Analysing Interventions in the Seed and Breeding System for Organic Carrot Seed Use in Germany - a Multi-Agent Value Chain Approach

by Eva Winter, Christian Grovermann, Monika M. Messmer, and Joachim Aurbacher

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1. Abstract

According to the EU organic regulation, organically multiplied seed should be used in organic farming. Due to organic seed shortage, derogations to use non-organic seed can be obtained. By 2036 the EU plans to phase out these derogations and achieve 100% organic seed for the sector. In order to identify measures to smooth this transition, we developed an ex-ante multi-agent value chain approach based on mathematical programming to evaluate potential strategies to boost the organic seed and breeding sector. We selected the case of organic carrots for the fresh market in Germany for its importance in the organic sector in Germany and in the EU as a whole. The identified measures at seed multiplication level are either a subsidy of at least 50 €/Mio organic seed production or an investment in pest control of organic carrots for seed production. Additionally, a subsidy of 150 to 500 €/ha organic carrot production or a price premium of 5 to 10 €/t organic carrots for the use of organic carrot seed at farm level would be advisable according to our estimations.

Keywords: simulation, mathematical programming, agent based modelling, seed and breeding value chain, organic seed, ex-ante policy evaluation

2. Introduction

One of the main principles of organic farming is that the agricultural inputs used in organic production systems, such as fertilisers or seed, should comply with the rules of organic agriculture (European Commission 2007). However, in the case of seed, this requirement is largely unmet. In fact, Döring et al. (2012) point out a lack of sufficient organic seed supply in the EU as a result of low investments in seed multiplication and breeding for the organic sector over the past decades. In response to organic seed shortage, the EU organic regulation allows for derogations at species or sub-species level to use not chemically treated (NCT) seed, which is not produced under organic conditions. However, no coordinated strategy has been implemented to ensure a development towards more organic seed production and use. As a consequence, the current regulation hampers the development of a well-functioning organic seed market (Döring et al. 2012). By 2036 the EU plans to phase out the derogations and achieve 100% organic seed for the sector (New Organic regulation 848/2018). A strategy is still missing on how to secure sufficient organic seed supply.

Organic seed production and use varies substantially among countries and crops (Solfanelli et al. 2019). Thus, there is a need to identify crops for which organic seed may be difficult to produce or where organic seed use at farm level is still very low in order to implement measures towards more organic seed production and use. In this study, we examine the case of organic carrots for storage and fresh market in Germany, as only very little organic seed is used so far, a general permission to use NCT seed is granted (Herstatt 2017), and seed producers are confronted with substantial challenges in organic seed production (Wohleb 2019). This case is also of interest, because organic carrots are among the most produced and consumed organic vegetables in Germany (Destatis 2018). As regards the current organic seed use, estimates indicate that about 90% of the seed used in this segment is from conventionally bred and conventionally multiplied cultivars, 9% of organically multiplied and 1% of organically bred cultivars where the entire selection process is conducted under organic conditions (Herstatt, 2017).

Very few measures have been implemented by European countries to encourage organic carrot seed production and use. Only in France, there is an on-going attempt to phase out derogations for organic carrots in a step-wise process. This measure was adopted in 2018, aiming for 40%, 66% and 100% organic carrot seed on farm level in 2019, 2020 and 2021, respectively (Orsini et al. 2019). Furthermore, in five EU countries, derogations to use NCT seed carrot seed have to be individually requested. In the remaining countries, NCT seed can be used without a derogation request. Overall, the non-organic seed amount granted through derogations in 2016 has increased by 96 % in comparison to the year 2014 on average in EU and Switzerland (Orsini et al. 2019).

There is a growing number of studies on specific aspects of the seed market for organic production. Breeding for organic farming, farmers' attitudes to organic seed and the current state of the EU organic regulation relating to organic seed have for example been subject to investigation (Döring et al. 2012; Lammerts van Bueren et al. 2011; Bocci et al. 2012; Rey et al. 2013; Orsini et al. 2020). However, there is a lack of studies focussing on obstacles in organic seed use and production that systematically analyse effects of interventions to boost organic seed use and production along the value chain from breeding to farming. Thus, more research is needed to better understand the decision-making and interactions of actors along the seed value chain and the influence of the enabling environment, so that feasible solutions for boosting organic seed use can be offered to the sector. We propose an agent-based ex ante value chain model as a means of analysis in this study to gain better insights into the EU seed market for organic production and the effect of organic seed policies.

3. Materials and Methods

Case study selection and description

The case of carrots production for the fresh market was selected for its importance in the organic sector in Germany and in the EU as a whole (Orsini et al., 2019). Moreover, there is still a great lack of organic seed and cultivars in this value chain, so that policies and private sector interventions can make a real difference in scaling up use and availability. Another major criterion was data availability so that the model can be fully parameterised. Availability of detailed production information was one of the greatest bottlenecks for this study, as economic data on breeding, multiplication, and organic farming is scarce and often confidential. There are ca. 800 organic carrot producers in Germany cultivating an area of around 2100 ha with a resulting seed demand of approximately 4000 Mio seeds per year (Destatis, 2018). Expert estimates indicate that around 50% of organic carrots produced in Germany are for the fresh market and thus need to be storable. There are around ten relevant seed companies, based in the Netherlands and Germany, most of which have a breeding department in addition to seed production. These companies are mostly international players that produce seed and cultivars for conventional and organic vegetable producers. Furthermore, there are some organic breeding and seed production initiatives exist. These initiatives produce open-pollinated (OP) cultivars are small and are not or only to a very limited extent internationally active (Orsini et al., 2019).

Conceptual background

Different actors and their interactions, i.e. breeders, seed producers and farmers, as well as the overarching political framework laid down in the EU organic regulation of the organic sector, contribute to the problems in the organic seed market. They are also all affected by current rules and regulations. Consequently, these actors need to be considered in a policy impact assessment. Mapping of value chains and subsequent benefit-cost or SWOT analyses with or without active stakeholder involvement have been repeatedly carried out in the past to analyse seed and other agricultural value chains (Bellù 2013; Mulugeta et al. 2010; Kumara et al. 2012).

These methods can be complemented by more sophisticated assessment approaches that can give more in-depth insights into system changes under certain conditions. Rich et al. (2011) and Nang'ole et al. (2011) give an overview of existing agricultural value chain analysis frameworks highlighting that they are to a large extent qualitative. They recommend system dynamics and agent-based models so that quantitative ex ante policy assessments of value chains can be carried out in the future.

Ex ante policy assessment via simulation models is a useful means of testing policy instruments that could smooth the transition period as well as propose long term solutions to increase organic seed production and use. Many studies exist where agricultural policies and private sector interventions are tested through ex-ante assessment. These models mostly assess policy implications at farm or sector level (Heckelei and Britz 2001; Janssen and van Ittersum 2007; Grovermann et al. 2017; Häring 2003; Bunte and Galen 2015; Schreinemachers and Berger 2011). Applications are often related to input choices under varying conditions (Schreinemachers and Berger 2011; Grovermann et al. 2017; Berger et al. 2017). In the following, the specific choices when implementing simulation modelling in this study are discussed.

