Department of Business Administration of the Agricultural and Food Sector, Justus Liebig University Giessen
Supervisor: Prof. Dr. Joachim Aurbacher

Assessing the seed and breeding system in organic agriculture

A dissertation submitted to the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, Justus Liebig University Giessen, for the degree of Doctor of Agriculture (Dr. agr.)

Presented by Eva Winter (M. Sc.)

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With the consent of the Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, Justus Liebig University Gießen, Dean: Prof. Dr. Klaus Eder

1. Referee: Prof. Dr. Joachim Aurbacher

2. Referee: Prof. Dr. Rainer Kühl

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I Abbreviations

BfO	Breeding for Organic
CAP	Common Agricultural Policy
DUS	Distinctness, Uniformity, Stability
EU	European Union
GMO	Genetically Modified Organism
IFOAM	International Federation of Organic Agriculture Movements
NCT	Not Chemically Treated
OHM	Organic Heterogenic Material
OP	Open-Pollinated
OPB	Organic Plant Breeding
R&D	Research and Development
RDP	Rural Development Programme
SME	Small to Medium sized Enterprise
SWOT	Strengths, Weaknesses, Opportunities and Threats analysis
UK	United Kingdom
U.S.	United States of America
WTP	Willingness To Pay

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1. Introduction

1.1 Organic agriculture and the EU organic regulation

According to the European Union (EU) organic regulation, organic production is a food production system with high animal welfare and production standards based on natural substances and processes. Furthermore, it maintains a high level of biodiversity, best practices of environmental and climate action, and nature conservation. The regulation claims that organic agriculture thus has a dual role in providing healthy products to consumers, as well as providing public goods (Organic Regulation 848/2018).

Consumers in Europe are more and more willing to buy organic products. The European market for organic products continues to grow and was valued at 45 billion € in 2019 (Willer et al. 2021) with an average annual growth rate of 9% between 2014 and 2019 (Willer et al. 2021, 2020; Willer and Lernoud 2019, 2017, 2016, 2018). The market is growing at such a rate that often, domestic supply cannot meet national demand (Willer and Lernoud 2016).

1.2 Inputs in organic agriculture

Regarding input use in organic agriculture, freedom of external inputs and a concentration of farm-internal inputs such as farm-yard manure or legumes, as far as possible, is one of the leading principles. If external inputs are used, they underlie the following restrictions: They have to be produced under organic conditions, and are therefore also subject to the organic regulation. Only natural or naturally-derived substances and slowly soluble mineral fertilisers are allowed for plant protection and nutrition. Furthermore, organic propagating material should be used for organic plant production and cultivars particularly suitable to organic agriculture should be selected (Organic Regulation 848/2018). All inputs must be free of genetically modified organisms (GMO) (Organic Regulation 848/2018). This shows that input markets for organic agriculture are largely different from input markets for non-organic agriculture. As a result, the organic input markets are likewise affected by the rapid growth of the organic sector.

In the following, some central concepts are defined that will be used throughout this thesis:

Cultivar: In this thesis, cultivar is the general term for officially released variety, landrace, heirloom variety, open-pollinated population, niche variety, composite cross population, organic heterogeneous material, etc.

Organic seed (Synonyms: organically multiplied seed, organically produced seed, seed in organic quality): Organic seed is seed produced under organic conditions according to the EU organic regulation (Organic Regulation 848/2018).

Not Chemically Treated (NCT) seed (Synonym: NCT seed): Seed that is produced under non-organic conditions, but not treated with chemical substances not in line with the EU organic regulation after harvest.

Organic cultivar (Synonyms: Cultivars resulting from Organic Plant Breeding (OPB), organically bred cultivar, seed from organic cultivars, organic crop improvement, cultivars bred under organic conditions): All breeding steps from crossing till final selections take place under organic conditions and the applied breeding techniques are in accordance with the techniques listed in the Annex of the position paper of the International Federation of Organic Agriculture Movements (IFOAM International) for organic breeding from November 2017 (Messmer et al. 2018). Moreover, cultivars derived from OPB shall also not be patented.

Breeding for Organic (BfO): Derived cultivars are suited for organic production. The applied breeding techniques are in accordance with the techniques listed in the Annex of the position paper of IFOAM International for organic cultivation from November 2017 (Messmer 2018). Breeding programmes for organic are more product-oriented and have a special focus on the breeding goals which are specific for organic agriculture (e.g. tolerance against seed-borne diseases, weed tolerance, nutrient use efficiency), they do not use critical breeding techniques and selection occurred at least partially under organic conditions.

