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Institute for Food and Resource Economics

University of Bonn

Technical Paper 2014:1

Analyzing structural change in dairy farming based on an Agent Based Model

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February 2014

Abstract

The nearing abolishment of the dairy quotas triggers already rapid changes in the farm sector, accompanied by a vivid discussion about market power of dairies. We present an Agent Based Model (ABM) which draws on high resolution land cover maps and farm structural statistics, incorporates land use cover change and farm exit modules and spatially explicit auction modules for plots and milk delivery contracts. Whereas existing ABMs directly employ Mathematical Programming models, we integrate the behavior of a highly detailed, fully dynamic mixed integer single farm model using a duality based meta-model approach. Explorative simulations hint at massive structural change in coming years.

Keywords:

Structural change, Agent Based Model, dairy farming, dairy processors, duality based meta-model

1 Introduction

Since the political decision about the abolition of the milk quota, German raw milk production is constantly growing to about 30.3 mio tons (+13% or from 26.98 mio tons in 2000; BLE 2013 and ZMB 2013). This increasing milk quantity is produced with less and less farmers (<80000 units in 2013 compared to 138500 in 2000; BLE 2013 and ZMB 2013), and less dairies (251 in 2000 to 147 in 2012; BLE 2013 and ZMB 2013). This implies a constant structural change where the move to larger units at farm and processing level is predominant. Notwithstanding the positive production developments, there is an extensive debate about market power asymmetries in the dairy sector and implications for the raw milk price ("EU Milk package").

In the past, farm level structural change was analyzed using different avenues: econometric approaches mainly using Markov-chains were successful in disclosing changes in the composition of the farm population (e.g. Zimmermann and Heckelei 2012), but also simulation approaches using Agent Based Models (ABM) were used to analyze farm structural change (Ostermeyer et al. 2011). The use of ABMs in the context of farm structural change is well established in the literature (cf. Happe et al. 2006, Lobianco et al. 2010 or Schreinermachers et al.2011), both to increase analytic understanding as well as to perform policy impact analysis. With respect to the analysis of structural change on processor level, however, empirical papers are more difficult to find. Some descriptive analysis of the development in the German milk processing sector are available (e.g. Drescher and Maurer 2000, Wissenschaftlicher Beirat 2000), but, to our knowledge, no econometric analysis and only few modeling approaches are available. One example is Boysen and Schröder (2006) who use a capacitated facility location problem that is solved with a generic algorithm to analyze structural change in dairy processing.[1]

[1] If we extend the geographical and product coverage, Hueth and Taylor (2013) and Graubner et al. (2011a and 2011b) may be mentioned.

In situations where large policy changes, as the abolition of the milk quota, may induce breaks in the structural adjustment process and complicate the prediction of ex ante developments from ex post behavior, ABMs provide a path forward for the analysis. The objective of this paper is to analyse structural change in the dairy sector which may arise from changes on farm or processing level. These adjustment processes are investigated using a newly developed dairy ABM that features spatially explicit competition between farmers in land rental markets simultaneously with competition between dairies for milk delivery contracts drawing information from high resolution land cover maps and farm structural statistics. Thus, the ABM can be seen as a “virtual lab” that allows to analyze how different behavioral and market structure assumptions impact structural change.

We compare two scenarios which solely differ in average milk prices paid by dairies to highlight interaction between milk, land markets and farm structural change. Hence, the paper can be seen as a first explorative analysis of the capabilities of the developed ABM.

2 Methodology

2.1 *Overview*

Graph 1 below gives an overview on the overall framework[2]. As for other ABMs found in literature, the platform described in here comprises a cellular component which represents land use pixel in a landscape and an agent-based component depicting human land use decisions (Parker et al., 2002; Robinson et al., 2007). A difference of the employed ABM to e.g. Kellermann et al. (2007) is that the ABM does not include Mathematical Programming (MP) directly, but rather uses a dual profit function to describe economic decisions of farmers. Using a dual profit

[2] A full documentation provides Britz (2013c) and Britz (2013d, ODD+D protocol) and Britz (2013e) for the underlying Java code.

function has the advantage of overcoming computational restriction of existing ABMs. Berger (2001) describes an application of an ABM comprising MP models to Chile with about 5000 farmers that requires solving 1.4 million MP models. But MP models which depict in realistic detail farm management and investment options can be quite large. To given an example: the MP model by Lenger and Britz (2012), underlying our dual profit function, has several ten thousands variables and equations and takes quite long to solve, even with modern Mixed Integer Programming (MIP) algorithms using several processors in parallel. An integration of such detailed models in an ABM framework is therefore not a viable option. Instead, we develop a framework where economic decisions are based on a dual profit functions that are estimated from systematic sensitivity analysis with a MP (see also Lengers and Britz, 2014).

