An agro-economic regional model for the Neckar river basin – first results of politic scenario calculations

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Abstract

ACRE is an **A**gro-e**C**onomic model for agricultural p**R**oduction on r**E**gional level. Based on an extension of Positive Mathematical Programming (PMP) this model was developed as a decision tool for politics with respect to questions of global change- and political scenarios. Currently, ACRE is applied in the RIVERTWIN-Neckar project and politic scenarios of the CAP reform 2003 were calculated. This paper introduces ACRE, its theoretical framework, and the first results of political scenario calculations, which where done for the Neckar river basin.

JEL classifications:

E23, Q15, Q21, Q18, C61

Keywords:

agricultural production model, regional model, interdisciplinary projects, CAP reform 2003, Positive Mathematical Programming

1. Introduction

In the past 20 years the relevance of modelling agricultural production on regional scale has grown. Including ecological and economic aspects, regional models have been developed as decision tools for agro-environmental questions (Dabbert et al., 1999) and are applied as instruments for supporting political decisions. For this issue, agricultural models require extensive data on farmers' production decisions with the possibility to simulate scenarios of global, climatic, political or economical changes. This paper introduces ACRE (**A**gro-e**C**onomic model for agricultural p**R**oduction on r**E**gional level) and first results of politic scenario calculations with the project specific version "ACRE-Neckar".

The Linear Programming (LP) method used traditionally for agricultural production modelling was replaced recently by the Positive Mathematical Programming (PMP) method. Extended versions of PMP make it possible to develop regional models with respect to specific questions of politics and production in agriculture. ACRE is based on a new extension of PMP. It is programmed in General Algebraic Modeling System (GAMS), in a way that interfaces to other models are possible. ACRE is a comparative static partial-equilibrium model, which optimizes the total gross margin on regional level by computing optimal production. Agricultural production in each of the model's sub regions (on district-level[1]) is represented by one single farm. The simulated time is one year. Agricultural production includes 23 food and non food crops, as well as 12 production processes for livestock. Consisting of a process analytical approach, feeding of animals and fertilization of crops are optimized by using feed and manure produced model-endogenously. Trade between the districts is not possible. By variation of model parameters scenarios can be simulated. Changes of production situation can be calculated by varying agricultural input parameters; for example by increasing input prices or reduction of arable land and grassland. Market

[1] A German district is equivalent to the international regional level NUTS (Nomenclature of Territorial Units for Statistics)-level 3.

situations can be represented by varying product prices or production quotas. To simulate political instruments parameters for subsidies (CAP-premiums and environmental programs) are applied. Changes in climate can be simulated by parameters for water supply and crop yields.

ACRE is applied in two projects where interdisciplinary models are developed for two German river basins with respect to water management and land use. Within these projects ACRE represents the agricultural production and simulates the impacts of scenario changes to agricultural production and agricultural income.

There are two versions of ACRE: The prototype of ACRE was developed by Winter (2005) for the Upper Danube catchment area within the framework of GLOWA-Danube[2] and is called ACRE-Danube. This version was adopted to the Neckar river basin for the EU project RIVERTWIN-Neckar as “ACRE-Neckar”.

2 Positive Mathematical Programming approach in ACRE

ACRE is based on the method of Positive Mathematical Programming (PMP). PMP is an optimisation approach that maximises an objective value of a total gross margin function. Compared to Linear Programming (LP), PMP has the following advantages:

a) PMP models are exactly calibrated by the reference situation and avoid overspecialization

b) PMP models react continuously to parameter variations and allow a flexible result calculation

c) PMP models tend to require less data than LP models (Umstätter, 1999)

These features characterise PMP as a method that promises a fruitful application for regional modelling of agricultural production.

[2] GLOWA-Danube is a subproject of the interdisciplinary project GLOWA (Global Change in the Hydrological Cycle), which is funded by the Federal Ministry of Education and Research (BMBF).