Different modelling approaches for decision-making

In this study, agent-based modelling was used in combination with mathematical programming and heuristics. Agent based modelling can be a useful tool when modelling the behaviour of different agents in a heterogeneous population where each entity has an individual decision-making behaviour, but also reacts on decisions of other entities (Gjerdrum et al. 2010; Schreinemachers and Berger 2006). Since not only the actors along the seed value chain, but additionally the actors within one level of the seed value chain are very heterogeneous with respect to their decision-making behaviour, a multi-agent system is well suited when modelling the seed value chain. Thus, we chose an individual decision making approach over an aggregate modelling approach. In this study, agent populations with individual decision making per agent are considered at farm level. At multiplication and breeding level, decision-making agents are represented by typical seed supply actors.

Mathematical programming (MP) is often used in agricultural economics to find optimal solutions for economic decisions, such as the optimal production plan at farm level under given constraints of resource availabilities and gross margins per crop. Generally, production costs are either minimised or gross margins maximised under numerous constraints in business entities (Hazell and Norton 1987). Based on microeconomic theory, MP provides flexibility for modelling the behaviour of individual agents by offering a vast range of decision options and objectives to choose from. This makes it particularly suitable for modelling detailed input decisions, such as seed use (Schreinemachers and Berger 2006, 2011). Therefore, it is also central to our research.

Heuristics, where decisions are taken based on a pre-defined decision-tree offer far reduced flexibility of choices as compared to MP, but can capture behaviour that is not fully rational from an economic perspective. Schreinemachers and Berger (2006) argue that a combination of agent-based modelling, MP and heuristics is advisable for realistic modelling of decision-making behaviour at the farm level. As a consequence, where evidence suggests that other decision rules need to be taken into account, we implemented heuristics in addition to optimisation, adopting a combined approach. Selected heuristics include e.g. an excess willingness to pay for organic seed at individual farm level.

Since we aimed at simulating several processes in one model that have different time horizons, a dynamic model approach is essential in order to understand developments emerging in the course of the different model runs. Moreover, a feed-back loop was needed between the stages of the value chain after activities in each year have been decided. As a consequence, the start values of a certain period need to be the end values of the previous period. We thus deemed a positive recursive-dynamic model with decision-making through a combination of mathematical programming and heuristics of a multi-agent system as the most suited approach to assess innovation in policies and private sector activities in the selected case of seed value chains for EU organic agriculture.

Objective functions

The objective functions we used in this study are the following: At farm level, we optimised the gross margins per farm enterprise. We defined the farm enterprise as the collection of crops in the organic carrot crop rotation. At multiplication level, we optimised the gross margin of organic and NCT carrot seed production. Processing, packaging, and marketing costs are largely the same for conventional untreated and organic seed, thus these costs were disregarded at multiplication level. Lastly, at breeding level, we optimised the overall yearly breeding budget of the crop section of the breeding company, including non-organic seed (Chemically treated (CT) and NCT). The breeding budget is represented by 10 to 30% of the seed sales revenue, depending on the typical actor. We chose the yearly breeding budget as objective value at breeding level, because both of the typical breeding actors we identified do not consider the gross margin at breeding level, but require a constant breeding budget as part of research and development (Kuin 2018; Syngenta 2015).

Interactions between the value chain levels are based on information and material exchange regarding seed sales, seed amounts, prices, and a feedback loop on demand and supply of seed types (organic seed from typically used cultivars, NCT seed from typically used cultivars, seed from organic cultivars). Figure 1 shows the interactions in the model in a simplified way. The consecutive decision options of the agents are shown also. The food industry and policy framework are depicted in the square box as they are exogenous agents with no endogenous decision making within the model. Their influence can be seen if scenarios change, such as higher end product prices for organic seed use and policy schemes such as the phasing out of derogations. The figure displays model processes in one year including the feedback loop ("update after sales") at the end of the year.

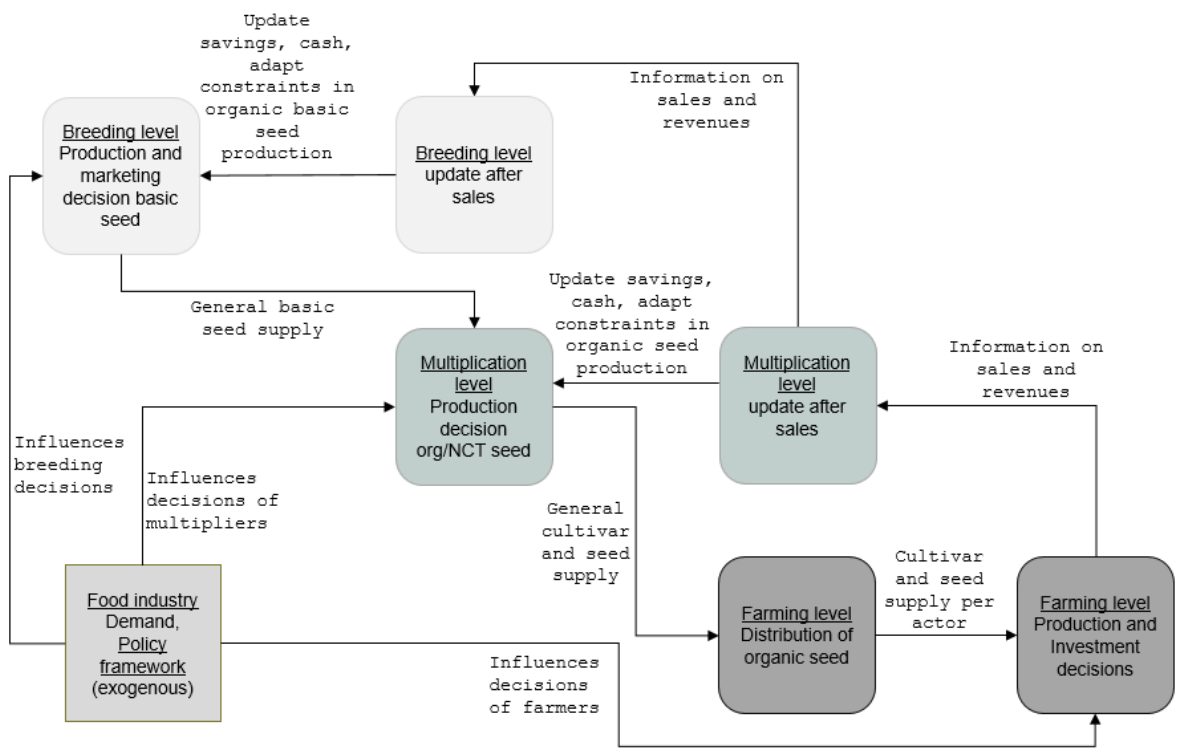

Figure 1: Technical implementation of simulation model

Adaptive Expectations of seed producers and breeders

As it is likely that seed producers will not immediately react to changes in demand for organic seed, we implemented an adaptive expectations mechanism at multiplication level to smooth the organic seed production supply quantity. The theory of adaptive expectations is based on the assumption that a behaviour, such as seed production, is determined by experiences of past sales (Galbács 2015). We defined the amount that is produced in a year as the average of the amount of the last two years multiplied with a growth expectation factor.