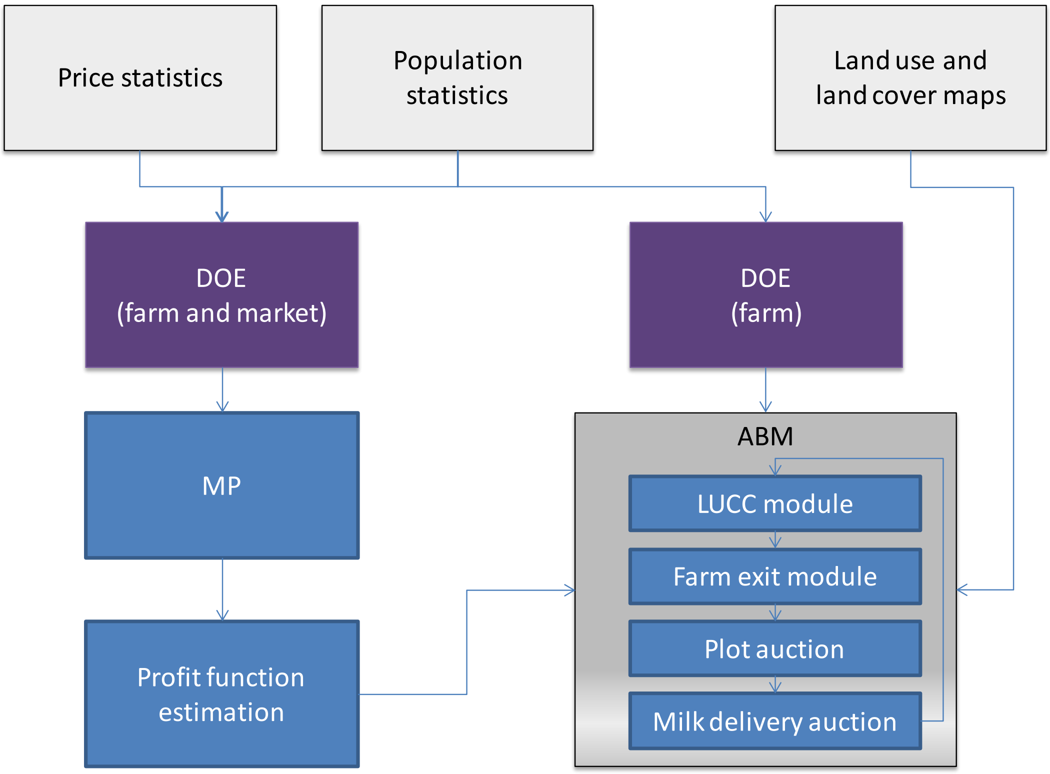

Figure 1. Overview on framework

Source: Own representation.

The left hand side of Graph 1 depicts the derivation of the profit function which steers the economic behavior of the farmers in the ABM. Using price and farm structural statistics, we define a set of computer experiments based on Design of Experiments (DOE) which cover the full range of all variables of interest. Each element in the set serves then as input for a simulation run with a highly detailed MP. The results from these runs are the observations for the estimation of the dual profit function. The parameter and structural form of that function are incorporated in the ABM.

The right hand side depicts the use of the ABM and its structure. The farm structural statistics serve again as input to a DOE, which now depicts the farm population presented in the ABM. Additional land use and land cover maps serve as geo-referenced input to define the landscape present in the ABM. In each year, first a land use cover change module accounts for changes in urbanized land cover. Next, the farm exit module determines which farmers leave the population. The plots so far managed by them become available for renting, along with plots where the rental contract ends in the current year. The plot auction assigns these plots to famers. Finally, an auction for milk delivery contracts is conducted. These processes are repeated until the end of the final simulation year.

