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Abstract: The majority of European farms are family farms. Farm succession, i.e. passing over the responsibility from farm owner and manager to their heir, is an important element of structural change in agriculture. We present a model implementation capturing farming household evolution in an agent-based model and explore the consequences of farm household composition and farm succession on agricultural production, investment and participation in agri-environmental policy schemes.

Keywords: *Agent-based modelling; Agriculture; Farm succession; Family farms; Structural change*

1 INTRODUCTION

The great majority (97%) of European farms are family-run and mainly employ family labour (Eurostat 2014). This organizational characteristic is a major determinant for the long-term development and structural change of the agricultural sector. Continuation of a family farming business is in the great majority of cases tied to the person of the farm manager. If he or she retires or dies prematurely and no successor is available to take over the farm, it will usually be closed down and the land is rented out. In the last decade before retirement, farm managers without successor tend to be reluctant to make long-term investments and instead reduce production intensity, whereas in the presence of a successor they increase investments to secure the long-term viability of the farm (Calus et al. 2008; Huber et al. 2015). When a successor takes over, this is often an occasion to make fundamental adjustments to the farm business (Potter & Lobley 1992). Farm succession is therefore a key process in forming the structure of the agricultural sector, which in turn affects production intensity, efficiency, but also participation in agri-environmental schemes or organic farming (Zagata & Sutherland 2015).

Agent-based models are especially suited for a bottom-up simulation of farm structural change as they allow for capturing the heterogeneity of existing farms, model their individual economic development potential, and their cooperative and competitive interaction with other farms of different types and sizes (Berger & Troost 2014). Last but not least, they allow to explicitly model the effect of farm household composition on farm evolution. In this article, we discuss the representation of farm household evolution in an agro-economic microsimulation model (an agent-based model that does not yet include interactions between farms) for the Central Swabian Jura in Southwest Germany. Farm household evolution is determined by three major components: (i) The demographic development of household composition comprising birth, death and finding a partner, which we model as purely statistical events based on demographic fertility, mortality and marriage rates; (ii) the decision of potential successors whether to take over the farm; (iii) the economic development of the farm that determines whether the household can remain a farming household or is forced to give up farming.

Our model goes beyond a narrow traditional microeconomic rationality framework that considers firms as purely profit-maximizing "black boxes" with perfect knowledge and foresight and without regard to their internal organizational structure. Nevertheless, we do assume rational behaviour – in the wider sense of Popperian situational analysis (Caldwell 1991; Koertge 1975): Given *their* appraisal of their situation and options for action, and *their* means of determining an optimal response, people are assumed to act rationally. If *our* appraisal and optimal response implemented in our simulation models does not coincide with *their* actions, then we first question our appraisal of the situation as researchers before we conclude that people acted irrationally. While there are certainly situations, in which other, e.g. neuro-psychological theories of behaviour are more fruitfully employed than the rationality assumption, economic production decisions of commercially oriented farms are arguably among the ones that can be deemed closest to rational, as long as the specific conditions of the single farm and the *boundedness*, *recursivity*, *locality* and *algorithmic* nature of these decisions are taken into account (Day 2008). Day further distinguishes between *strategic* and *tactical* decisions. Strategic decisions relate to 'lifestyle paradigms' that define what kind of person one wants to be and set a frame for further action. They are taken only from time to time and not necessarily taken with resource constraints in mind. Tactical decisions, in contrast, are decisions on concrete actions, which are restricted by the lifestyle paradigm, but also by economic considerations.

In this sense, the decision of a farmer's son or daughter to take over the family farm is a strategic decision that determines a lifestyle and frames further action. Following Mann (2007), this decision can be understood in terms of two groups of factors: Identity-related factors, such as a preference for working outdoors or the desire to continue family tradition, and environment-related factors, i.e. mainly the perceived long-term economic viability of the family's farm business, which determines whether an interested child does indeed continue the family farm business when the moment of taking a decision finally arrives. While the personality-related preferences of potential successors may be explained by social-psychological analysis (e.g. Fischer & Burton 2014), we abstain from a detailed model implementation and include these as an independent random variable in our model. A second personality-related determinant in farm succession is the willingness of the current farm manager to proactively plan for passing over the farm or even step back earlier to foster a successful continuation of the family business. Here, we assess the effects of different behavioural assumptions comparing three scenarios.