This growth expectation factor indicates the trend in demand and is the difference in percentage between the sum of the current and last year and the sum of the last year and the year before, times the production reserve factor. The production reserve factor indicates how much more than the estimated amount is produced for reserve in the case of unexpected higher demand. More information can be found in Appendix A.1.

Scaling factor

To ensure the compatibility between the size of the farmers' buying market and the seed multipliers' selling market, scaling factors were implemented. As the present agent-based value chain model is the first to include the seed value chain, there is no precedent for this procedure. Nevertheless, scaling factors are commonly used to ensure compatibility between agents or activities in multi-agent and integrated farm system modelling (Troost and Berger 2015; Gibbons and Ramsden 2008). In this study, scaling factors are used to connect the three value chain levels in order to match supply and demand.

Defining typical companies and initiatives at seed production and breeding levels

It was necessary to identify typical breeding and seed production entities against the background of data scarcity due to limited willingness of actors to share economic data. We defined a typical entity as a kind of company or initiative with a large market share in organic seed production and/or organic breeding. A value chain mapping of the seed and breeding value chain of German organic carrot production was conducted to get an overview of the actor landscape. Data on typical breeding and multiplication processes was then obtained through a series of stakeholder and expert interviews in the course of the research project between 2017 and 2020. The mapping revealed that around ten companies are involved in providing seed for organic carrot producers in Germany and that only very few have a large market share (Herstatt 2017; Orsini et al. 2019). The ten companies and initiatives were contacted and face-to-face interviews with identified actors willing to participate in our study were conducted. Two types of actors could be identified. One type is an internationally active commercial seed and breeding company that sells NCT hybrid seed and organic hybrid seed to organic carrot producers in Germany. This type will be referred to as Type I. The second type is a small company or initiative dedicated to breeding and/or locally selling open-pollinated vegetable seed produced under fully organic conditions. This type will be referred to as Type II. We interviewed three companies corresponding to the first type and three initiatives corresponding to the second type.

They gave insights into market structures and general figures on breeding and multiplication costs, as well as challenges in carrot seed production and breeding. One company and two organic breeding and seed production initiatives shared detailed information on costs and revenues, inputs and outputs of carrot breeding and multiplication, as well as bottlenecks in seed production, promising breeding goals, and scenarios to boost the organic seed and breeding sector.

Input data and creation of an agent population at farming level

In order to generate the farm agent population, we relied on the farm accountancy data ("Agrarstrukturerhebung") of the year 2016, provided by the national statistical office in Germany (RDC of the Federal Statistical Office and Statistical Offices of the Federal States 2016). A copula approach to estimate a joint distribution between selected farm characteristics was used following the procedure proposed by Berger and Troost (2014). For the joint distribution, farm characteristics variables were divided into quintiles (a higher resolution was not possible due to privacy restrictions) and then matrices were created from the combinations of quintiles along the farm characteristics of each observation in the data set. The observed frequencies within the multidimensional categories served as empirical copula from which the agents for the agent population were drawn. We created one main copula including the farm characteristics total farm area, total agricultural area, organic vegetable area in rotation with other vegetable and with arable crops, and available labour per farm. As a second step, we created copulae including only two characteristics. In each of these smaller copulae, the total agricultural area was included in combination with one other relevant crop area or the farm manager's education. This approach was adopted in order to avoid the barring of values in the copulae due to privacy restrictions.

Further input data for the farm population are described in the following: Whole-sale price data for washed carrots for the fresh market were obtained as a time series for ten years from AMI and detrended to correct for trend-related changes (Baum 2006). The ranges of the prices were implemented in the model as triangular distributions for sensitivity analysis. From the German national statistics on vegetable yields (time series data comprising five years), yields of crops in the crop rotation were estimated and the ranges were implemented in the model as triangular distributions for sensitivity analysis (see Section "Sensitivity analyses" for further information).

Technical coefficients, variable costs, and fixed costs for the crops in the crop rotation were taken from Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL 2016), the German national data base on agricultural figures, and were matched with the agent population. The main matching variable was the vegetable area. With the help of a small survey among German organic carrot producers (more information in Appendix A.2), we gathered and narrowed down information relating to the range of plot sizes, degrees of mechanisation, typical crop rotations, distance between farm and field, and the type of production system (bed or bank cropping).

Theory of the diffusion of innovations and application in this study

As described before, an agent population at farm level based on German statistical agricultural census data and the procedure proposed by Schreinemachers and Berger (2006) and Berger and Troost (2014) was created. Furthermore, the model includes a feature that represents the diffusion of an innovation according to the network threshold theory of Rogers (2003). According to this theory, farms can be categorised into five segments: Innovators (2.5% of the population), early adopters (13.5%), early majority (34%), late majority (34%), laggards (16%). This reflects learning in a social network and incomplete information as can often be observed in reality. The mechanism behind this is that only if the first group has adopted the innovation, the second group is able to adopt and so on. The agents in the model were assigned to the network segments based on a statistical estimation of propensity scores.

In order to establish the innovativeness scores in the agent population, influential characteristics were identified based on an analysis of a survey among organic farmers on organic seed use (Orsini et al. 2020). More information can be found in Appendix A.3.

Verification, calibration, and validation

Agent-based models need to be verified, calibrated and validated. During verification, the generated agent population is examined as to how well it represents the characteristics of the original data set. The agent population in our case was ***verified*** by cross-checking summary statistics of generated variables and correlations between generated variables with the original farm accountancy data set.

Calibration of a model is the process to adjust certain parameters so that the model produces results that are similar to the real world in the baseline (Howitt 1995; Troost and Berger 2015). Calibration of the simulation model was conducted by calibrating the amount of organic seed used in the model to the real world observation of 10% seed use for German organic storage carrot, and of 1% seed used from organically bred cultivars (Herstatt 2017). This was achieved by assuming an excess willingness to pay for organic seed, depending on the innovativeness score of the actor. This excess willingness to pay can be assumed as there is no subsidy for organic seed use and no evidence for a higher farm gate price rewarding organic seed use

(Herstatt 2017; AMI 2020) and still we observe a certain share of organic seed use already now. The overall distribution of the excess willingness to pay for organic seed in comparison to the NCT price was derived from a small survey among organic carrot producers in Germany that was described in the section above. In Appendix A.4, further details can be found.

Validation is the process of cross-checking if the model gives realistic results in its baseline run (Troost and Berger 2020). This was conducted by comparing the model outcomes with general statistics about areas, yields, and gross margins at farm level as well as overall sums of model results such as overall area, production amounts, and number of agents (Table 1).