2.2 *Land use and land use cover change*

The landscape underlying the ABM can be understood as a spatially explicit representation of land cover as well as property rights to farmed plots, where each plot is characterized by its location, length and width. The underlying land use cover data used are a combination of CORINE (‘coordination of information on the environment', European Topic Centre on Terrestrial Environment, 2000) with a 100m x 100m resolution and the data set of Leip et al. 2008 which spatially downscales land use and agricultural statistics to 1x1 km pixel clusters, as well as comprising other data of interest such as climate and soil data, elevation or slope. The CORINE data are available for all EU Member States and can be clipped to input regions for the ABM platform with a GIS program. The data set by Leip et al.

2008 is readily usable for all Member States without further pre-processing for EU 25.

The algorithm populates the agricultural part of the landscape with rectangular plots between 1 and up to 25 ha pixels; the maximal size can be changed. Farmsteads are assumed to occupy one pixel. Plot location and sizes and locations of farmsteads do not change during a simulation. However, existing farmsteads might no longer be linked to farmed land, but occupied by an agent who then only rents out agricultural land.

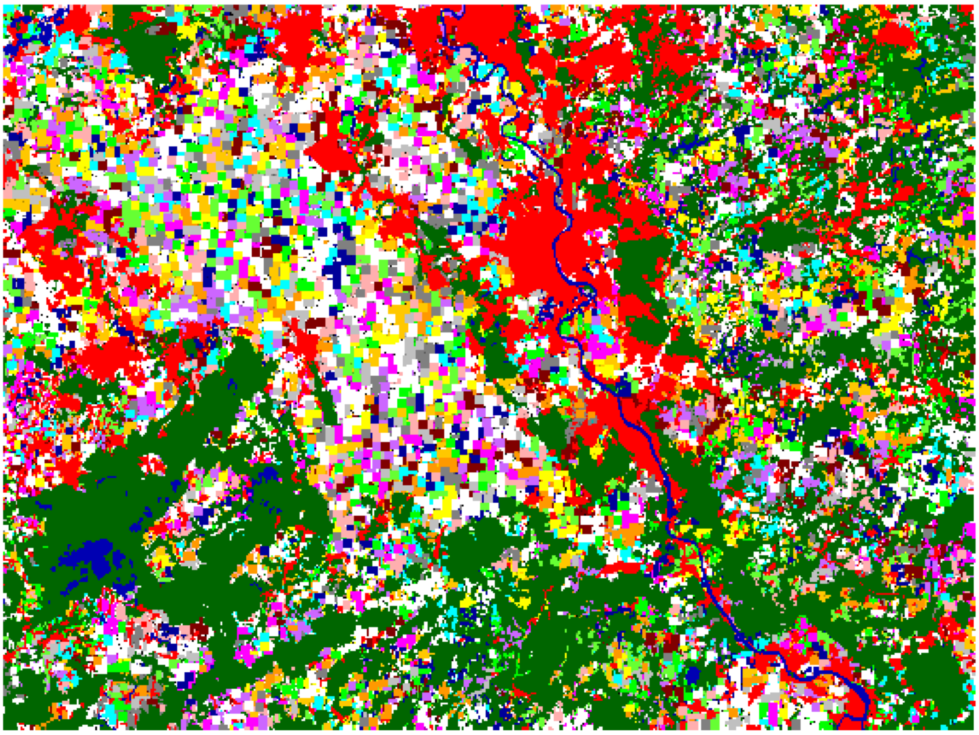

Figure 2. Landscape from land cover data for “Regierungsbezirk Köln”

Source: Own representation.