1.3 The state of organic seed and organic breeding

This thesis focuses on the input markets for seed and cultivars in European organic agriculture. Although, as stated above, it is stipulated in the EU organic regulation that propagating material should be organically produced, there has been a derogation system in place for this rule since the EU organic regulation was put into effect: Under certain conditions, farmers can apply for a derogation to use not chemically treated (NCT) seed that is produced under non-organic conditions. Furthermore, although the organic regulation advises to use cultivars particularly suited for organic agriculture, there are no control mechanisms for this in place. As a consequence, organic agriculture is generally supplied by non-organic seed producers and breeders with NCT seed from non-organically bred cultivars. In the following, firstly, the topic of and issues revolving around the supply and use of adapted cultivars for organic agriculture is discussed in further detail. Secondly, the topic of and issues revolving around the supply and use of organic seed are described.

1.4 Differences in organic and non-organic agricultural systems concerning requirements of cultivars and challenges to finance organic breeding

The practices of organic agriculture differ largely from those in conventional agricultural systems. As was mentioned earlier, in organic agriculture, external inputs are kept to a minimum, preventive measures for e.g. pest management are central, and external inputs need to be mostly organic. Consequently, the used inputs need to fulfil different performance criteria in the respective system. However, in the case of organic seed and organic cultivars, this requirement is not met. It is estimated that around 95% of organic produce is grown with conventional cultivars not adapted to the needs of organic or low input agriculture in general. As breeding is conducted under the use of chemical pesticides and fertilisers, traits desirable for organic agriculture cannot be observed and are therefore not taken into consideration. Furthermore, breeding for certain needs in intensive agriculture such as the reduction of lodging through introducing semi-dwarf genes can have a negative influence on traits needed in organic agriculture, such as disease resistances (Lammerts van Bueren et al. 2011).

Another aspect is that organic agriculture has different demands regarding agricultural crop diversity exploitation than non-organic agriculture. Crop biodiversity organised in crop rotations or crop associations is central to organic agriculture. This creates the need for breeding a wide range of crops with a small total area each. As organic agriculture aims for diverse crop species and locally adapted cultivars, it can be expected that the area under production of a single organic-bred cultivar may remain relatively small, even if organic acreage share would grow rapidly in the future. Therefore, refinancing OPB through a royalty system on seeds of protected cultivars is likely to be insufficient for many crops (Kotschi and Wirz 2015). Moreover, most organic breeders do not want to protect their cultivars but motivate organic farmers to produce their own seed. This is a challenge to the prevailing system of refinancing breeding investments through royalties or seed sales.

1.5 Organic seed shortage and the possibility of derogations for the use of NCT seed

There is a lack of sufficient organic seed supply in the EU with regards to multiplication and breeding as a result of low investments in these areas along the whole value chain over the past decades (Döring et al. 2012; Solfanelli et al. 2020). In order to tackle the organic seed shortage, the EU organic regulation allows for derogations with three possible categories in which crop species and sub-species can be classed. First, if there is sufficient availability of organic seed for a crop species or sub-species, these seeds must be used. The EU organic regulation does so far not list any crop species or sub-species (Organic Regulation 848/2018). Nevertheless, as the derogation system is implemented at country level, some countries have a few Category 1 crop species or sub-species. Second, if a certain cultivar with characteristics organic farmers depend upon is not available in organic quality, individual derogations can be issued. And third, if it is well known that there is not enough organic seed available in a crop species or sub-species, a general derogation can be issued, i.e. farmers only need to document which seed they bought and do not have to ask for a single derogation. Some actors in the sector argue that the derogations permitted under the EU organic regulation cause market distortions, which are additionally aggravated by the differing implementation modalities at country level. The market distortions are the following: If there is no obligation to use organic seed, farmers often rely on NCT seed, because it is cheaper and a larger range of cultivars is available (Orsini et al. 2020). Thus, a stable market for organic seed is difficult to develop. Derogations further cause unfair conditions between countries, as farmers in a country with many crops in Category 1 have higher relative input costs due to organic seed. As a consequence, the regulation itself hampers the development of a well-functioning organic seed market (Döring et al. 2012).

In general, throughout the EU, the trend regarding derogations has been increasing disproportionally compared to the organic land area (Orsini et al. 2019). Only very few crops in very few countries are placed in Category 1, most remain in the two higher categories. NCT seed is still commonly used for most crops and in all European regions, although some differences can be observed. NCT seed use is highest for some forage crops and in the South and East of Europe, whereas for cereals and vegetables in Central Europe, NCT seed use is estimated to be below 25% (Orsini et al. 2019).