Table 1: Overview of validation indicators, real-world observations and model results

Validation indicator	Observation	Model baseline result (Average of three model runs)
Farm level		
Total organic carrot production in tons and hectares	2102.5 ha, 102418.3 tons (Destatis 2018) On 50 – 60 % of the area, carrots for the fresh market and storage are produced (own data collection)	Carrots for the fresh market and storage: 1300 ha, 51,023.3 tons
Organic carrot seed use in Mio seed	10% organic seed use and less than 1% organic seed use from organically bred cultivars (Herstatt 2017)	11 % organic seed use, 0.4% seed use from organically bred cultivars
Farm enterprise gross margins in €	An estimated gross margin at farm enterprise level is 7,503.8 € for a crop rotation comprising mostly arable crops and 14,954.79 € for a crop rotation comprising mostly vegetable crops	The average yearly gross margin at farm enterprise level over all farms is 6,457.82 € of the farms with a crop rotation comprising mostly arable crops and 11,589.45 € of the farms with

	(KTBL 2016; AMI 2020; Destatis 2018)	a crop rotation comprising mostly vegetable crops
Seed multiplication and breeding level		
Gross margin at organic carrot multiplication level in € (excluding costs for processing and packaging).	Type I: 848,025 € Type II: 5,975.2 € (own data collection)	Type I: 707,687 € Type II: 1,461 €
Breeding budget for carrots in €	Type I: 5,180,480 € Type II: 30,000 € of yearly carrot breeding budget mostly acquired through donations and only less than 5 % acquired through re-financing (own data collection)	Type I: 5,122,658 € Type II: 335 € if 10% of sales revenue goes back into breeding. However, the breeding budget is mostly financed through alternative sources. This assumption of 10% seed sales going back into organic breeding results in a coverage of around 1% of the current yearly breeding budget in the baseline scenario.

Scenario selection

Promising scenarios were co-designed during interviews with project stakeholders and value chain actors in the period of 2018 to 2019, as well as during an expert workshop (Orsini et al. 2019). The chosen scenarios are listed in the following:

- Step-wise phasing out of derogations at farm level to use organic seed and/or organic cultivars
- Organic carrot farm gate price premium per ton for organic seed and/or organic cultivars use
- Subsidy for organic seed and/or organic cultivars use related to cultivation area
- Condition “Higher germination rate”: Investment in lygus bug control in organic carrot seed production and testing the three above mentioned scenarios with the lygus bug control in place (Weijland 2020) The lygus bug causes considerable damage in carrot seed production

if it is not controlled. In conventional production, there is a multitude of pesticides available for control (Wohleb 2019). In organic production, solutions have yet to be found. Investments in finding solutions could lead to a germination rate equal to conventional seed and the possibility to increase the production amount at a faster rate.

- Condition "Sufficient seed": Organic seed and/or organic cultivar supply can meet organic seed and/or organic cultivar demand

Scenario development involved a number of specifications. Table 2 provides a detailed overview of the scenarios and model specifications.

Table 2: Overview of scenarios and specifications

(1) Baseline ***[Bsl]***	Adaptive expectations mechanism: Growth expectation factor's upper bound equals 2 Production reserve factor ranges between 1.2 – 1.5
(2) Step-wise phasing out of derogations at farm level to use organic seed and organic cultivars ***[Derog]***	Same specifications as in Scenario 1 Step-wise phasing out of derogations for NCT seed Two-year steps: Year 2: 80% NCT seed allowed per farm, year 4: 50%, year 6: 30%, year 8: 0%
(3) Organic carrot farm gate price premium per ton for organic seed and organic cultivar use at farm level ***[Prce]***	Same specifications as in Scenario 1 Different levels of price premiums at farm level are tested. The goal of this process was to identify price premium levels that induce farm agents to adopt organic seed and organic cultivars up to certain thresholds (e.g. up to the last adopter group)
(4) Subsidy for organic seed and organic cultivars use related to cultivation area ***[Subs]***	Same specifications as in Scenario 1 Different levels of subsidies at farm level are tested. The goal of this process was to identify subsidy levels that induce farm agents to adopt

	organic seed and organic cultivars up to certain thresholds (e.g. up to the last adopter group)
(5) Scenario 2 and Condition “Higher germination rate” ***[HgermR]***	Adaptive expectation mechanism: Upper bound of growth expectation factor equals 3 Production reserve factor equals 1.5 as uncertainty is reduced Multiplication level: Organic hybrid seed price 1 Mio organic seed increases by 20% Farm level: Germination rate increases by 20%, thus reducing the sown density from 2.4 Mio seed/ha to 2 Mio seed/ha
(6) Scenarios 3 and 5 ***[Prce] + [HgermR]***	No new specifications
(7) Scenarios 4 and 5 ***[Subs] + [HgermR]***	No new specifications
(8) Scenarios 2 and 5 and Condition “Sufficient organic seed” ***[Derog] + [HgermR] + [SuffS]***	The adaptive expectations mechanism of seed producers is relaxed to the extent that organic seed supply can meet organic seed demand

Sensitivity analyses

Sensitivity analyses were conducted to obtain greater insight into the variations of the outcomes caused by specific model parameters in the agent population, e.g. input prices or expected yields. Sensitivity analysis looks at the changes to the model results that different model parameters cause (Musshoff and Hirschauer 2010). We created three different farm agent populations and let all scenarios run with different random seed values (initialization of the random number generator) for each agent population. As the excess willingness to pay, yields and prices at farm level are implemented as random triangular distributions, these values changed with each model run if the seed value was changed.

4. Results

Description of the modelled agents

In the following, the farm level agents are described. 85 % of farm agents depicted in the simulation model are of the farm type “carrot production in crop rotation with arable crops”. The crop rotation comprises carrots, onion, winter wheat, winter rye, beans, and green manure. The farm type “carrots in rotation with other vegetable” comprises 15 % of all farm agents with a crop rotation comprising carrot, salad, leak, cabbage, and green manure for vegetable production. The average agricultural area of the two types at farm enterprise level are 25 ha and the vegetable area 3.79 ha on average. These data are generated based on own calculations using the data from the RDC of the Federal Statistical Office and Statistical Offices of the Federal States (2016).

In Figure 2, an example of the copula between agricultural area and winter wheat area is depicted. Winter wheat is part of the crop rotation for the arable type that produces carrots in rotation with arable crops. The copula approach captures linear as well as non-linear relationships between farm characteristics.

