table 2 shows a selection of model results in order to prove exact calibration for the base period and to give an impression of the degree of differentiation of the model. Table 2 contains base period data and model results for crop and livestock allocation in municipality 1.

Table 2 clearly indicates that the model calibrates exactly when PMP cost functions are used instead of explicit calibration constraints. By changing certain parameters in the model the corresponding effects on land use and livestock production can be calculated in scenarios. From an economic viewpoint, the effects of changes in prices, subsidies, premiums, input and output quotas and taxes on the profitability of agricultural production - just to mention a few - are the most relevant questions which could be answered with the economic model by comparing total gross margin from a scenario run to the base period total gross margin (which in municipality 1 amounts to $12.8 * 10^6$ DM). However, as indicated earlier, in order to analyze the effects of certain policy changes on environmental parameters the changes in land use are as well important as they are used in the ecological parts of the interdisciplinary project. Since land use changes resulting from the economic model must be translated to the grid level and allocated to each of the 222,335 grids in the Kraichgau region the use of municipalities rather than the whole region of investigation as spatial model units contributes to a simplification of this translation process and presumably to a higher accuracy.

Soil erosion and nitrate concentration

In addition to providing data for the interdisciplinary project, the economic component is able to calculate effects of agricultural land use on the state of the environment directly with the help of the soil erosion and nitrate equations (8) and (9). The equations have the same functional form as in the natural science models of the project where they are used to calculate soil erosion and nitrate concentration on the grid level. Yet, erosion and nitrate results from the economic model will not necessarily be equal to the values calculated on the grid level since they are obtained using municipality averages for all relevant natural parameters entering the ecological equations, e.g. soil type, precipitation and infiltration water. However, it will be possible to verify the degree of precision of environmental data calculated at the municipality level at a later point in time. Table 3 shows the results of the soil erosion equation (8) for the base period indicated in tons per hectare and year. An equivalent table could be presented for nitrate concentration.

Table 1. γ-Coefficients, Observed Base Period Land Allocations [ha], Linear and PMP Marginal Costs and PMP Average Costs for Winter Wheat [DM/ha]

Munici-pality	γ	$\hat{x}$	MCPMP (γX)	ACPMP (0.5γX)	MCLP (c)	Munici-pality	γ	$\hat{x}$	MCPMP (γX)	ACPMP (0.5γX)	MCLP (c)
1	1.209	2019	2441	1221	1565	16	7.379	282	2080	1040	1565
2	7.712	214	1648	824	1565	17	4.297	461	1980	990	1565
3	8.391	260	2181	1090	1565	18	3.449	551	1899	950	1565
4	1.781	1168	2080	1040	1565	19	2.417	786	1900	950	1565
5	3.151	523	1648	824	1565	20	4.150	477	1980	990	1565
6	3.074	611	1879	940	1565	21	4.067	487	1979	990	1565
7	1.075	2403	2583	1292	1565	22	7.587	221	1678	839	1565
8	7.306	312	2281	1141	1565	23	2.851	885	2523	1261	1565
9	2.116	1078	2281	1141	1565	24	0.907	2403	2180	1090	1565
10	3.034	652	1979	990	1565	25	5.725	346	1980	990	1565
11	3.727	531	1980	990	1565	26	4.178	455	1899	950	1565
12	4.440	514	2281	1141	1565	27	5.346	308	1648	824	1565
13	10.851	182	1980	990	1565	28	1.391	1567	2180	1090	1565
14	1.692	1123	1900	950	1565	29	3.859	435	1678	839	1565
15	7.136	306	2181	1090	1565						

Source: Original calculations

The erosion levels differ significantly between municipalities. They cover a range from 3 t/ha/a in municipality 2 to 32 t/ha/a in municipality 25. This shows clearly that the state of the environment can be significantly different even within a relatively homogeneous region. Since the ecological equations (8) and (9) can be used as environmental constraints in the economic model in the calculation of scenarios by assigning an upper boundary to each of the two indicators, erosion and nitrate, it is possible to set environmental quality standards and let the model search for the necessary adaptations the economic units have to go through in order to achieve the quality standards at minimal costs. If, for example, the critical level of soil erosion was limited to 5 t/ha/a, the intensity of the adaptation process as well as the corresponding costs would be significantly higher in municipality 25 than in municipality 2.