1.6 Perceptions of farmers regarding organic seed

In the following, an overview of the current literature of farmers' perspectives on chances and bottlenecks to use organic seed and cultivars is given: Studies conducted in the United States of America (U.S.), Canada and some European countries reveal that organic farmers face multiple constraints with respect to the use of organic cultivars and organic certified seed: Organic farmers in the U.S. and in Italy argue that there is a lack of supply of organic seed in the quantity they need (Hubbard and Zystro 2016; Bocci et al. 2012).

Several studies carried out in the U.S., Canada and Europe show that the majority of organic farmers rely on cultivars that are not available as organic seed with respect to most crops (Levert 2014; Hubbard and Zystro 2016; Bocci et al. 2012). Poor quality of organic seed regarding germination, contamination by weed seed, physically suboptimal appearance and seed-borne diseases can be further constraints for organic farmers (Hubbard and Zystro 2016; Renaud et al. 2016).

The higher organic seed price as compared to the conventional price is repeatedly mentioned in literature with varying degrees of importance (Hubbard and Zystro 2016; Levert 2014; Pedersen and Rey 2016). For example, organic hybrid precision seed for carrot production can be around 60% more expensive than its conventional untreated counterpart (Bejo 2017). However, it needs to be considered that a price difference is not an official reason for a derogation and therefore farmers may be reluctant to name it in a survey.

Furthermore, some organic farmers rely on their own or their neighbour's farm-saved seed and therefore do not purchase seed at all. This is mostly relevant for crops such as cereals, where seed multiplication is straight-forward (Hubbard and Zystro 2016; Bocci et al. 2012).

Finally, a recent study that analysed data from 749 organic farmers in 20 European countries highlights that farmers using mostly direct marketing and long established organic farmers are more likely to use organic seed. Moreover, farmers faced with the societal expectation of organic certifiers and consumers that they use organic seed are also more likely to use it. There are, however, large differences between geographical regions (Orsini et al. 2020).

1.7 Perceptions of seed providers regarding organic seed

In the following, an overview of the current literature of seed suppliers' and breeders' perspectives on chances and bottlenecks to provide organic seed and cultivars is given.

Some seed suppliers in the EU argue that there are no economic incentives to enter the organic seed market as the market is small, initial investments are high and the seed multiplication process is complicated and therefore risky (Pedersen and Rey 2016). Additionally, due to the possibility of derogations, they do not see a pressing need to offer organic seed in order to satisfy the demand of their organic clients (Pedersen and Rey 2016). Breeding a new cultivar often takes around 10 years (Lammerts van Bueren et al. 2011) and only offers a low return on investment. Furthermore, the current cultivar registration rules not being adapted to the organic sector has been identified as another barrier to breeding organic cultivars (Pedersen and Rey 2016). This refers mostly to the "DUS (Distinctness, Uniformity, Stability)" test that cultivars have to pass. Often, organic cultivars are not sufficiently homogeneous to pass this test. This is the case on the one hand, because open-pollinated (OP) cultivars as opposed to hybrid cultivars are more often used in organic breeding. OP cultivars pollinate openly and do not reach the same homogeneity as F1 Hybrids where the parent lines are first inbred and then crossed under controlled conditions (Messmer et al. 2015). On the other hand, organic heterogenic material

(OHM) is an individual type of cultivars that is popular in organic breeding. Here, a population of heterogeneous cultivars are grown together on purpose in order to increase the resilience of the system (Messmer et al. 2015). An adaptation for the registration of this type of cultivar is currently under review (Organic Regulation 848/2018). A recent study argues that the market for organic seed and cultivars in its current state cannot provide sufficient organic seed and cultivars and that public intervention is necessary. Reasons for this conclusion are a lack of information about demand and supply, as well as planning insecurity caused by the current derogation system (Padel et al. 2021).

1.8 Changing regulations, growing importance of organic agriculture and the related input markets

By 2036 the EU plans to phase out the derogations and achieve 100% organic seed for the organic sector (Organic Regulation 848/2018). However, there is not yet a strategy put in place on how to secure sufficient organic seed supply.

Furthermore, the new Organic Regulation does not prescribe the kind of cultivar used by organic farmers, but recommends the use of cultivars suitable for organic agriculture. In this context, the European Commission has announced a 7-year temporary experiment to foster development and marketing of organic varieties within the scope of the EU seed marketing directives (Organic Regulation 848/2018). This experiment aims to show the suitability of organic cultivars for organic farming and to create easier market access for them.