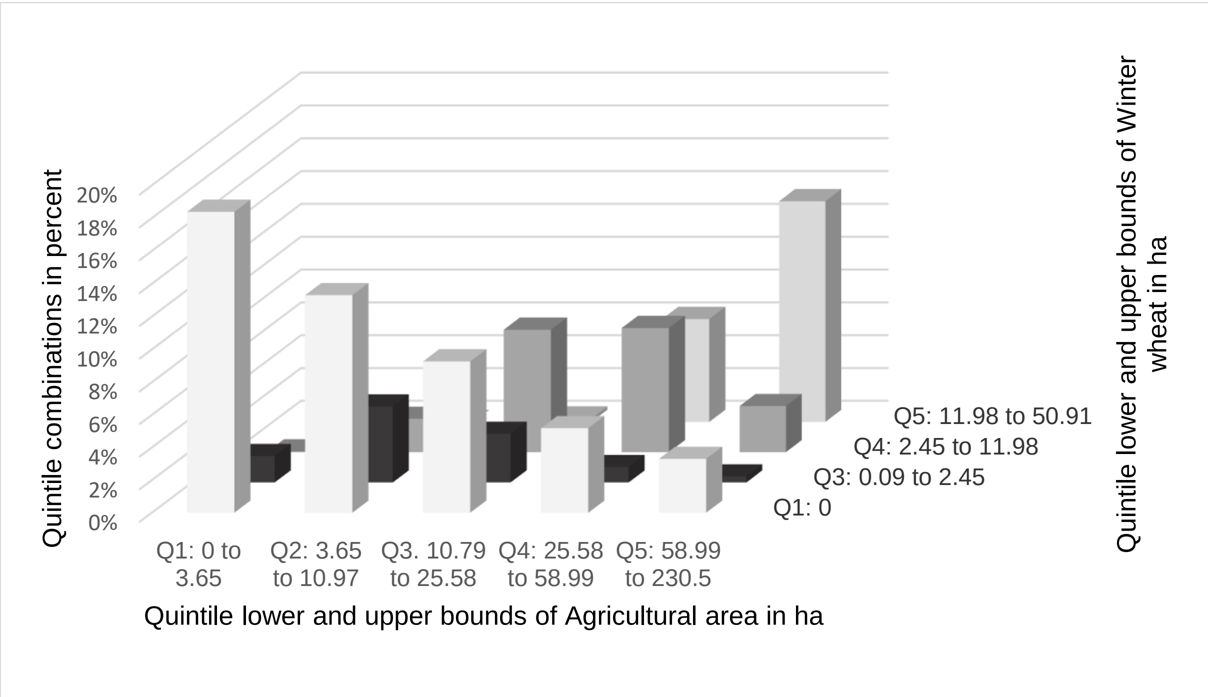

Figure 2: Copula of arable area and winter wheat

The estimated distribution of the excess willingness to pay (WTP) more for organic seed across the agent population is shown in Figure 3.The distribution shows the excess WTP resulting from sensitivity analysis. The figure shows that the organic carrot producers’ willingness to pay for organic seed and cultivars is on average about 45% of the NCT seed, some farmers are even willing to pay more than 65% additionally.

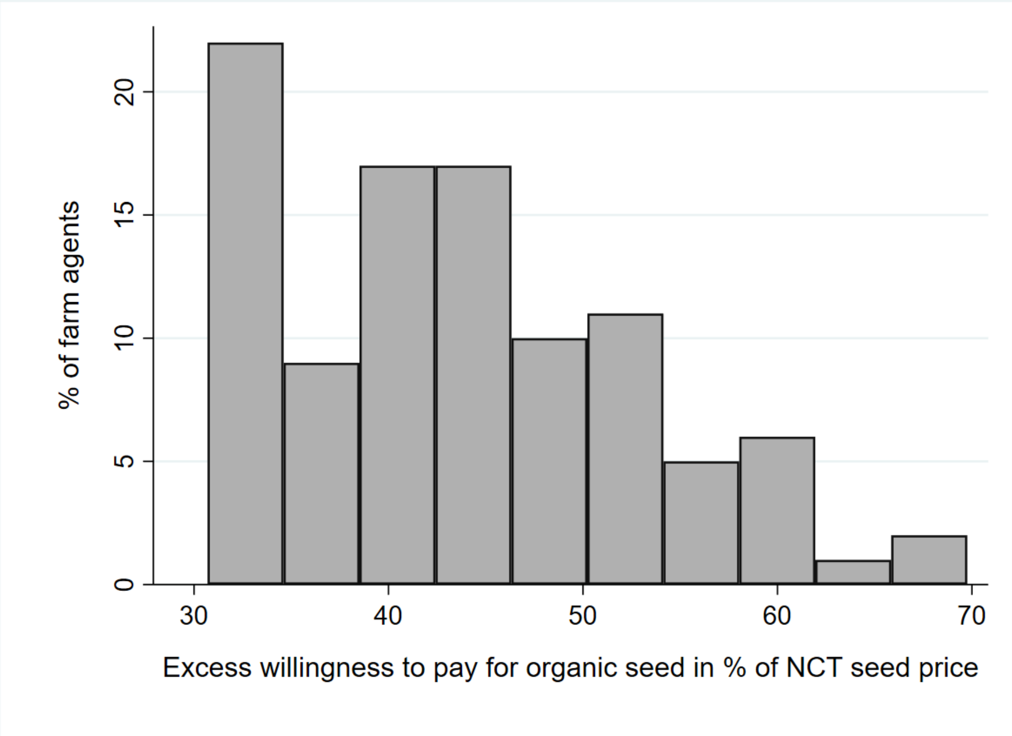

Figure 3: Distribution of excess willingness to pay in % of NCT price across the agent population

Furthermore, two multiplication types were considered. The first chosen multiplication company type has the following profile: The governance model is a family owned company and its financing strategy for seed and breeding is re-financing of breeding through commercial seed sales. The size of the company is large with a yearly total sales revenue of above 150 Mio €. Its target markets are national and international. Organic, NCT and CT vegetable seed is produced. It is the market leader in carrot seed and breeding in Europe.

The second chosen seed multiplication type is specialised in organic vegetable seed and only produces open pollinated organic bred cultivars. Its governance model is a shareholder owned company. It is small sized (yearly sales revenue below 10 Mio €) and its target markets are mostly Germany and Switzerland. As regards the financing strategy of the company, it covers its costs with its seed revenues. However, breeding does not need to be re-financed. Cultivars are provided by a breeding initiative that will be described further in the next section.

The two chosen breeding types that are represented in the simulation model are the following. The first is the breeding department of the internationally active company that also produces the seed. No breeding programmes specifically or uniquely for organic carrot production are conducted, nevertheless, organic cultivar trials to choose the best suited cultivars for organic conditions are carried out. Hybrids are developed. It produces eight to ten new carrot cultivars each year to stay competitive. They have a life span of around 12 years. To re-finance their breeding programmes, 13,545 ha carrot production planted with the company's seed are needed. Their organic area share is 1,505 ha, 10%. Their yearly fresh market carrot breeding budget is estimated to be around 30% of the revenue.

The second typical breeding actor is specialised on breeding under organic conditions and exclusively develops open pollinated cultivars. The governance model is a breeding initiative with fragmented funding. Their financing strategy is pre-financing through voluntary contributions from seed multipliers, but mostly from donations and sponsorships. We assume that around 10% of the total seed sales from their cultivars is voluntarily given back to them to re-finance their breeding activities. In the following, the simulation model results are presented.