The land use change algorithm in the prototype is rather simple, but follows the general attributes of cellular based land use cover change modeling (cf. Verburg et al. 2004). In each year, an exogenous growth rate determines by how much the total urbanized area in the overall region should increase. The algorithm then determines which pixels will change their land cover based on their cover change probability. The algorithm currently assumes that forest is protected, a reasonable assumption at least for Germany, and that other land cover – representing e.g. water bodies – is fixed. That leaves farmed land as the only buffer for extension of urbanized land cover. The transition probabilities depend on the share of agricultural and urbanized pixels in its neighborhood. A high share of urbanized pixels increases the probability, which captures the effect that urbanized land cover spreads typically out from existing settlements. On the other hand, lower shares of agricultural land cover depress the probability, assuming that if the urbanized share is already quite high, non-urbanized landscape elements will tend to be protected by zoning laws.

2.3 *Mathematical programming model and estimation of dual profit function*

We draw on the model developed by Lengers and Britz (2012), a fully dynamic mixed integer programming model with a focus on dairy farming. The model is rather complex (for details see the detailed model documentation, Britz et al. 2013) with features such as accounting for monthly work restrictions, available field working days depending on the soil type, explicit investment decisions in stables and a larger set of agricultural machinery, cow herds differentiated by milk yield or a detailed feeding module which an inter-annual resolution to account for differences in fodder availability over the growing season while differentiating cow requirements by lactation period. Investment and off-farm labor use decisions are implemented as integer variables. Based on a modular approach, further detail can be used on demand such as step-wise yield functions for arable crops or different tillage options (Remble et al. 2013).

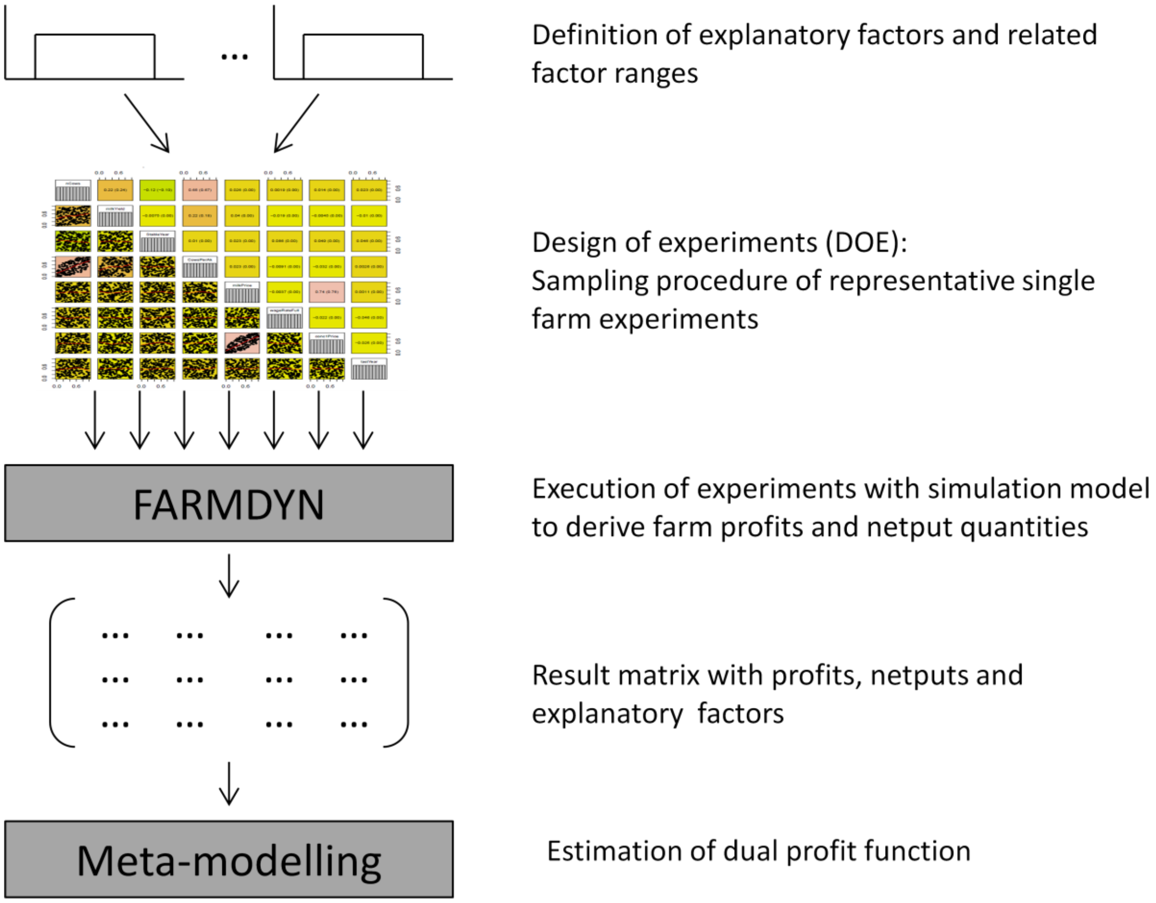

Figure 3. Overview on profit function estimation

Source: Own representation.