Next to the control and command measure of phasing out derogations, there are some individual country efforts to increase the use and production of organic seed. These policy schemes are measures that target the support of voluntary organic seed use and production. The use of certified organic seeds for cereals is supported by the Estonian government with a 20% premium that tops up the EU Common Agricultural Policy (CAP) area payments for the area where organic seeds are used. Similar measures have been put in effect in the Czech Republic and Slovenia. For cereal seed production in Italy, an additional endorsement of 273 €/ha is paid (Orsini et al. 2019). Additional payments under the Rural Development Program (RDP) scheme are made in Lithuania to support organic seed production. Lastly, training on seed production is offered to organic farmers in Latvia (Fuss et al. 2020).

Organic agriculture has become of increased importance in all of the EU since the Green Deal was put in effect in 2020. The Green Deal is an agreement between all EU member states to address the risks of climate change and environmental degradation. A key goal is to become climate-neutral by 2050 (European Commission 2019). As part of this deal, the Farm-to-Fork strategy (European Commission 2020) was formulated to facilitate a sustainable food system transformation. Its main aim is to create a fair, healthy and environmentally-friendly food system. In line with this strategy, the governmental goal to increase organic land area in Europe has become a priority in the EU policy agenda. The Farm-to-Fork strategy sets the ambitious goal to increase organic land area in Europe by 25% until the year 2030. This shows that in order to fulfil both policy goals, the phasing out of derogations for NCT seed use and the Farm-to-Fork strategy, practical solutions for the provision of organic seed and cultivars are required. The evidence laid out above shows that there is a market failure[1] with respect to organic seed. In the specific case of the organic seed market in the EU, the market fails to create sufficient supply as well as demand for organic seed. It is likely that not all costs and benefits of its production by seed suppliers and its usage by farmers are reflected by the price of organic seed. The current political framework creates insecurity for farmers and seed providers and thus hampers the development of a functioning organic seed and cultivar market.

1.9 Resulting overarching research question and sub-questions

The current situation and market failure for organic seed and cultivars have been laid out in Sections 1.1. to 1.8.. As a consequence, this thesis strives to identify and analyse possible solutions to overcome the market failure for organic seed and cultivars. The two leading themes are:

1) What use and need is there for organic seed and cultivars?
2) Which effects do different measures have to increase organic seed and cultivar use and production?

More specifically, as a first step, the value of organic breeding for society shall be critically reviewed and proven with the help of a case study. This can serve as a justification for the need to find solutions for financing organic breeding. Consequently, as a second step, existing financing strategies for organic breeding shall be evaluated and further developed. As a third step, two typical seed and breeding value chains in organic agriculture as case studies shall be modelled under different scenarios aiming at increased organic seed and cultivar use. As a fourth step, one value chain case study of particular importance to the organic sector shall be modelled with an extended modelling approach that takes representative farm agents and their interactions with each other into account. The specific research gaps and resulting research

[1] Market failure is generally defined as a market situation where price mechanisms fail to create a pareto optimum (an overall optimum of societal welfare) due to externalities, information asymmetry, market power concentration, or mal-functioning political frameworks (Arrow 1969)

questions this thesis will answer are the following:

- Study 1:
    - Research gap: There is a lack of evidence for impact at national level and returns to investment in organic cultivars.
    - Research questions: What is the social welfare gain of organic breeding? More specifically, what is the adoption, economic impact, and rates of return to organic crop improvement research of the winter wheat cultivar Wiwa as one of the most wide spread organic cultivars in Switzerland and Germany?
- Study 2:
    - Research gap: There is a lack of well functioning financing strategies for organic breeding.
    - Research questions: Which financing strategies for breeding for the organic sector exist, what are their bottlenecks and potentials for upscaling? Against this background, what would a promising intervention targeting value chain collaboration look like to boost organic breeding and seed production? What effect do organic marketing channels currently have in terms of organic breeding and seed use at the farm level? How do they influence farmers' perception of the importance of organic seed and breeding?
- Study 3:
    - Research gap: There is a lack of comprehensive quantitative analyses of the seed and breeding value chain in organic agriculture.
    - Research questions: Which novel approach for quantitative ex-ante value chain analysis can be developed, using typical value chain actors as agents in an agent-based model? Which outcomes can be generated if this approach is applied to test interventions aiming at increased organic seed use and production?
- Study 4:
    - Research gap: There is a lack of comprehensive quantitative analyses of the seed and breeding value chain in organic agriculture. Furthermore, decision-making at farm level is not sufficiently represented in the model developed in Study 3.
    - Research questions: How can the model developed in Study 3 be extended to give more comprehensive insights into the production and use of organic seed and to evaluate the effects of organic seed policies in the EU? Which outcomes

can be generated if this approach is applied to test interventions aiming at increased organic seed use and production?