Scenario 1: Baseline

In the baseline model results, around 11 % of the entire organic carrot area that is planted in the model is planted with organic carrot seed, and around 0.4 % with seed from organic cultivars. Furthermore, the organic hybrid seed producer has a willingness to accept a loss for organic seed production of 50 € per 1 Mio marketed seed in comparison to NCT seed in the current conditions. Further information on gross margins, seed use, and breeding budgets were reported and validated in Table 1. The baseline runs serve as basis for further scenario runs which will be compared against them in the following. In Table 3, the results of the different scenarios are depicted relative to the baseline. Three policy or private sector interventions were tested under two different conditions. The three interventions are a phasing out of derogations over three two year steps, a higher organic carrot price for organic seed use, and a subsidy for organic seed and organic cultivars use related to cultivation area. In the following two sub-sections, the results of the scenarios concerning the promotion of organic seed use and production in general (i.e. organic hybrid seed and organic bred OP seed from organic cultivars) are presented.

Scenarios 2, 5 and 8: Command and control measure step-wise phasing out of derogations to use conventional untreated seed

As regards the derogation scenarios, an interval of two year steps (Year 2: 80% NCT seed allowed per farm, year 4: 50%, year 6: 30%, year 8: 0%) was tested. In the scenario representing the status quo (Scenario 2), not enough organic seed can be produced with the current technical difficulties according to the model results. The farmers would have to bear the burden of additional seed costs, which would amount to an average of 11% loss in farm enterprise gross margin. This would be due to additional seed costs, but also because they would have to switch to other, less profitable crops.

Under the condition “higher germination rate”, organic seed production is still not fast enough for this scenario if seed producers are conservative with their production increase and form their expectations based on former experiences. However, organic seed production becomes more profitable than NCT seed and organic seed production can be substantially increased (Table 3, row 8, column 8). If seed producers increase their production according to expected future demand with a higher risk of losses if they cannot sell everything as expected (condition “SuffS”), farmers have only a gross margin loss of 3% according to our calculations (Figure 4, “Derog + HgermR + SuffS”). The distribution of average yearly gross margins per farm enterprise (excluding values that do not lie within 1.5 times the interquartile range (outside values)) across the farm population are depicted in Figure 4. Furthermore, the trajectory of the aggregated mean of organic seed uptake in different derogation scenarios are shown in Figure 5. In this figure, the line named “organic seed” shows the aggregated average organic seed use development under a step-wise derogation scenario with no further changes. The line “HgermR” shows the organic seed use development in the scenario as “higher germination rate”. Finally, the line “HgermR + SuffS” shows the development of organic seed use if organic seed producers can match farmers’ demand.

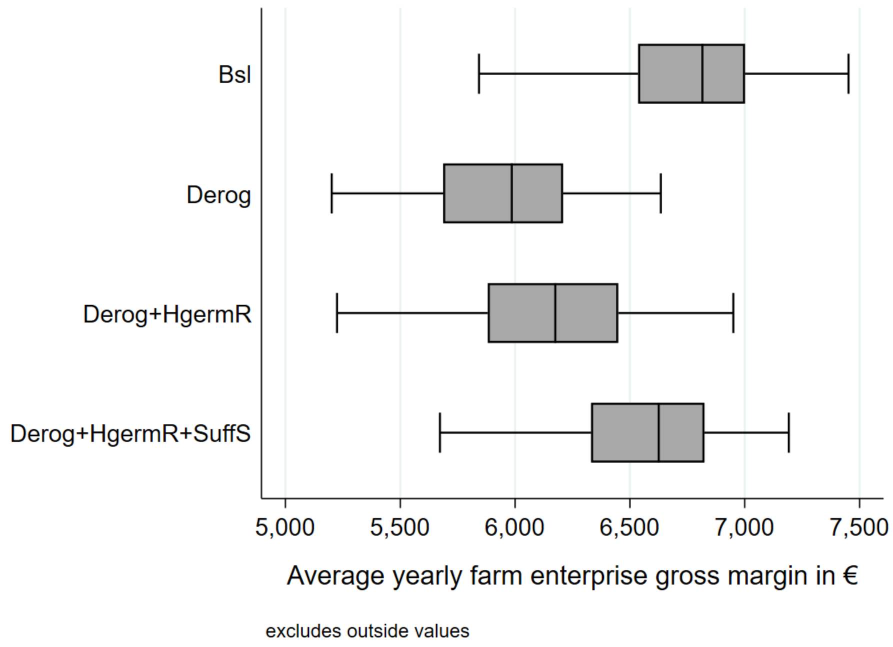

Figure 4: Distribution of yearly gross margins at farm enterprise level per hectare under a step-wise phasing out of derogations of NCT seed

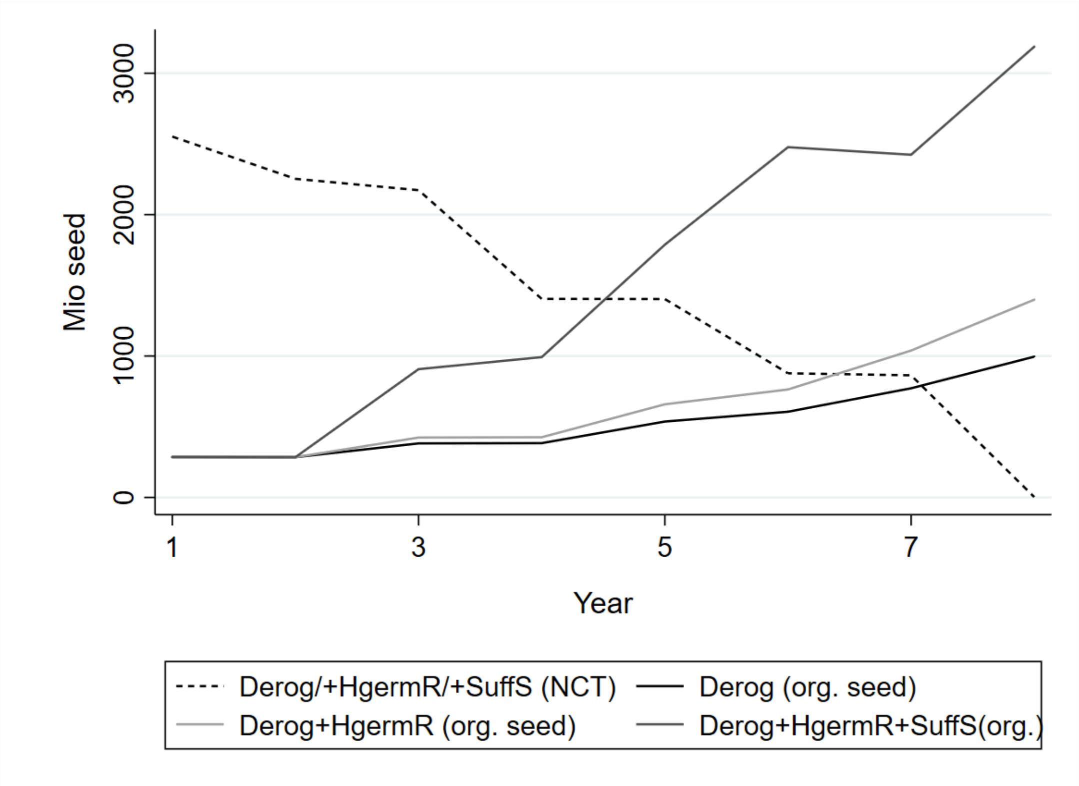

Figure 5: Development of the mean of aggregated organic seed use in a modelling period of eight years under a step-wise phasing out of derogations scheme