PMP was originally developed by Howitt (Howitt and Mean, 1983). In several revisions the method was improved: Paris (1988) developed a version that requires a reduced set of information, Howitt (1995) complemented the approach of decreasing marginal cost by the approach of increasing marginal yields, and Paris and Howitt (1998) combined PMP with the method of maximum entropy (Röhm, 2001). Recently, Röhm and Dabbert (2003) published a version of PMP, which extended PMP by a further sub-dimension, the variant-activity. This variant-activity extension differentiates between different levels of activities with different degrees of substitution characteristics.

The basic idea[3] of PMP approach is to build the model in to steps: An LP-model calculates dual values, which are used to calibrate the second part, the PMP-model. Thus, a PMP-model is not calibrated by means of flexibility constraints. Instead, it is calibrated by the shadow prices of restrictions making sure that the observed production pattern is reproduced by the model. Therefore, PMP simulations are not limited by fixed restrictions.

According to Röhm and Dabbert (2003) a variant-activity version of PMP is described by Equation (1) to Equation (8).

Equation (1) is the total gross margin function (*TGM*), and the objective function of the LP-model. *TGM* is maximised by LP subject to Equation (2) to (6). $GM_{i,v}$ is the gross margin of variant-activity *i*, *v*, with $X_{i,v}$ as the optimised extension variant-activities and $\hat{X}_{i,v}$ as the extension of the variant-activity observed in the baseline situation.

$$\max\ f(X)\ \text{where}$$

$$f(X) = TGM = \sum_i \sum_v (X_{i,v} * GM_{i,v}) \tag{1}$$

subject to

[3] Specific extensions of PMP models differ in detail from the method described here.

$$\sum_i \sum_v (X_{i,v}) \leq \sum_i \sum_v (\hat{X}_{i,v}) \qquad (2)$$

Equation (2) limits the resource land and produces the dual value λ_{land} which is, as the other dual values, used in the second step by the PMP-model.

$$\sum_v (X_{i,v}) \leq \sum_v (\hat{X}_{i,v}) * (1+\varepsilon_1) \qquad (3)$$

Equation (3) constraints the amount of the total-activities. The total-activities (X_i) (which can be e.g. crop activities) are the sums of the corresponding variant-activities ($X_{i,v}$). This total-activity constraint produces the dual value λ_i.

$$X_{i,v} \leq \hat{X}_{i,v} * (1+\varepsilon_2) \qquad (4)$$

Analogously, equation (4) restricts the amount of the variant-activities ($X_{i,v}$) and produces the dual value of the variant-activities $\lambda_{i,v}$.

The perturbation coefficients ε_1, ε_2 in Equation (3) and (4) are small positive numbers. Therefore, the right hand side factor enlarges the restriction of the observed amounts of the activities $(\hat{X}_i$ and $\hat{X}_{i,v})$ by a small value. This enforces the LP-model to produce dual value for each activity. Nevertheless, because the number of constraints exceeds the number of variables by one constraint, one total-activity constraint produces the dual value zero. This problem has to be solved by the calibration of the least attractive total-activity (for details cf. Röhm and Dabbert, 2003; Röhm, 2001 and Umstätter, 1999). Equation (5) represents a stricter restriction given by Equation (3) for the total-activities than the constraint given by

Equation (4) for the variant-activities. This leads to the effect that the model substitutes the variant-activities in total-activity rather than substitute a total-activity by another total-activity. (For example a production variant in a crop activity is rather replaced than a crop activity by another crop activity).

$$\varepsilon_1 < \varepsilon_2 \tag{5}$$

$$X_{i,v} \geq 0 \tag{6}$$

Equation (7) describes the objective function of PMP version without the variant-activity extension. Only a crop activity (X_i and λ_i) appears and *TGM* is a sum of index *i*. The formulation of Equation (8) shows the hierarchical relationship between variant-activities and total-activities. Inside the curly brackets the summands where summed up by index *v*, whereas the *TGM* is summed up by index *i*.

$$TGM = \sum_i X_i \left[X_i * \left(GM_i + \lambda_i * \left(1 - \frac{X_i}{\hat{X}_i} \right) \right) \right] \tag{7}$$

$$TGM = \sum_i \left\{ \sum_v \left[GM_{i,v} * X_{i,v} + \lambda_{i,v} * X_{i,v} * \left(1 - \frac{X_{i,v}}{\hat{X}_{i,v}} \right) \right] + \lambda_{i,v} * \sum_v X_{i,v} * \left(1 - \frac{\sum_v X_{i,v}}{\sum_v \hat{X}_{i,v}} \right) \right\} \tag{8}$$

