Modelling the probability of land abandonment at parcel level

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Abstract

To forecast future land abandonment on the level of cadastral parcels a GIS-based modelling concept is developed, called PROBAT. A logistic regression function is used to calculate the probability of agricultural abandonment. The theoretical modelling concept integrates individual attitudes and behaviour patterns of the farmers with bio-physical, economic and socio-economic factors. PROBAT provides useful information for spatial and agricultural land use planning. In further research steps the model has to be proved empirically and may need to be adapted.

Keywords: land abandonment, model, GIS, logistic regression.

1. Introduction

In Austria the abandonment of agricultural land has increased during the last four decades (e.g. about + 1,000 km² of set-aside land since 1970 (BMLFUW, 2004) and + 2,700 km² forest area since 1960 (BFW, 2004)). This trend is likely to continue, given the ongoing change in agricultural structures. If land use planners and policy makers are to address this phenomenon they need specific information (SILBER and WYTRZENS, 2005). A current research project (PROBAT) investigates the characteristics of parcels which are threatened by abandonment of agricultural cultivation and the probability of its occurrence.

Over the last decades a range of models have been developed to collate information about the past, present and future trends in agricultural

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land use changes (LAMBIN et al., 2000). However hardly any of these models focus on retreat of agriculture. Most of the existing models which were explicitly developed to identify agricultural land affected by abandonment operate at a regional level (BALDOCK et al., 1996, BETHE et al., 1995). General driving forces for land abandonment – the "end-result of agricultural marginalisation" according to VERSCHUUR et al. (2003, 21) – mentioned in the literature are environmental, social, economic and policy factors, geographic location and agricultural structures (BALDOCK et al., 1996, BEBI and BAUR, 2002, COPPOLA, 2004, BENDER et al., 2005). However, the explanation and the forecast of local differences in land abandonment – which is the case in Austria due to small-structured agriculture and heterogeneous natural conditions and which is particularly required by land use planning – need a (i) micro-scale modelling approach and (ii) the integration of individual behaviour patterns beside bio-physical and (socio-)economic variables. Literature analyses showed that both are innovations when modelling land abandonment.
In this paper a GIS-based modelling concept to forecast the probability of land abandonment (PROBAT) at the level of cadastral parcels is presented. Also, some pragmatic considerations when developing and empirically testing the model are discussed. As PROBAT is an ongoing research project this paper is a preliminary report.

2. Methods

When developing the model concept a deductive approach based on both micro-economic and behavioural theory was used. A literature review of papers and scientific studies about land abandonment, forest expansion, land use modelling, land rent theory, farm succession, behaviour patterns of farmers etc. lead to a list of factors that may influence abandonment of farmland. These driving forces were classified systematically according to spatial (global, EU, national, regional, local, farm-related, individual and parcel-related) determinants and factual (political and legal, socio-economic and infrastructural, and bio-physical factors) determinants. After selecting those determinants which are likely to be relevant on a micro-scale level by using specific selection and exclusion criteria (reference to parcel level, data availability), measurable explanatory variables were

derived to explain the dependent variable 'probability of land abandonment at parcel level' (p_k). The independent variables were classified into four groups: (i) parcel characteristics, (ii) personal and farm-related determinants, (iii) political and legal determinants and (iv) individual behaviour patterns of the farmers.
After data acquisition (secondary data as well as own survey data in a study area) the variables will be combined in GIS (ESRI's ArcGIS 9.0) by using a specific logistic regression formula (derived with SPSS 12.0) to estimate the occurrence probability of land abandonment ($0 \leq p_k \leq 1$).

3. Micro-scale modelling concept to assess the probability of future land abandonment (PROBAT)

In this study the term "land abandonment" is meant as taking utilized agricultural area out of agricultural management, e.g. marginal farmland is afforested or set-aside permanently. Abandoning the cultivation of a parcel or not is a decision made by the farmer (and possibly his family). As PROBAT is a micro-scale model, specific determinants with parcel relevance influence this decision. Both micro-economic considerations (costs and benefits of managing a parcel, land rents) and farmers' behaviour (rational but also non-rational aspects) played a role when identifying input variables. The factors included in the model and their underlying assumptions are (see also Fig. 1):
Parcel characteristics: Agricultural land use depends strongly on the natural conditions of a site. Potential yield is determined by the interaction of various factors like soil quality, climate and topography (BALDOCK et al., 1996). Land that supplies small yield at high costs (marginal land) is more often affected by land abandonment (BEBI and BAUR, 2002). PROBAT includes *slope*, *altitude* and *soil quality* as explanatory variables of natural parcel characteristics. It is assumed that the probability of land abandonment on a given parcel (p_k) rises with increasing slope and altitude, and decreasing soil quality of a site. Beside natural conditions *parcel size* and the *distance of a parcel to the farm* will probably determine land abandonment as well. Small parcels with a high distance to the farm are more likely to be abandoned than well accessible and large plots due to high transportation and labour costs (PEZZATTI, 2001).