Making the yearly farm production plan is then a tactical decision, which we model as a mathematical programming (MP) problem (Berger & Troost 2012). Although this may seem to contradict the "algorithmic" (i.e. heuristic, satisficing, non-optimal) nature of decision-making postulated by Day (2008), it can be justified in this case given the following considerations: Many German farms work with consultants or software that do actually use Operations Research methods such as MP to find optimal production plans. Most of the constraints in a mathematical program (MP) describing a farm production decision problem are physical and technical relationships that farmers cannot ignore even if they wanted to. Heuristic rules known to be applied by farmers can be incorporated as constraints in the MP if adequate. Assuming that farmers did the best they could focuses policy analysis on deficiencies in the institutional and economic environment (Schreinemachers & Berger 2006). Compared with purely observation-derived behavioural rules, an empirically parameterised MP implementation provides guidance on how agents might act when a structural break such as climate change alters production conditions and requires a complete reassessment of production options and is thus much more suited for out-of-sample simulation (Troost & Berger 2015).

2 METHODOLOGY

We use the farm-level model presented in Troost & Berger (2015) and Troost et al. (2015), which simulates the investment and production decisions of more than 500 full-time farms in the Central Swabian Jura, a low mountainous range in Southwest Germany. The model has been implemented using the agent-based modelling package MPMAS (Schreinemachers & Berger 2011) and employs MP to reflect the multi-output multi-input production decision problem of farm managers (Berger & Troost 2012). Full documentation following the ODD protocol is available from http://mp-mas.uni-hohenheim.de. Here, we focus on the description of the composition and evolution of farm agent households and their effect on investment and production decisions in the model.

2.1 Farm household composition and evolution

In our simulations, we compare four scenarios that reflect different model assumptions for farm organization and its effect on investment and production decisions: Scenario NONFAMILY acts as control and treats all farm agents as non-family farms: All labour is hired, the farm agent has an infinite planning-horizon, and there are no minimum withdrawals for household consumption. In the other three scenarios, FAMILY_PASSIVE, FAMILY_ACTIVE, and FAMILY_PROACTIVE, all farm agents are simulated as family farms consisting of ten types of members: Household head, partner of household head, young farmer, young non-farmer, and retired farmer, all either male or female. Each household member type is associated with gender and age-specific probabilities of dying, giving birth and marrying derived from general population statistics (Statistisches Bundesamt 2012a-c) and used to determine marriage, birth and death as random events during the course of simulation.

New members enter the agent household either by marriage or by birth. All unmarried household members (above 16) have a positive probability of marrying a member of the same type. Female household members between 15 and 49 have a positive probability of giving birth. Newborn household members have a fifty-fifty chance to be male or female.

Mann (2007)'s identity-related factors for farm succession are represented in the model by the distinction between young farmer and young non-farmer household members, which is modelled as a purely statistical relationship. The probability for a newborn male household member to be a “young farmer” (parameter $probsucmale \in \{0.5;1\}$) is assumed to be 0.5 or 1, while the probability for a newborn female household member to become a young farmer is only 0.1. This gender bias follows the patterns observed by Mann (2007). Young non-farmers have no interest in farming as their profession and leave the household with 20 years. Young farmers may be employed on the farm also after they surpassed the age of 20. Whether they are indeed employed or search work somewhere else is part of the farm agent production decision. Once they surpassed the age of 22, they become eligible to succeed the current household head.