3 First results of CAP-scenario calculations for the Neckar river basin

The research project RIVERTWIN (A Regional Model for Integrated Water Management in Twinned River Basins) aims at providing a management tool for the implementation of the European Union (EU) Water Framework Directive. In support of the EU Water Initiative an integrated regional model for the strategic planning of water resources management in twinned river basins will initially be developed and tested in the German Neckar Basin and later on transferred to the river catchments in the partner regions of Uzbekistan and Bénin. The model, which is based on a Geographic Information System (GIS) copes with impacts of economic and technological development, demographic trends and effects of global climate and land use changes on the availability and quality of water bodies (Gaiser and Dukhovny, 2004).

The German Neckar catchment covers an area of 13,000 km² enclosing highly populated industrial metropolitan areas such as the "Middle Neckar" and major areas of intensive agricultural use. Important water management issues are frequent floods due to sealing of

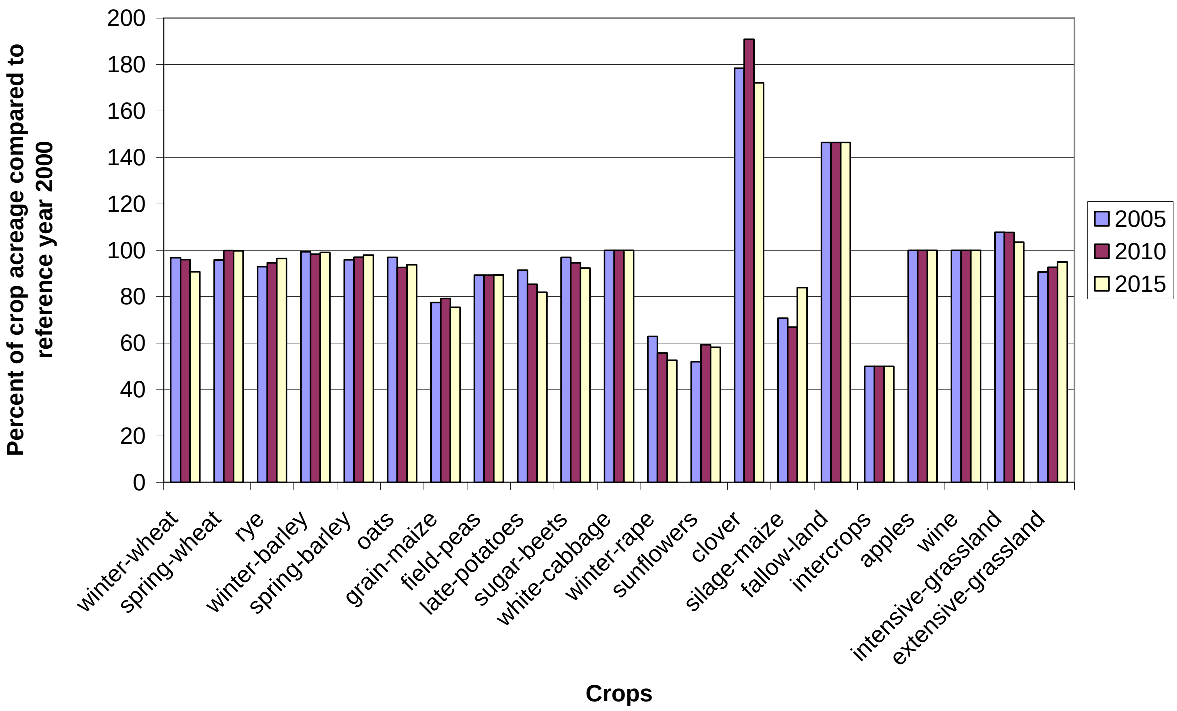

Figure 1. Deviation of crop[4] acreages in Neckar river basin for CAP reform scenario years. Source: own calculations

[4] Not all of the 23 crops, which are possible to model in the basic version ACRE, are modelled in the version ACRE-Neckar.

floodplain areas, poor annual water supply and the deterioration of riverine habitats due to industrial emissions and changes of riverbed morphology. Major problems for drinking water quality can be attributed to nitrate, phosphate and pesticide leaching from agriculture.