1.10 Theoretical framework

1.10.1 Value chain framework

As a basis for a theoretical framework in this thesis, the value chain framework by Neven (2014) is relied upon. This is a widely used framework indicating the relevant actors in a value chain, as well as their interactions. Furthermore, the enabling environment for a proper functioning of the value chain is described, comprising of a formal and an informal part. The formal part covers regulations and institutions, while the informal part deals with attitudes and behaviours. In Figure 1, an adaptation of this framework for the seed and breeding value chain in organic agriculture in the EU can be seen.

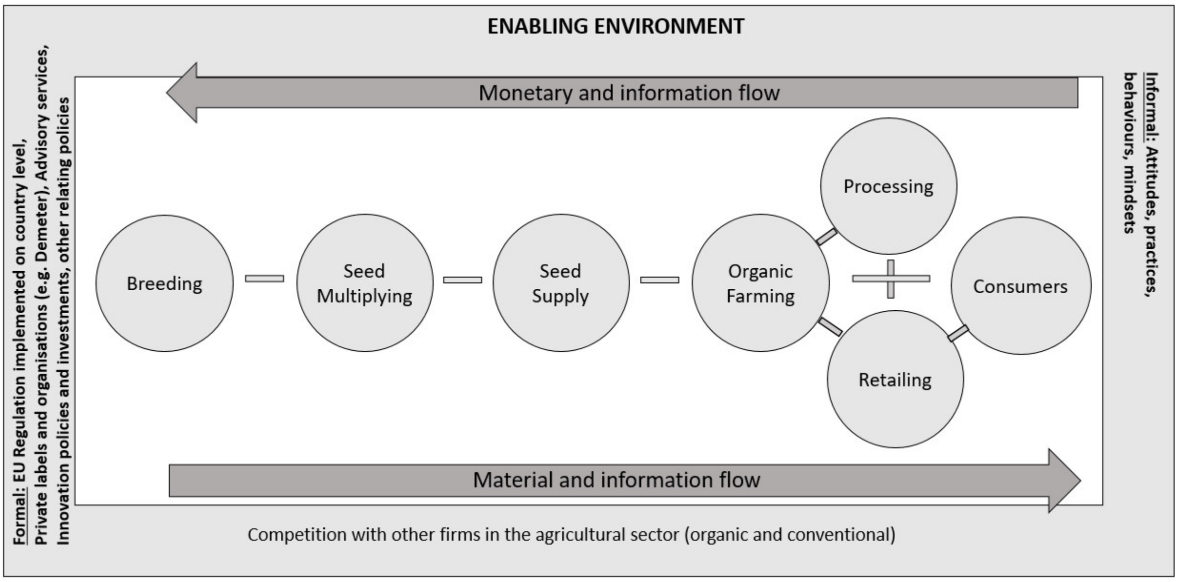

Figure 1: Conceptual framework of the seed and breeding value chain in organic agriculture (Adapted from (Neven 2014))

The most important actors are listed in Figure 1. All mentioned actors are considered directly or indirectly in this thesis to give a comprehensive picture. The seed value chain in EU organic agriculture comprises around five to seven value chain levels, i.e., breeding, multiplication, seed trading, farming, processing, wholesale, consumption, mostly depending on the crop of interest. In the following, an overview of typical possible characteristics of these actors with regard to seed and cultivars is given. These typical characteristics will play a major role in determining the decision space of the different agents that will be modelled, and are thus of importance for this thesis.

Breeding:

- Governance model (Small to Medium sized Enterprises (SMEs) / Family owned breeding companies / Shareholder owned breeding companies / Community supported breeding initiatives / Breeding initiatives with fragmented funding / Public breeding or pre-breeding)
- Financing strategy (Re-financing of breeding through commercial seed sales or licenses / Pre-financing of breeding by value chain actors / Pre-financing of breeding by the public sector / Government financed breeding / Pre-financing of breeding by a mix of public and private funds)
- Size of company
- Target markets (Local / National / International)
- Type of breeding (Organic breeding / Breeding for organic / Conventional breeding)

Seed multiplication:

- Governance model (SMEs / Family owned companies / Shareholder owned companies / Community supported seed production / Seed production with fragmented funding (Charity or projects) / Farmer's own seed production)
- Financing strategy (Commercial seed sales / Contract seed production for a breeding company / Pre-financing of seed production by value chain actors / Farmer pays royalty to breeder and finances own seed production by farm product sales)
- Size of company
- Target markets (Local / National / International)
- Type of seed production (Organic seed production / Conventional seed production)