Farm succession can be triggered by either death or retirement of the current household head in the model. Household heads above 70 are obliged to retire. Successful succession requires a potential successor and economic viability, i.e. that the agent farm generates income covering at least the minimum household consumption times parameter $sucmin \in [0.9, 1.4]$ (including payments to the new retiree(s), see below). If succession fails in the case of death or obligatory retirement, the agent farm will be shut down. Household heads may also voluntarily retire earlier if a successor is willing to take over the farm. In the scenario FAMILY_PASSIVE, farm managers wait until they reach the common retirement age of 65 before they make an attempt at passing over the farm. In the scenarios FAMILY_ACTIVE and FAMILY_PROACTIVE, they start making their first attempt with 55. In addition to surpassing the minimum income threshold, successors need to have been employed on the agent farm for voluntary succession to succeed. If voluntary succession fails, the current household head will remain the farm manager and try to retire the following year again.

If several potential successors are available, the one with the highest priority becomes the new household head. The oldest male young farmer household member between 23 and 45 years has highest priority, followed by the youngest male young farmer between 46 and 65 years, the oldest female young farmer between 23 and 45 years, and the youngest female young farmer between 46 and 65 years. In the case of death of the current household head, the spouse of the deceased household head follows with lowest priority if it is under 65.

2.2 Effects of household composition on investment and production decisions

In our simulation model, household composition affects farm production and investment decisions in three ways: It determines the amount of withdrawals for own consumption from farm income, it determines the household labour available for production, and it determines the length of the planning horizon of farm managers.

Withdrawals for consumption correspond to a minimum household consumption of 26,000 Euro plus 8,000 Euro for each retiree (former household head or spouse of household head). If the agent income is higher than the minimum consumption, a certain percentage determined by parameter $sconextra \in [0.25, 0.75]$ of the surpassing income is consumed in addition. When agent income falls below minimum consumption, it is consumed entirely. A certain share of minimum consumption determined by the parameter $sconred \in [0.5, 1]$ is consumed even if income does not suffice to cover it. Cash is then either taken from the agent farm cash reserves or, if no cash is left, the agent is illiquid, closes down the farm and exits the model. In the case of the NONFAMILY scenario, there is no minimum consumption, only the *sconextra* share is consumed.

In the model, household heads and retirees until the age of 70 as well as young farmer household members over the age of 19 count as full workers. Household members between 14 and 18 years of age have a labour provision of 30% of a full worker. Spouses of household heads provide 60%, retirees between 70 and 75 years 50% and retirees between 76 and 80 years 20% of the labor capacity of a full-time worker. The labour of farm managers, their spouses, retirees and young family members under 23 is remunerated through the household withdrawals. Young farmers over 23 that are employed on the farm have to be paid a regular permanent employee's wage. In scenarios FAMILY_ACTIVE and FAMILY_PROACTIVE, this wage paid to potential successors is offset by a utility term of equal value as soon as the minimum consumption of the household is expected to be covered by the agent farm income. In other words, as soon as their own income expectation is met, employing their potential successors is considered as cash flow, but not as an economic cost by the agent farm manager during planning. This model implementation reflects the empirical observation (Zagata & Sutherland 2015) that farm managers tend to enhance their business in order to be able to employ their potential successors, potentially even foregoing a chance to increase their own income.

When farm agents make investments, they do consider the expected profitability of the investment over the expected lifetime of the asset, but at maximum over the expected remaining lifetime of the farm. In other words, farm managers close to retirement without successor will not make investments that pay out only over a much longer time than they expect to remain in business. In scenarios FAMILY_PASSIVE and FAMILY_ACTIVE, the expected remaining farm life is the remaining time until the current household head turns 65. In the scenario FAMILY_PROACTIVE the expected farm life is extended in case a potential successor is present, until the point when the latter will turn 65.

2.3 Initialization of farm household composition

In general, Troost & Berger (2015) determined the initial state of agent farms (i.e. their land, building and machinery endowments) using a Monte-Carlo sampling procedure based on joint probability distributions derived from FDZ (2010). This dataset did, however, not contain sufficiently detailed information on farm household composition, so that this was generated independently using a separate Monte-Carlo procedure. Household composition sampling started from drawing the age and marriage status of the agent household head from the corresponding statistical distributions provided in Statistisches Bundesamt (2011, 2012a). Based on this, the presence and age of the household head's wife, children, children-in-law, grandchildren and parents in the agent household was determined by “replaying” their lives following the same birth, death, and marriage probabilities that are used to simulate household evolution during the actual model simulation (cf. the online model documentation for details). To reflect slightly higher rural birth rates in past decades in Germany, we repeated the procedure using an increased fertility (+5%) as an alternative for uncertainty analysis $bfpast \in \{1; 1.05\}$. Both versions were run with both settings for the probability of male descendants to be interested in farming ($probsucmale \in \{0.5; 1\}$) leading to four different final household compositions per Monte-Carlo random seed used.