In first scenario calculations the effects of the CAP reform 2003 were simulated for the Neckar basin. The results show the effects on agriculture in 30 districts of the Neckar basin for scenario years 2005 to 2015.

Following the CAP reform 2003, premiums were decoupled from production and payments are received for the cultivation of grassland, arable land and fallow land. In the final state of the reform, which will be reached in 2013 the land premiums for all classes are unified. The scenario year 2015 was calculated assuming the conditions of the final status of CAP reform in 2013. It is expected that changes of premiums will have a big impact on agricultural production. Figure 1 presents the development of crop acreages in the model region Neckar river basin for the scenario years 2005, 2010 and 2015. The percentage of the reference year 2000 is 100%. Crops, which are less influenced by the CAP reform 2003 on a profitability level, due to small influence on gross margin by new premiums (e.g. winter-spring wheat and rye), and crops, which acreages are restricted by contingents (e.g. sugar-beets) do not show significant changes from reference year. Crops, which gross margin is reduced by new premiums decreases significantly (e.g. winter-rape, sunflowers and silage-maize). In reference situation no premiums were paid for clover. The share of clover increased significantly because the gross margin of clover increases by CAP reform 2003 premiums. Therefore, clover substitutes silage-maize, which loses in profitability due to shorter premiums. The gross margin of fallow land is influenced by premiums. However, the share of fallow land is prescribed since 2005 as 8.58 % of arable land, which is more then the prescribed set aside rate in 2000. The share of spring barley increases because their gross margin is relatively high in the reference situation and production is extended by acreage, which is set free by reduced acreage of the less favoured crops.

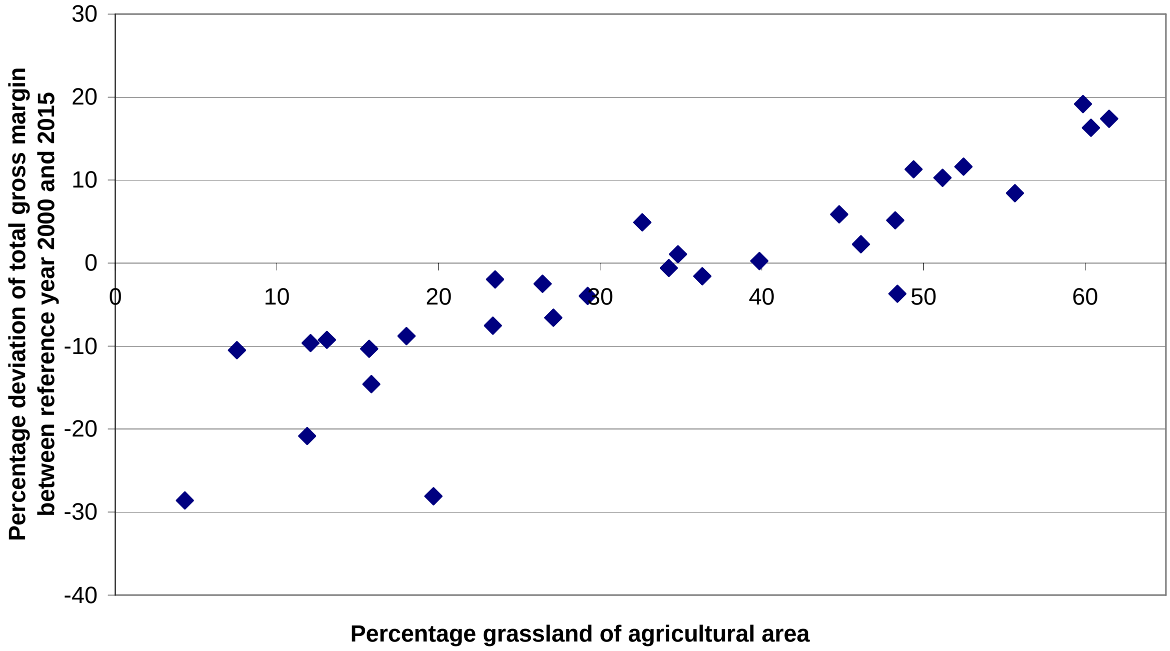

Figure 2. Regression of the percentage of grassland of agricultural area to percentage deviation of average gross margin between reference year 2000 and 2015. The diamonds represent the district-farms. Source: own calculations