Drawing on the methodology of Lengers et al. (2014) who estimate a meta-model for abatement costs of Green House Gases from simulations with the same MP as used by us, we employ Design of Experiments (Kleijnen 2005) based on a Latin-hypercube sampling method procedure according to Iman and Conover (1982) to conduct a set of 500 simulation experiments with the MP model (see also Figure 3). In these experiments, both farm (cow herd size, cow yield, endowment with arable and grass land and family labor, age of stables) and market (milk price, concentrate prices, prices for arable crops, wage rates) attributes are systematically varied, where the range and partly correlations stem from farm structural and price statistics. The resulting set of observations is then used to estimate symmetric normalized quadratic profit functions, where the prices and farm attributes mentioned above serve as exogenous variables. In opposite to the estimation from real-world data, we fully control the data generation process such that coefficients are highly significant. Despite the partially jumpy response of the underlying MP, explained variances are quite high (>0.9 R^2). These results underline that the behavior of the MP can indeed be accurately enough be summarized with a dual profit function in the ABM. Currently, the ABM differentiates between arable and dairy farmers for which separate parameters are estimated and subsequently integrated in the ABM.

2.4 *Farm population and farm exit module*

The farming population in the model is generated using farm structural statistics. We use DOE to generate a stratified random sample which covers the observed range of farms structural attributes in the population (number of cows, milk yield, AKs, stocking rates and thus hectares managed, arable land share) and their correlation. These farmers are randomly located in the landscape where agricultural land cover is reported in land cover statistics, while accounting for the share of arable and grass lands when locating dairy and arable farrms.

In each year, the probability of a farmer to quit farming is determined. That probability is in the prototype calculated from three elements: firstly, the relation between the farmer's current profit in relation to the maximum of a pre-determined quantile of the profits in the farms population and the expected net wage in the industrial sector minus commuting costs. Secondly, a normally distributed random number which expresses other not controlled for factors impacting exit decisions. Thirdly, we determine the profit maximal share of on-farm labor use and assume that the farm has practically exited once a minimum threshold share of on-farm labor use is undercut.

2.5 *Land rental market*

The land rental market works with 10 year contracts. We currently assume at 20% of the plot are rented in the starting situation. Exiting farmers will offer their land for rent, such that the share will increase over time in scenarios.

Farmers put bids on all plot open for rent in a maximal distance around the farmstead. For the analysis at hand, we assume full rational behavior such that farmers bids according to marginal returns, differentiated by arable or permanent grass land plots. There is a deduction in the bid depending on the distance to the plot.

The auctioneer will auction the plot with the highest bid first; afterwards, the winning farmer can update any other bids to plots not yet auctioned. His rental price is equal to the second highest offer (Vickrey auction). The auction stops once no longer any positive bid is found or all plots are auctioned.

The framework can use different types of bidding behavior diverging from full rationality, such as bidding according to average returns to land or by using solely prices of neighboring renting contracts. The share of farmers using different bidding behavior can be adjusted as well. Equally, further attributes of the auction can be changed, e.g. with regard to the order of plots in the auction (highest surplus/price first, lowest surplus/price first, random) or how the price is determined (Vickrey as used, fixed distribution of surplus, distribution of surplus depending on relation between supply and demand). However, for the results presented below, we use the most easy to interpret bidding behavior and auction attributes.