3 DESIGN OF THE SIMULATION EXPERIMENTS

We run the model for 10 simulation years starting in 2007. The farm agent population's asset endowments have been initialised with the 2007 synthetic population derived from Farm Structure Survey Data (FDZ 2010) as described in Troost & Berger (2015). Prices and price expectations are held constant at 2000-2009 averages. The policy environment includes the full transition from EU 2003 MidTermReview regulations to the most recent 2015 changes to the CAP. With respect to national policies, our simulations include the 2004, 2009 and 2012 revisions of the German Renewable Energy Act and continuation of the MEKA III agri-environmental policy scheme throughout the full simulation time (cf. Troost et al. 2015).

As explained in the previous section, we compare four different scenarios that represent ways in which family farms may deal with long-term planning and farm succession in their investment planning. Table 1 summarizes the differences in agent decision-making between scenarios. For uncertainty analysis, each scenario is repeated with varying parameter settings. On the one hand, parameter variation reflects aleatory uncertainty, i.e. the random seeds determining initial household composition and household member events (death, marriage, birth) during simulation. Here, ten different seeds for household member initialization have been paired with twenty different seeds for household member events (two per each initialization seed), so that twenty different design points represent aleatory uncertainty. A common random number scheme (Law 2007, Stout & Goldie 2008) using the RngStream random number generator (L'Ecuyer et al. 2002) ensures that the same events occur in each household whenever the same seed for the random number generator is used (cf. Troost & Berger 2016 in session B2 of these proceedings).

Table 1: Scenarios

Scenario	Investment horizon	Labor	Attempts to retire voluntarily
NONFAMILY	infinite	only hired	-
FAMILY_PASSIVE	until current farm manager turns 65	family labor, no utility from employing successor	≥ 65
FAMILY_ACTIVE	until current farm manager turns 65	family labor, utility from employing successor	≥ 55
FAMILY_PROACTIVE	until potential successor turns 65	family labor, utility from employing successor	≥ 55

On the other hand, epistemic uncertainty is reflected in 17 model parameters that are systematically varied following the space-filling Sobol' quasi-random number sequence. Apart from uncertainties in the farm production function (yields, market access, initial asset endowments, etc., see Troost & Berger 2015), these include the five parameters (*bfpast, probsucmale, sucmin, sconred, sconextra*) directly related to agent household composition and evolution, which were described in the previous section. Sixty points of the Sobol' sequence are repeated for each of the twenty points of the aleatory sample, leading to 1,200 model runs for each of the four scenarios. Since the same repetition in two scenarios differs only by scenario setting and is otherwise equal with respect to epistemic and aleatory parameter variation, each repetition constitutes a fully controlled experiment allowing us to isolate the scenario effect and assessing its robustness.

4 RESULTS

Table 2 shows some key differences in the simulation results for the four scenarios. To reflect the uncertainty involved in the simulated responses, the median as well as the 5th and 95th percentile (in parentheses) of the range of values simulated in the 1,200 repetitions are given. Underlined values indicate that the values were higher (resp. lower) in more than 95% of 1,200 pairwise comparisons with the corresponding repetition in the scenario to the left and the difference to the scenario to the left can thus be considered unambiguous and robust.