Table 2. Base Period Crop and Livestock Allocation in Municipality 1

Production Activity	Base Period Data	Model Results	Production Activity	Base Period Data	Model Results
Winter Wheat (c)	1769.42	1769.42	Sunflower c)	4.84	4.84
Winter Wheat (m)	249.62	249.62	Sunflower (m)	3.01	3.01
Winter Barley (c)	439.68	439.68	Fallow Land (c)	687.37	687.37
Winter Barley (m)	34.40	34.40	Silage Corn (c)	163.81	163.81
Sugar Beets (c)	595.95	595.95	Silage Corn (i)	129.07	129.07
Sugar Beets (m)	562.18	562.18	Silage Corn (m)	63.22	63.22
Summer Barley (c)	430.09	430.09	Clover (c)	49.22	49.22
Summer Barley (i)	140.62	140.62	Clover (m)	6.64	6.64
Summer Barley (m)	43.70	43.70	Grassland (c)	392.56	392.56
Corn (c)	78.30	78.30	Dairy Cows	1019	1019
Corn (i)	51.51	51.51	Feeder Cattle	899	899
Corn (m)	40.40	40.40	Heifers	930	930
Oats (c)	85.54	85.54	Suckling Cows	51	51
Oats (m)	2.34	2.34	Calves	140	140
Rapeseed (c)	54.52	54.52	Feeding Pigs	3604	3604
Rapeseed (m)	17.19	17.19	Breeding Pigs	804	804
Rye (c)	72.14	72.14	Sheep	130	130
Rye (m)	0.54	0.54	Horses	182	182
Potatoes (c)	10.96	10.96			

Crops allocations are given in hectar, livestock allocations in number of animals.
C, m, and i indicate the production alternatives conventional farming, mulch drilling, and catch crop growing.
Source: Original Calculations

Table 3. Soil Erosion in 29 Kraichgau Municipalities in 1995

Municipality	Erosion [t/ha/a]	Municipality	Erosion [t/ha/a]	Municipality	Erosion [t/ha/a]	Municipality	Erosion [t/ha/a]	Municipality	Erosion [t/ha/a]
1	10.61	7	11.90	13	16.18	19	15.69	25	31.99
2	2.70	8	15.54	14	14.86	20	18.52	26	11.24
3	10.39	9	11.30	15	12.01	21	4.00	27	14.68
4	14.87	10	15.78	16	16.00	22	10.72	28	12.96
5	20.91	11	17.19	17	5.65	23	10.41	29	12.99
6	14.00	12	7.35	18	13.35	24	18.09		

Source: Original Calculations

Concluding Remarks

In order to link regional economic models to ecological models in interdisciplinary studies it is desirable to differentiate them as much as possible with respect to the size of the economic decision units. The municipality approach used in this model facilitates the mutual interchange of economic and ecological data within the interdisciplinary Baden-Württemberg project. It eases the necessary process of translating economic model results for land use on the municipality level into smaller spatial units such as the grids of 1 hectare used in the project. When the model is used as an independent economic-ecological model, the use of municipalities rather than the whole region as smallest spatial units facilitates the inclusion of ecological functions such as the erosion and nitrate concentration functions because the aggregation bias that stems from using average values of relevant natural parameters can be reduced. In addition, the ecological equations can be used as environmental constraints by assigning an upper boundary to each of the two indicators which makes it possible to search for the necessary adaptations to achieve certain environmental quality standards at minimal costs. The problem of missing data on some economic parameters which are not available at the municipality level, especially spatially differentiated production costs, can be solved with PMP. By calculating individual non-linear cost functions using actually observed crop and livestock allocations in a base period, the decision units of the model can be chosen as small as data on crop and livestock allocations are still available. Another advantage of PMP is that it makes the model more flexible in the calculation of scenarios by omitting calibration constraints.

Therefore, it can be concluded that the municipality approach combined with Positive Mathematical Programming as a necessary methodological prerequisite is a promising approach to modeling causal linkages between agricultural land use and the environment either in the form of independent economic-ecological models or as components in interdisciplinary research projects and will lead to improved accuracy in these models.

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