Scenarios 3, 4, 6, 7, and 9: Voluntary measures to incentivise farmers to use organic seed

Identified measures to support farmers with the additional costs in the short term can be increased product prices or additional payments (subsidies) at production level. It can be seen in Table 3, row 2, that a price increase of 10 € per ton organic carrots could be an incentive for all farmers (down to the last adopter group, the "laggards") to use organic seed when available. In the modelling period of eight years, this would amount to a total organic carrot farm gate price premium per ton of around 135,132 €, and around 666,667 € when organic seed production capacities have increased enough to match demand. The modelled expected development of seed use in the status quo, under the condition "higher germination rate", and under the two conditions "higher germination rate" and "sufficient seed" can be seen in Figure 6. The same effects along the organic carrot seed and breeding value chain could be obtained for these three scenarios with an area subsidy for using organic carrot seed of 500 € per ha on average.

With a price premium of 5 € per ton organic carrot produced with organic seed, the early majority of the farm population is reached and the intervention would only cost around 18,842 €, while approximately 50% organic seed is being used. This intervention would be more cost-effective (Table 3, row 4, columns 6 and 7), but would not induce the entire agent population to adopt organic seed.

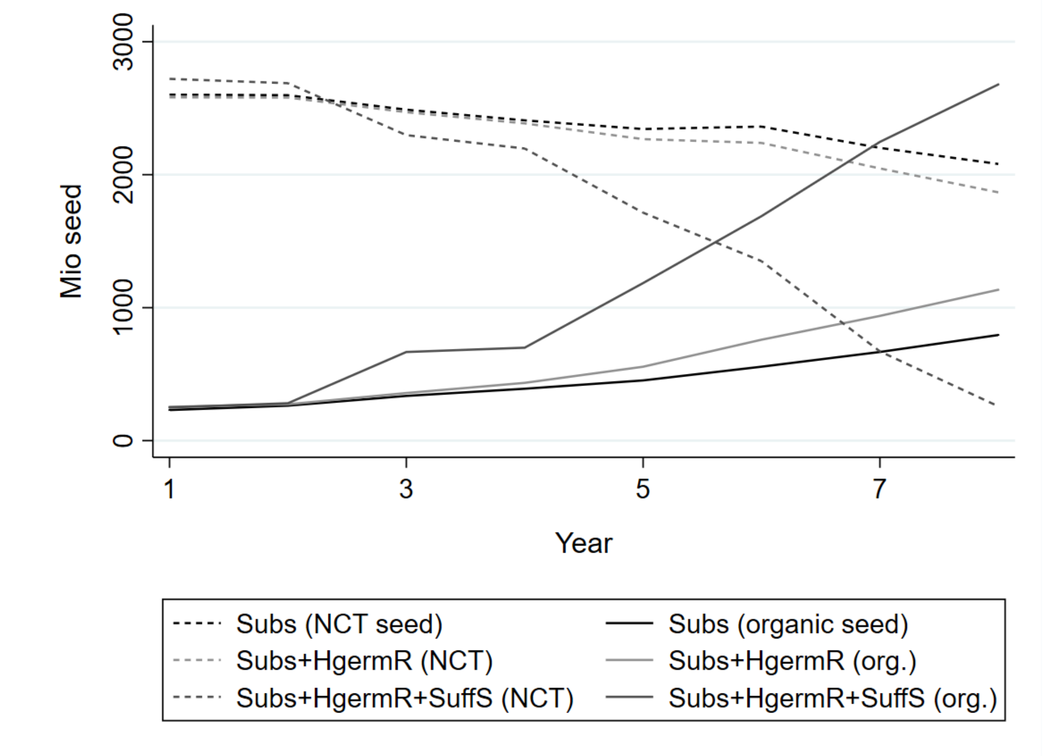

Figure 6: Development of the mean of aggregated organic seed use in a modelling period of eight years under a subsidy scheme of 500 €/ha or a 10 € price premium, under current conditions, under the condition "higher germination rate", and under the two conditions "higher germination rate" and "sufficient seed"

Table 3: Summary of means of outcome variables

Scenarios	% Δ GM/ Farm Enterp.	% Δ GM/seed multipl. org. + NCT seed	% Δ GM/seed multipl. org. cultivars	% Δ breeding budget (org., NCT, CT seed)	% Δ breeding budget org. cultivars	Costs of interv. in model period in €	Predicted total costs of interv. or Germany in €	%marketed organic seed of total market	%marketed seed of org. cult. of total market	Adopter group reached by innovation	Cost effectiveness (Ha planted with organic seed per €)
Promoting the use of organic seed											
Derog	-11%	-1.91%	454%	0.78%	355%	n/a	n/a	23.4%	1.8%	n/a	n/a
Prce (10 €/ton org. carrots)	0%	2.3%	1111%	0.20%	1115%	135,132	666,667	17.5%	3.6%	Laggards	0.0020
Prce (5 €/ton org. carrots)	0%	2.7%	1087%	0.18%	1111%	18,842	100,000	16.6%	2.9%	Early Majority	0.0067
Subs (500 €/ha)	0%	2.4%	1350%	0.19%	1247%	135,132	666,667	17.5%	3.6%	Laggards	0.0020
Subs (150 €/ha)	0%	2.6%	1087%	0.16%	1111%	18,842	100,000	16.5%	2.9%	Early Maj.	0.0067
Condition "Higher germination rate"											
Derog + HgermR	-9%	11.2%	554%	3%	453%	n/a	n/a	37.9%	2.4%	n/a	n/a
Derog + HgermR + SuffS	-3%	43.7%	1493.5%	5.5%	1394%	n/a	n/a	80.7%	4.4%	Laggards	n/a
Prce (10 €/ton org. carrots) + HgermR	0%	15.6%	1789%	2%	1698%	188,459	666,667	23.9%	6.0%	Laggards	n/a
Subs (500 €/ha) + HgermR	0%	16.0%	1880%	2%	1706%	190,606	666,667	24.0%	6.4%	Laggards	0.0020
Subs (500 €/ha) + HgermR + SuffS	0%	43.7%	2266%	5.5%	2146%	700,000	666,667	76.1%	7.5%	Laggards	0.0020

5. Discussion and Conclusion

Organic carrot seed use from hybrids or OP cultivars in carrots as main crop cultivated for storage for the fresh market is very pricy (around 60% more expensive than NCT seed). Nevertheless, organic carrot producers in Germany have a rather high excess willingness to pay for organic seed and cultivars was estimated among organic carrot producers, on average 45% more than the NCT seed price. Other studies confirm that the higher price of organic seed is not necessarily the main obstacle for farmers to use organic seed (Hubbard and Zystro 2016; Levert 2014). In order to encourage willing farmers and to stimulate investments in organic seed and breeding in this segment, a subsidy at country level or a premium price at e.g. processor level may be a potential first step. In Estonia, Slovenia, and Czech Republic, a payment for organic seed use is already integrated in the common agricultural politics payments (Fuss et al. 2020). However, as this payment was only integrated recently, so there is no evidence available about its effectiveness. We estimated, based on simulation runs, that a hectare based subsidy of around 500 €/ha or a higher product price of around 10 €/ton would be necessary to induce the entire farm population to adopt organic seed. The early majority of the modelled organic carrot producer population could be reached with a hectare based subsidy of around 150 €/ha or a higher product price of around 5 €/ton. A recent study shows that social norm is a major factor for organic farmers to use organic seed. Thus, it is possible that once organic seed use has diffused to the early majority, diffusion would be accelerated (Orsini et al. 2020).