2.6 *Representation of dairies*

In this explorative version of the ABM, four dairies are equally dispersed in the landscape (north, east, south, and west). All dairies have the same processing capacity where the actual processing amount is determined by the sum over the milk deliver contract bids accepted by the farmers. The price offered by the dairy is dependent on distance of the farm to the dairy and delivered quantity, but not on the price bid of the neighboring dairies. Hence, in principle, each dairy acts as a "local monopolist" but in this explorative version, the competitive behavior of the dairy is not yet explicitly modeled. Instead, the raw milk input demand of the dairies is implemented as a quantity dependent stepwise function where the offered price of the dairy depends on the delivery quantity. Also not considered in this initial version is processing of raw milk into dairy products and related differences in output and subsequently input prices.

In the next version of the model, it is envisaged, similar to the duality based supply response function for the farm sector, to specify also an input demand response function for the dairies and to investigate how different competitive behaviours can considered. In this regard, Graubner et al. (2011a, 2011b) offer interesting insights regarding the spatial pricing behavior on input markets, Zavelberg et al. (2013) provide insights on the competitive effects of different contract durations for inputs.

2.7 *Milk delivery contract auction*

The auction for milk delivery contracts offers conceptually the same flexibility as for land renting contracts. We use a "take it or leave it" type of auction where the dairy offers a price which the farmer can accept or not. That price offered is a function of the delivered quantity and the distance to the farm stead. All farmers receive offers from all dairies.

The farmer will, based on his profit function, determine the profit maximal milk quantity at the offered price. If the profit maximal quantity is above the minimum delivery quantity necessary to receive the price and the profit is positive, the farmer will put a bid forward to the auctioneer.

The auctioneer will award the contract with the highest prices first. If several contract have the same price, the ones with the highest quantities come first. Formally, dairies might withdraw outstanding offers to farmers once their maximal processing quantity for milk is reached.

2.8 *IT aspects*

The ABM is implemented in Java, however without drawing on a specific ABM library. Java as an object oriented language was chosen to ease the link between the conceptual design of the ABM and its software implementation. Object orientation allows depicting the agents as entities which are characterized by a set of attributes describing e.g. asset endowments and behavior, as well as methods which describe their interactions with other objects such as farmed plots in a landscape. That approach seems to be rather standard in the ABM community (cf. Laniak et al. 2013). The German scientific community focusing on ABMs related to agriculture seems to rely mostly on a software package dating back at least a decade, developed by Balman and Happe (2001) and implemented in C++ and using OSL from IBM as a MIP solver. The wider ABM community in social sciences seems to employ today rather libraries such as "repast" (North et al. 2006), often based on Java. There is often the argument made that Java based implementation are slow. Tests with the current Java implementation seem however to underline that the framework is fast enough[3].

The Graphical User Interface and further utilities for data handling are based on GGIG (Britz 2013a), which is also used e.g. for CAPRI (Britz 2013b). That seemed specifically important for the efficient re-use of the spatially explicit agricultural data from Leip et al. 2008. The MP is encoded in GAMS and uses CPLEX as the MIP solver. Econometrics draw on R (cf. Kleiber and Zeilies 2008), Version 3.02 (CRAN 2013), specifically, the profit function estimation uses the package micEconSNQP by Henningsen 2010. Data I/O is mostly based on the proprietary

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[3] Parts of the algorithm used can certainly further tuned for performance. Tests were run for landscape with around 10.000 farmers and 30.000 plots, processing one year takes about 15 second. A larger share of that time is due to the spatial search for each active farmer to determine the share of industrial land cover. That could be sped up dramatically if industrial land cover is considered static for that algorithm, such that the share would need to be determined only once.

GDX format of GAMS which allows efficient storage of sparse multi-dimensional matrices, using the GDX API from GAMS (GAMS 2013).

3 An exemplary simulation

As mentioned above, for the exemplary simulation, we assume full economic rationality as well as relative straightforward auction models (Vickrey, highest surplus/price first). The sole differences between the simulations are the mean milk prices offered by the dairies. The analysis is conducted for a part of the German NUTS1 region “Regierungsbezirk Trier”, a less favorable region in the German context due the prevalence of low mountain ranges such that many plots have higher slopes. Soils are often poor, such that the region shows a relatively high share of forest cover as well as of permanent grass land. The total size of the simulated landscape is about 130.000 ha of which about 60.000 ha of farm land are managed by about 750 farms in our starting situation, of which about 450 are dairy farms.