Seed trader/supplier:

- Trading actor (Breeding company directly / Third party)
- Point of sale (Central point of sale / De-centralised points of sale)

Organic farming:

- Procurement of seed (Individual / Collective (e.g. in cooperative) / Seed production by farmer)
- Decision on cultivar and seed (Farmer's own decision / Prescription by buyer / Recommendation by buyer / Recommendation by advisor)

Processor/retailer:

- Buying decision (Buying of agricultural good according to quality or similar characteristics, no influence on seed or cultivar used / Recommendation / Prescription / Procurement of seed for farmers)

Consumer:

- Awareness (Aware of the lack of organic seed / Unaware)
- Willingness to pay (Willing to pay more for organic seed or cultivar / Unwilling)

As can be seen, there is a diversity of actors with different characteristics in the seed and breeding value chain for organic farmers, as well as interactions among these actors. This needs to be taken into account when analysing the status quo and possible changes in the system.

Furthermore, these actors are influenced by an enabling environment: The formal environment is shaped by the EU Regulation implemented at country level, private labels and organisations (e.g. Demeter), advisory services, innovation policies and investments, or other relating policies, such as have been described in Section 1.8.. The informal enabling environment consists of attitudes towards organic seed and cultivars, common practices around cultivar use or seed choice, behaviours, and mind-sets of individuals and collectives.

1.10.2 Decision making of actors in the value chain

Next to a value chain perspective, decision-making of actors in the value chain is a central theme in this thesis. It is assumed in this study that decision making in the seed and breeding value chain for organic agriculture can mostly be explained by neoclassical economics, i.e. rational choice theory. Actors are mostly profit-maximising entities. An extension of this is utility maximisation, as it can include the rationale of profit maximisation as well as other utilities an economic actor may want to optimise (Kobayashi 1975). Other utilities that may be considered in a seed and breeding context are a willingness to pay of farmers for organic seed and the willingness of organic breeders to produce only organic bred OP cultivars, although they are not the most profitable cultivars.

A further extension that can be taken into account lies in the realm of behavioural economics. Behavioural economics revolves around how psychological, cognitive, emotional, cultural and social factors influence decisions of individuals and institutions. Those decisions are assumed to be different from those assumed in classical economic theory, as they are not purely rational. Examples are how market decisions are made and the mechanisms that drive public choice (Teitelbaum and Zeiler 2018). Here, three main themes can be distinguished that suggest a purely rational economic behaviour cannot always be assumed (Shefrin 2002):

Firstly, there is the theme of the "Heuristic driven bias". This suggests that mostly, decisions are not taken based on statistics and resulting probabilities, but based on simple decision rules. These decision rules are prone to be affected by biases or errors. An example for this is the anchoring-and-adjustment heuristics. Here, a person starts off with an anchor, an initial value e.g. about current house prices. The person then continues to adjust this initial value over time until an acceptable value is reached, e.g. in a negotiation. This behaviour can have a disadvantageous effect if the anchor deviates from the true value, as the adjustments generally stay close to the original anchor value.

Secondly, the theme of "frame dependence" can play a role. It points out that decisions are influenced by the way facts about the different options are presented. An example for this is loss aversion. Decisions are taken differently if the probable loss is indicated than if the probable gain of an option is indicated. Another example for frame dependence is hedonic editing. In hedonic editing, frames are chosen that are more attractive in comparison to other frames. This gives the possibility for direct comparison, so that the best one out of the given ones can be chosen. This method is likely to neglect some not mentioned possibilities and is thus prone to bias.

And thirdly and lastly, the above mentioned themes can lead to the third theme, "inefficient markets". It suggests that decisions taken based on heuristic driven biases and frame dependencies lead to inefficient markets, as e.g. market prices do no longer coincide with intrinsic value.

In Study 4, an extension of the rational choice theory including profit- and utility maximisation towards some behavioural economics aspects was included. More specifically, an excess willingness to pay for organic seed in the case of some farmers was accounted for, as it could be observed in reality. Even though organic seed is more expensive, some farmers already use it. Thus, decision-making contrary to rationality takes place.

1.11 Review of chosen methods

A step-wise and complementary approach was developed and applied to shed light on the seed and breeding system for organic agriculture from different angles. The key actors and mechanisms identified in Section 1.10.1. of the value chain were considered. The first two research foci (Studies 1 and 2) included *ex post* assessments to assess the status quo of societal value of organic breeding, financing of organic breeding, and the relationship of marketing channels with organic farmers' seed choices and attitudes towards organic seed and cultivars.