High uncertainty in seed production occurs with respect to organic carrots as main crops for storage and fresh market, as there are a number of technical problems in organic seed production. Furthermore, under current conditions, the results of this study imply that organic seed production is not yet profitable. If technical problems are not addressed first, there may be a seed shortage under scenarios like a phasing out of derogations to use NCT seed. It has been argued that a phasing out of the derogations could serve as a sufficient market stimulant. However, earlier attempts at phasing out derogations of non-organic seed often resulted in a severe shortage of organic propagation material and the subsequent need to re-introduce the derogation regime. In recent years, the number of derogations in many countries for many crops has increased (Solfanelli et al. 2019). Thus, it seems advisable to invest in research on how to make organic carrot seed production for the investigated segment more stable as a priority. Furthermore, under the condition "higher germination rate", organic hybrid carrot seed production becomes more profitable than NCT, possibly inducing more actors to join the market. The investigated organic and NCT carrot seed multiplier can increase their gross margin by 44% if they produced organic seed as opposed to NCT seed under the condition "higher germination rate”, according to our modelling results. This is in line with statements from seed producers that so far, organic carrot seed production is not yet as profitable as NCT seed and that advances in pest management would be most important to change this.

Some limitations of this study need to be addressed. We used a case study approach by selecting the analysed country-crop combination, but also by selecting companies and initiatives for data collection. Thus, all drawn conclusions are not representative of the organic sector and they also need to be interpreted with caution at value chain level. Furthermore, some parameters that have a great influence on the simulation outcome are based on assumptions, such as the growth expectation factor. Uncertainties in these parameters were addressed by considering result ranges through sensitivity analyses where possible.

Nevertheless, this is the first study to our knowledge that models the behaviour of an entire value chain in an agent-based approach. The seed and breeding value chain as well as the entire farm population could be represented over time. It is moreover the only study that simulates future policy scenarios for the organic seed and breeding sector taking the economic situation of the entire chain into account and investigating into an important crop country case in Europe. For future research, potential extensions could be the incorporation of risk or external effects, as innovations that reduce risk or have positive external effects (e.g. pesticide reductions and diversification of crop rotations) seem to gain in importance to achieve more sustainable food systems, as e.g. implied in the farm-to-fork strategy of the European Commission (European Commission 2020).

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6. Appendix

A.1 Specifications of the growth expectation factor

Lower and upper bounds of the growth expectation factor were defined as 0.5 and 2, unless differently specified in certain scenarios. Given the technical difficulties in organic hybrid carrot seed production, we assume that any increase above a doubling of seed production from one year to another is highly unlikely.

Furthermore, in order to account for uncertainties due to technical difficulties, the production reserve factor under a growth scenario where an increasing organic seed demand is expected is always indicated between 1.2 and 1.5. This range reflects the uncertainty based on difficulties to find organic carrot seed producers, suitable areas, and technical difficulties in production. These difficulties are substantial in the chosen case. However, the bounds of the growth expectation factor and the values of the production reserve factor are expert-based estimations and do not have an empirical foundation, as such a foundation was impossible to come by. The values need thus be interpreted with caution.

A.2 Specifications of a survey among organic carrot producers in Germany

We conducted a survey among German organic carrot producers partly with the online tool Lime survey and partly via phone in the period of January to July 2019. The online survey was distributed through organic vegetable extension services and organic marketing organisations. We obtained 20 responses from organic carrot producers willing to take the survey. The results are not representative, however, a variety of distribution channels for sharing the survey were used, such as consultancies and a wide variety of marketing organisations. There is no obvious bias as regards organic seed or cultivar use (e.g. much more organic seed is used by the interviewed farmers than is likely to be observed in reality). The questions in the survey focused on organic carrot production in Germany, i.e. on crop rotations, used cultivars, and differences in production costs between organic carrots produced with organic seed, NCT seed, and organic cultivars, among other items. Furthermore, we included specific questions about the willingness to pay for organic seed and cultivars.

A.3 Analysis of a European survey among organic farmers on organic seed use to establish the innovativeness scores

A subsample of a European survey of 128 observations comprising those farms that produce vegetable in the countries Germany, Netherlands, Switzerland, and Austria was analysed with OLS regression. We took these additional countries into account to obtain a sample size that could be analysed in a meaningful way. As these countries are all in Central Europe, we expect the observations to be rather homogeneous and valid for the countries in the analysis. Independent variables in the analysis were *Education*, *Farm size*, *Country* (for correction, as we include other Central European countries to obtain the sample size), and *farm type* (arable or vegetable). The dependent variable was *organic seed use per farm enterprise*. The coefficients of the OLS regression are given in Table 4. Based on the estimated coefficients and the three selected characteristics in agent population, innovativeness scores were computed for all 100 farm agents. On that basis, the assignment to innovation segments was determined.

Table 4: Regression coefficients of different farm characteristics on *organic seed use per farm enterprise*

Variable	**Coefficient**	**Significance**
Farm size in ha	-0.066	***
Farm type (arable=0, vegetable=1)	-0.134	*
Education (no education 0, education in farming 1)	0.21	**
Constant	0.91	
Error term	0.28	

A.4 Specification of an excess willingness to pay

We integrated an excess willingness to pay into the simulation model. The upper bound of the overall distribution of the excess willingness to pay across the farm population was assumed to represent the upper bound of the innovator group. Similarly, the lower bound of the overall distribution represented the lower bound of the laggards group. The overall distribution was then divided into five symmetric triangular sub-distributions that all have the same width on the x-axis indicating the willingness to pay. In the calibration process, the sub-distributions were simultaneously shifted with the goal to adapt the willingness to pay distribution in a way that the model results in an organic seed use share equal to the observation level of 10%. The actual value per farm agent was then randomly drawn from the triangular sub-distribution representing the farm agent's innovativeness class. These generated values were then again cross-checked with the distribution derived from the small survey among organic carrot producers in Germany to ensure that occurring deviations are of an acceptable magnitude. This procedure is inspired from the calibration process of PMP models, where usually cost functions are calibrated according to observed farm areas (Heckelei et al. 2012; Howitt 1995).

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