Table 2: Simulation results

	NON FAMILY	FAMILY PASSIVE	FAMILY ACTIVE	FAMILY PROACTIVE
Agent exits due to	5 (3; 7)	174 (132; 208)	176 (134; 211)	175 (132; 209)
- illiquidity	5 (3; 7)	128 (85; 164)	128 (85; 164)	128 (85; 164)
- lack of potential successor	-	11 (6; 16.5)	11 (6; 18)	11 (6; 17)
- succession failed economically	-	46 (33; 60)	48 (35; 62)	47 (34; 62)
Successions	-	30 (21; 41)	43 (29; 58.5)	45 (30; 62)
Expected remaining lifetime of farm [yrs]	-	10.7 (9.9; 11.5)	12.8 (11; 14.2)	15.8 (13.3; 17.8)
Investments from equity [1'000 Euro]	80 (56; 101)	46 (31; 62)	49 (33; 66)	50 (34; 68)

As we can see, modelling farms as family farms leads to much higher farm exit rates than modelling them as standard firms with unlimited investment horizons. Interestingly, however, failed successions cause only a minority of farm exits, while the majority of the difference is caused by illiquidity. Apparently, the minimum consumption requirements of farm families cause family farm agents to close down business more often than non-family farms, which can abstain from income withdrawals if the economic situation is unfavourable. More active succession planning in the third and fourth scenario lead to a higher number of successions occurring during the simulation, although the small, ambiguous differences in the number of failed successions indicate that this is mainly caused by shifting attempts at successions to earlier points in time. These earlier successions lead to longer investment horizons and consequently to more liquidity being channelled into investments, although investments still remain much lower than in the NONFAMILY scenario.

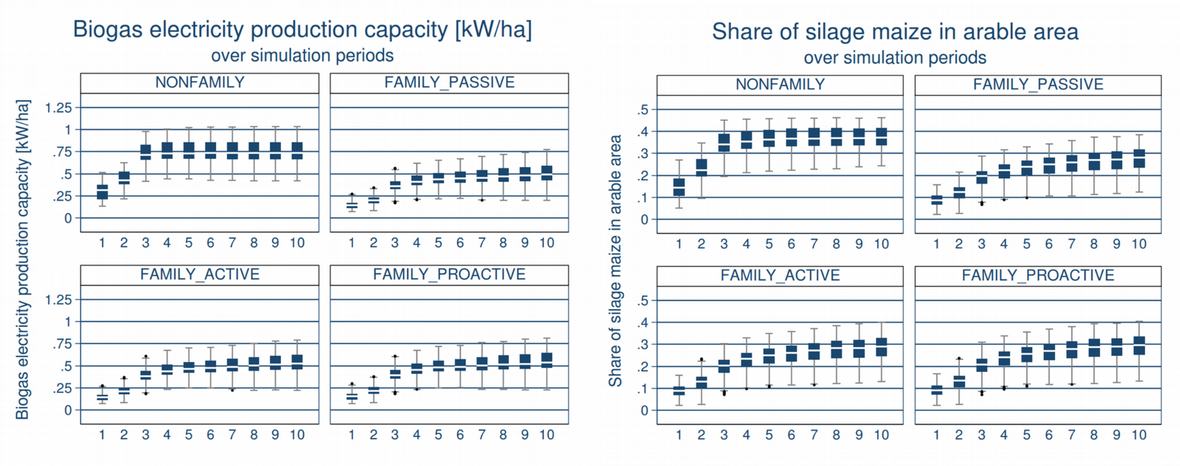

Figure 1: Expansion in production capacity for biogas electricity per agricultural area and silage maize share of arable area over simulation periods

The effect of the difference in investments between the NONFAMILY and the FAMILY scenarios can most clearly be observed in the expansion of the biogas electricity capacity installed on farms and the silage maize area cropped (Figure 1). (Since the simulations do not yet include land markets, land of exiting agents is lost from the simulation. We therefore show values per agricultural resp. arable area to allow for a consistent comparison and make sure that the observable effect is not merely caused by differences in agent exits.) Although the effect is rather modest, capacity and area expansion are consistently higher in FAMILY_ACTIVE compared with FAMILY_PASSIVE, and still higher in at least 90% of the cases in FAMILY_PROACTIVE compared with FAMILY_ACTIVE. At the same time, the FAMILY scenarios show consistently higher participation rates in the agri-environmental measures MEKA A2 (crop diversification) and B4 (biodiversity-rich grasslands) indicating less extensive production systems than in the NONFAMILY scenario.