As first research focus, the societal value of organic breeding and seed was assessed. For this, a commonly used method to quantify crop improvement was chosen and enhanced in order to include some external effects.

The second research focus revolved around analysing the status quo of financing strategies of organic breeding and the importance of marketing channels for organic seed use at farm level. Some recommendations with regard to further financing of organic breeding could be given. These recommendations were established through an explorative process based on a stakeholder dialogue and qualitative interviews. The analysis of the relationship of marketing channels and organic farmers' seed choices was conducted to better understand the role of down-stream value chain actors. Here, a doubly robust standard method for the analysis of observational data was used, i.e., a combination of inverse probability weighting and regression adjustment. The results then allowed for the exclusion of further assessments of the downstream food industry in the ex-ante evaluations that followed.

Furthermore, for the third and the fourth research foci information about typical seed producers and breeders could be used. Lastly, promising interventions could be derived. There were synergies between the research foci, e.g., for the same survey data could be used for the second and the fourth research foci. For the fourth research focus (Study 4), the data could be used for the calibration of the innovation diffusion element. The third and the fourth research foci were *ex ante* assessments. This was necessary to be able to provide a scientific analysis of a possible road map towards an increased organic seed and cultivar use and production.

The methods used in Studies 1 and 2 are mostly standard methods that are established in agricultural economics. However, the methods used in Studies 3 and 4 require some justification, as they have partly been newly developed in this thesis. So far only a few studies dealing with the failing organic seed market in the EU have been carried out. These studies either investigate cases in individual countries or in a small number of countries in Europe (Bocci et al. 2012; Rey et al. 2013; Le Doaré 2017).

Moreover, the focus has so far not been on whole value chains, but on specific aspects of the seed market for organic production, such as breeding for organic farming, farmers' attitudes to organic seed and the current state of the EU organic regulation with relating to organic seed (Döring et al. 2012; Lammerts van Bueren et al. 2011; Bocci et al. 2012; Rey et al. 2013; Orsini et al. 2020; Pedersen and Rey 2016). These studies cannot provide a clear picture of the overall situation of the organic seed market and seed value chains for organic production in Europe. Thus, more thematic research is needed here to better understand the decision-making of actors along the seed value chain and the influence of the enabling environment, so that feasible solutions can be offered.

Concerning the methodology, a value chain approach as means of analysis in this study to gain sufficient insight into the EU seed market for organic production is proposed in this study. The reason for this is that 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 failing of the organic seed market and need therefore all be considered in further analysis. Bellù (2013) defines value chain analysis as "the assessment of a portion of an economic system where upstream agents in production and distribution processes are linked to downstream partners by technical, economic, territorial, institutional and social relationships" and recommends a cost-benefit approach for policy evaluation at value chain level. Some studies analysing seed value chain can be found.

Mulugeta et al. (2010) conducted a value chain analysis in order to ensure the sustainability of the Ethiopian seed supply chain for wheat and barley production. First, all involved actors were mapped. Second, constraints in seed production such as insufficient availability of inputs (e.g. basic seed) for seed production, a poor incentive system, inadequate facilities and the lack of sub-sectoral organization were identified. Used methods were first, a Cost-Benefit Analysis to validate the assumption of profitability of the two chosen crops and second, a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis to identify constraints in the seed value chain. Finally, recommendations were given based on the results of these analyses. Some of the key points for improving sustainability in wheat and barley seed value chains in Ethiopia were: A higher degree of organisation of seed producing farmers in e.g. cooperatives, more communication between suppliers and farmers through a forum and more training on improved seed production and usage for seed producers and farmers.

Another study was conducted in Bihar, India, analysing the maize seed value chain with the goal of strengthening maize production in this state with a similar methodological approach including a participatory element. The recommendations given comprised the creation of stronger backward and forward linkages in the value chain to increase returns from maize production as well as an enabling environment that improves the efficiency of maize seed supply (Kumara et al. 2012). A number of other studies with similar approaches have been conducted (Senyolo et al. 2018; Das and Roy 2021; Mallick et al. 2017).