Political and legal determinants: Several official measures and laws influence agricultural production. Agricultural subsidies with a spatial relation to the parcel level (*area-related subsidies*) – like some measures of the Austrian agri-environmental programme (ÖPUL) and compensatory payments for less favoured regions – should particularly help maintaining agricultural land use even on marginal sites as farmers are obliged to manage subsidised land for the agreed time period. The higher those premiums are and the longer the agreement is concluded, the lower the probability of land abandonment will presumably be.

Personal and farm-related determinants: Socio-economic factors heavily affect future development of a farm and therefore management strategies in the broadest sense. Larger holdings (*UAA [utilized agricultural area] and LU [livestock units]*) with a greater income potential (*standard gross margin*) have probably a higher chance than small farms to maintain farm business and agricultural management. Farm organisation like *type of farming* (e.g. a higher share of forest may lead to a higher probability of afforestation of UAA because of further specialisation), *full time* (lower p_k) or *part time farming* (higher p_k) and *labour capacity* (the more hours family members work at the farm the lower p_k will be) will probably affect p_k too. If *succession* on a farm is uncertain future maintenance of agricultural cultivation may be uncertain as well. Finally *age* and *agricultural education of the farmer* are included in the model; it is assumed that p_k rises with increasing age as younger farmers have better non-agricultural job opportunities and p_k decreases with rising level of technical education (better future perspectives in agri-business).

Individual behaviour patterns of the farmers: Decision making processes of farmers are not only influenced by economic considerations but also by non-economic individual attitudes, values or preferences. In contrast to land use models at regional scale, differing behaviour patterns of farmers play a substantial role when modelling land use changes (e.g. land abandonment) at a micro-scale level (LAMBIN et al., 2000). PROBAT takes farmers' *attitudes to landscape conservation*, their *traditional attitudes* and their individual estimations on *future perspectives* into account. For instance, if farmers are willing to conserve landscape without subsidies and if they have optimistic future prospects, p_k will be relatively low. Traditional farmers tending

to non-economic values will rather maintain cultivation of marginal sites than predominantly economically orientated farmers (VOGEL et al., 2003). Individual data will be integrated in the model by (i) surveying different Likert-scale items representing attitudes and behaviour patterns of farmers and by (ii) deriving indices according to the method of Likert (SCHNELL et al., 1999).

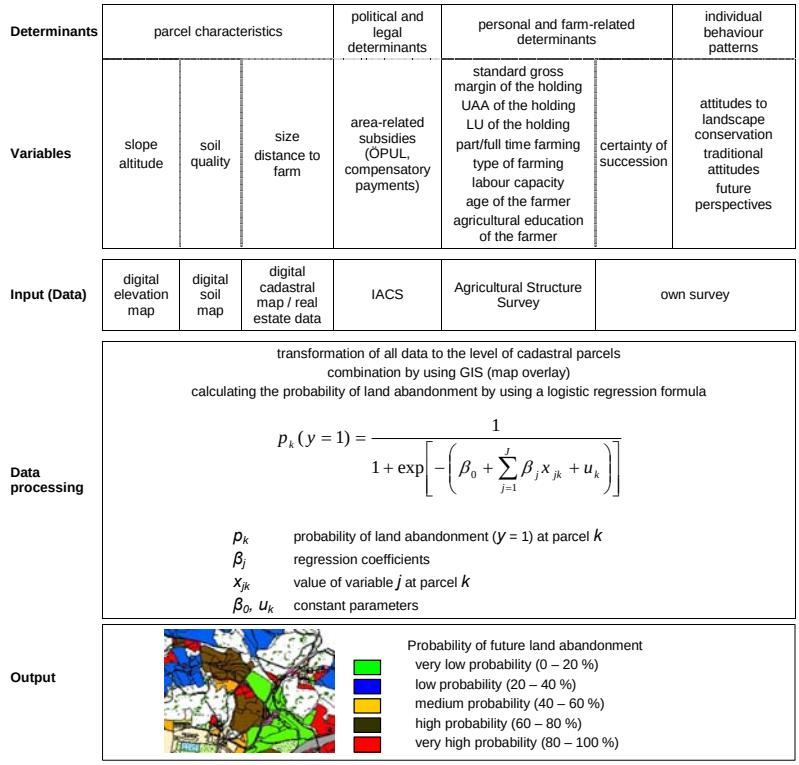

Figure 1: Concept of a GIS-based model to assess the probability of future land abandonment (PROBAT)

Different data sources will be used to collect the values of the above mentioned variables, e.g. digital elevation map and soil map, digital cadastral map and real estate data, data of the Integrated Administration and Control System (IACS) and Agricultural Structure Survey. To generate new information PROBAT thus mainly uses

existing secondary data. An own survey is necessary to gain information about individual behaviour patterns and succession situation.