The scenarios show that long-time prevailing differences in milk prices can have distinct differences on structural change in dairy farming. Such differences could root in either different global or European market conditions or in different regional competition between dairies. That long-term interpretation is the outcome of how the profit function is constructed: the underlying simulations with the single farm model cover a planning horizon of 30 years, such that basically labor and capital are assumed fully variable. It seems appropriate to base farm exit conditions on expected long-term profits of farming; equally, decisions about delivered milk quantities which are linked to the dairy herd size and typically also the available land have a medium to long-term horizon. We thus refrain from analyzing possible short-term fluctuations in milk supply and related adjusted in farm management.

In our standard baseline, we assume milk prices around 26 ct/kg under moderate prices of feed concentrates. That goes along with reduction in the number of dairy farms of around 1% p.a. where farms leave the sector if their expected long-term returns to labor for on-farm work fall beyond the reserve wage rate (blue line in

Figure 4 below). A 10% increase in milk price (green line) at unchanged input costs basically removes exits based on wage differences between dairy farming and the non-agricultural sector, whereas a 10% decrease in milk prices accelerates farm exits quite substantially.

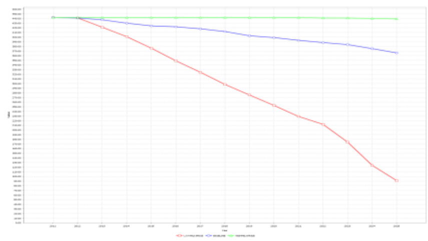

Figure 4. Number of dairy farms under different milk prices

Source: Own representation.

Differences in milk prices clearly also impact the land market, as marginal returns to land differ. Figure 5 below reports the average rent for grass land under the three scenarios. Under the low milk scenario, the land rents drop constantly, whereas they grow under the high price scenario.

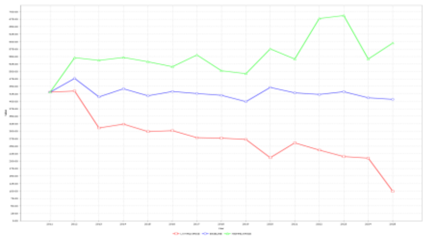

Figure 5. Average rental rates for grass land [Euro/ha]

Source: Own representation.

Finally, we have a look at the farm size distribution under different milk prices. As seen from figure 6 below, under low prices (red bars), only 20% of the farms survive and only few small scale farms with less than 600.000 kg survive. But also large-scale farms show less growth, especially compared to the high price scenario where a considerable share of farms is found with milk output of around 1.4 to 1.5 Mio t of milk per year.

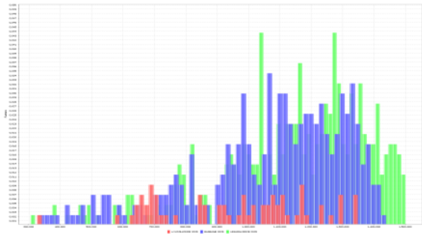

Figure 6. Histograms of distribution of active dairy farms by yearly milk output

Source: Own representation.

4 Summary and conclusions

We presented a newly developed, modular framework for an Agent Based Model (ABM) for farm structural change which incorporates the simulation behavior of highly a detailed Mathematical Programming model (MP) based on a statistical meta-model in the form of a dual profit function. That specific solution overcomes computational restrictions from a direct incorporation of the MP in the ABM and thus allows for larger farm populations to be modeled. Based on spatial explicit auction modules for rented plots and milk delivery contracts and a farm exit module, the ABM allows simulating structural change in dairy farming under different assumption on how dairies compete for milk delivery contracts. Our explorative simulations under different milk prices show that under a baseline scenario with about 26 ct milk price around 1% p.a. where farms leave the sector if their expected long-term returns to labor for on-farm work fall beyond a comparative non-farm wage rate. A 10% higher milk price basically removes farm exits whereas a 10% decrease accelerates farm exits quite substantially. Further work will add more farm types (pig farms, bull fattening), improve the dual profit function estimation and develop different price settings behavior for dairies.

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