In Figure 2 the relation between the percentage of grassland of agricultural area and the development of average gross margin is illustrated. The deviation of average premiums describes the difference between the reference situation in 2000 and the final scenario year 2015. In 2000 premiums were coupled to crops products and animals while in 2015 the final status of CAP reform 2003 is reached and premiums are paid on the basis of a regional amount equal for grassland, arable land and fallow land. Figure 2 illustrates that in districts with a small share of grassland the total gross margin per hectare farmland tend to decrease by 5 to 20 %. For districts with an equal share of grassland and arable land an increase of total gross margin from 6 to 10 % was calculated. The largest increase is given for districts with a grassland share of about 60 % of agricultural area. The observations for districts with decreasing average total gross margin can be explained by the deletion of coupled premiums. Instead of premiums for former high premium arable crops (e.g. winter-rape with 499 EUR per ha) or animals (e.g. bulls with 210 EUR per bull) these districts receive in 2015 only the uniform amount of 302 EUR per hectare farmland. This reduces the average total gross margin for arable-land dominated districts significantly. For districts where the share of grassland is half or more than half of the arable land, average total gross margin increases. Here, the premium received for grassland may be the cause. While in the reference situation for grassland premiums from 30 to 50 EUR per hectare were received, in 2015 the regional payment of 302 EUR per hectare raises the average total gross margin significantly the higher the share of grassland is. Districts where such a trend is not evident have to be dealt more detailed especially with regard to their production structure (e.g. the diamond-coordinate 49/-1.1, cf. Figure 2).

4 Summary and conclusions

ACRE-Neckar is a regional model that simulates agricultural production in the Neckar riverbasin within the interdisciplinary project RIVERTWIN-Neckar. This model is developed to calculate scenarios for climate changes as well as political or economic scenarios. For these issues, PMP-method is used to maximise the regional total gross margin in the ACRE-Neckar model.

Within RIVERTWIN-Neckar, where ACRE-Neckar simulates the agricultural production in the Neckar river basin, political scenarios of CAP reform 2003 has been calculated.

For the current status and future of ACRE's development we conclude following aspects:

1) The model ACRE (which means the basic version of ACRE-Danube, the ACRE-version for the Danube basin, and ACRE-Neckar) is still in the process of development for further applicability. ACRE is modified and adopted to the project specific requirements and results are tested.

2) An ex-post-analysis for ACRE-Neckar have to be undertaken in order to test ACRE-Neckar algorithms and parameters. Also, results of scenario calculations have to be compared more accurately with the results of other studies.

3) Further analysis is necessary to exclude inaccuracies in aggregation. Therefore, the model should be re-run with data based on the municipality level, for smaller parts of the catchment areas

4) The similarity of the model regions of ACRE-Neckar and ACRE-Danube offers the possibility to merge both regions in a regional model that simulates agricultural production for nearly the whole of Southern Germany.

5) In addition to the enlargement of the model region, the development of interfaces to an agricultural market model can promise a more realistic approximated simulation of the agricultural sector.

Summarizing, ACRE can be considered as a regional model, which was applied in RIVERTWIN-Neckar successfully. In interaction with natural science models ACRE’s output data can contribute to fruitful applications in interdisciplinary modelling projects. Development of ACRE is still in progress and offers several possibilities for extensions in regional modelling science.

Acknowledgments

RIVERTWIN-Neckar is a subproject of the interdisciplinary project RIVERTWIN (A Regional Model for Integrated Water Management in Twinned River Basins), which is funded by the European Commission (Contract-No. GOCE-CT-2003-505401).

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