Each spatially explicit model demands a specified spatial reference unit to compare and to combine different data within a GIS. For PROBAT the reference unit of a cadastral parcel (rather than a block parcel or a small-scaled raster) was chosen because (i) agricultural land use changes usually occur at this spatial level and (ii) predictions should be carried out at an official level (cadastral surveying, land register, basis for planning). All input data are transferred into parcel level. Some variables have to be generated from existing data by GIS analyses, e.g. distance to farm or slope of a parcel. The use of GIS will also enable data storage and data management as well as visualisation of data and modelling results.

To calculate the probability of land abandonment data are combined by using a specific algorithm (see Fig. 1). Different weighting factors according to the extent of influence of the variables have to be derived by carrying out a binary logistic regression analysis. Aim of the logistic regression is to find out the best fitting model to determine the occurrence probability to which future land abandonment has to be expected in dependence of specific input variables. Generally, binary logistic regression is adequate for situations when the dependent variable (y) takes only one of two possible values (0/1 event); in this case abandonment ($y = 1$) or further cultivation ($y = 0$) of an agricultural parcel. The occurrence probabilities (p) of the events have the following relation (BACKHAUS et al., 2003, 418ff):

$$p\,(y=1) + p\,(y=0) = 1$$

The probability (p_k) that the event 'land abandonment' occurs on any given parcel is a logistic regression function of j explanatory variables x. The independent variables can be measured on a nominal, ordinal, interval or ratio scale. Regression coefficients (β_j) – interpreted as different weights – will be estimated by using the method of maximum likelihood. To select essential variables for the logistic regression a stepwise variable selection procedure will be carried out.

The output of PROBAT will be a map showing the probabilities of future land abandonment for each parcel of a study area. The forecasts should be made for a time horizon of about five to ten years. Longer

predictions seem to be unconfident as agricultural politics may change rapidly, which makes modelling results uncertain. Shorter time periods (e.g. three to five years) are not long enough for farm managers to react on changed conditions with abandonment of specific parcels as path dependencies (alternative job, retirement, subsidies, agreements etc.) have to be considered. Furthermore for a short time visible impacts of (permanent) land abandonment on vegetation (bushes, trees) can not be observed in reality, so maybe a particular parcel is only abandoned temporarily.

4. Discussion and outlook

In further research steps the theoretical model and the deduced hypotheses need to be proved empirically. Therefore a study area will be chosen where (i) land abandonment already poses a threat and (ii) secondary data are available. By analysing data of pilot parcels that have been either abandoned in recent years or that are further cultivated a logistic regression formula will be generated. The sample size will be calculated by considering measures of statistical spread and number of independent variables. For identifying abandoned parcels results from interviews with local experts (farmers, planners) as well as of land use/cover maps and aerial photos will be compared. (Former) cultivators will be interviewed and secondary data of the study area will be analysed. Integrating attitudes and behaviour pattern of farmers shall enhance the quality of land use models. In this study a direct survey of Likert-scale items will be preferred to using proxy variables (KANTELHARDT et al., 2005).

Generally different methods to model the probability of land abandonment would have been possible, e.g. transition probability models (like Markov chains), dynamic simulation models or a cellular automata approach (LAMBIN et al., 2000). In this study an empirical-statistical model was chosen. Logistic regression is preferred to discriminant analysis (which is also adequate for 0/1 events) because logistic regression demands less strict data premises (BACKHAUS et al., 2003). However, logistic regression models cannot be used for wide ranging extrapolations as they only fit well in homogenous regions (LAMBIN et al., 2000). This leads to the question of transferability of PROBAT. Outside of the study area different weights for the

determining factors are likely, given varying natural conditions, socio-economic structures and individual attitudes. PROBAT will not be a universally useable instrument. It will supply practical results for a study area (village, small region) with a relatively homogeneous agricultural structure. For using PROBAT in other regions model adaptations will be necessary.

Beside transferability of the model further aspects have to be addressed within the ongoing research project:

- Validation and calibration of the forecasting model;
- Dealing with uncertainties when modelling future land abandonment, e.g. changing agricultural policy, (bio)technological change, social and economic change;
- Integration of new data sets (e.g. GIS-data of IACS) that enable new possibilities and simplified analysis.

Based on the current development status of the model, PROBAT is expected to give better insights into future agricultural land use changes.

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