5 DISCUSSION

There are a number of limitations to the simulations we presented here: The absence of a land market means that we cannot simulate the growth of farms that remain in the simulation by absorbing the land freed by exiting farm agents. Since economies of size may stimulate investments, rental market effects might have a somewhat counterbalancing effect to the lower intensification in the family farm scenarios. (Work on a land market parameterisation in our model is currently ongoing, cf. Troost & Berger 2016.) We omitted year-to-year variations in prices and crop yields that lead to planning errors and potentially lower investments and higher drop-out rates in reality, especially for non-family farms that cannot reduce labour costs by temporarily reducing household consumption. Since we are modelling full-time farms, we also did not include the uptake of off-farm employment by family farm managers that might offer an option to balance income shortages. Taken together this certainly overestimates the difference in drop-outs between family and corporate farming organization.

The rather short span of ten simulation years means that the initial household composition is far more important than agent household events unfolding during the simulation (e.g. newborns will not reach adult age during simulation) except for premature deaths. On the other hand, this also means the differences in the three family farm scenarios affect only a limited number of farm agents and could lead to more pronounced effects in longer simulations when more agents face succession.

Uncertainty testing for initial populations was limited to ten seed values and four epistemic parameter combinations. Covariance between initial household composition and other farm characteristics was neglected due to data gaps. Nevertheless, the 4,800 model runs (each with a run-time of approximately 3.5 h on a parallel computing cluster) show robust effects on key agricultural and environmental policy variables when varying assumptions about the organizational structure and behaviour of family farms.

In our simulations, we applied the different behavioural assumptions embodied in our four scenarios to all farms, whereas in reality we would expect to find a mix of more passive and more forward planning family farm managers side by side. (According to FDZ (2010), 88% of full-time farms in the area are single holder farms and 11% are partnerships of natural persons, often between father and son, so that only a tiny minority of farms can be thought of as acting like corporations.) Determining the actual prevalence of behavioural assumptions and especially its covariance with observable farm characteristics in the real farming population remains a major empirical challenge. Similarly, effects of farming conditions on identity-related factors such as postulated by Fischer & Burton (2014) have been omitted in our model and remain worthy of further empirical analysis. While our model may be tested against empirical data once a land market has been included, a validation of the model or an identification of the correct model and parameters for farm succession by calibration will, however, only be possible to a very limited extent as discussed in Troost & Berger (2015).

6 CONCLUSIONS

Our simulations underline the importance of taking into account the organizational characteristics of family farms when modelling structural change in agriculture and its consequences for agricultural policy response of farmers. We implemented a representation of farm household evolution and its influence on farm production decisions combining demographic statistical models with agricultural economic farm-level models of production and investments decisions. We tested the model with three scenarios representing increasing degrees of forward-planning of farm managers with respect to succession and compared the outcomes with a fourth control scenario that modelled farms as non-family farms with unlimited investment horizon, no family labour and no need for succession in farm ownership. We analysed scenario differences over a set of parameter variations representing aleatory and epistemic model uncertainty. Our results show clear and robust differences in key policy variables such as investments in biogas plants, silage maize area, and participation in agri-environmental measures between modelling farms as family and as non-family farms. Differences between the three sets of behavioural assumptions on farm succession planning of family farms show less pronounced differences in policy outcomes, but the robustness of the effects and the differences in investment behaviour indicate that these may turn out important for other decisions and in longer simulations.

While our implementation constitutes an advancement in terms of detail and grounding in empirical and theoretical knowledge compared with previous, more simplistic implementations of farm succession in agent-based models (e.g. Freeman et al. 2009; Happe et al. 2009), its parameterization still remains somewhat *ad hoc*. Given our simulation results, we would, nevertheless, conclude that the most important step has been to include a representation of farm household processes and attention to improve the model should turn to processes that have been omitted so far (land markets, off-farm income, part-time farming, income variation) before focusing on improving the details of parameterising the forward-looking succession planning.

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