However, in order to assess the impacts of policies prior to implementation, these methods are not sufficient and more sophisticated assessment approaches are required. As mentioned in Section 1.3., derogations allowing for the use of conventional untreated seeds are likely to be phased out within the next 15 years (Organic Regulation 848/2018). *Ex ante* policy assessment via positive simulation models is a useful means of testing policy instruments (Rich et al. 2011) that could smooth the transition period. Positive models assess reactions of the modelled entities under different scenarios (Schreinemachers and Berger 2006). Many such models exist that assess policy implications at farm or sector level (Janssen and van Ittersum 2007; Grovermann et al. 2017; Häring 2003; Bunte and Galen 2015; Heckelei et al. 2012). Janssen and van Ittersum (2007) give an overview of 48 bio-economic simulation models that evaluate policy and innovation implications on farming systems using different mathematical programming approaches.

An example is TYPI-CAL, a simulation model that assesses policy impacts on different typical farms. It has been used e.g. to test the effect of different policy options within the EU CAP on typical organic farms in the EU (Häring 2003). As an extension, several multi-agent models were developed building on mathematical programming and heuristics to model individual farmers' decision-making across an agent population and to take heterogeneity in a population into account (Appel et al. 2019; Huber et al. 2018; Schreinemachers and Berger 2011; Happe et al. 2006). For example, Schreinemachers and Berger (2011) introduce a mathematical programming based multi-agent model to simulate farm decision-making in complex agricultural systems. Grovermann et al. (2017) used it to assess outcomes of pesticide-use reduction policies in Thai agriculture.

Sector models are for example CAPRI, a positive mathematical programming model of the European agricultural sector that has e.g. been used for CAP evaluations (Heckelei et al. 2012) or HORTUS, a partial equilibrium model related to horticultural production in Europe (Bunte and Galen 2015).

Such models do not exist for simulating the behaviour of specific value chains under different policy scenarios. Some studies already included agents of other value chain stages into their models (e.g. banks and market spots (Fonteijn et al. 2021)) or simulated the diffusion of cultivars as innovations (Berger et al. 2017). A comprehensive positive modelling approach along the seed and breeding value chain does not exist so far. The numerous value chain models using mathematical programming techniques are normative models in the field of operations research striving to optimise the economic and/or environmental behaviour of one or more actors in the value chain under given or predicted conditions (Beamon 1998; Gjerdrum et al. 2010; Banasik et al. 2017). However, in this thesis, a positive approach assessing reactions along the value chain under different conditions is needed in order to identify the most promising scenarios for the increase of organic seed production and use. Thus, the above mentioned normative models are not suitable.

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. This is especially the case in this thesis, because the heterogeneity of the value chain actors is high and as a consequence, their individual decision-making is unique (Orsini et al. 2019). Taking these aspects into account seems crucial to understand the system and to identify well-functioning interventions to increase organic seed use and production.

The literature review shows a lack of sufficient knowledge about the seed value chains of organic production in the EU as well as a lack of an appropriate value chain model for policy evaluation. Therefore, there is a dual research gap when attempting to draw definite conclusions on the key reasons why the organic seed market is failing in many countries, or what would be the best strategies to overcome these constraints.

Due to data constraints, for the third research focus, typical actors instead of individual actors were used as agents in the agent-based model. This means that the number of agents was reduced from the real number of actors (e.g. the real number of organic farms in a defined region) to two actors that are considered typical according to the typical farm approach (Chibanda et al. 2020). However, for the fourth research focus, individual actors could be used as agents at farm level. This means that a farm agent population similar to the real farm population in terms of the number of agents and in terms of the heterogeneity of the agents could be modelled. This made it possible to include a simulation of the diffusion of innovations and calibration of organic seed use at farm level.

2. Portfolio of publications

Study 1: Three decades of organic wheat improvement: Assessing the impact and returns on investment

This is an Accepted Manuscript of an article published by Oxford Academic in Q Open on 22.02.2022. The appendix can be found on the CD enclosed in this thesis.

Three decades of organic wheat improvement: Assessing the impact and returns on investment

Christian Grovermann[1*], Mareike Weiner[1], Lilia Levy[2], Michael Locher[3], Juan Manuel Herrera[2], Eva Winter[1]

[1] Research Institute of Organic Agriculture (FiBL), Frick, Switzerland

[2] Agroscope, Nyon, Switzerland

[3] Getreidezüchtung Peter Kunz (GZPK), Feldbach ZH, Switzerland

* Corresponding author

Abstract

A changing regulatory environment and growing awareness are driving the need for crop improvement in organic agriculture. Contrary to conventional breeding, evidence on the economic effects of research and development in organic breeding is lacking. This study assesses adoption, economic impact, and rates of return to organic crop improvement research. The economic surplus method is used to quantify the impact of the Wiwa winter wheat variety. The standard model is enhanced by considering the economic benefits of improvements in crop nutrient and processing quality as well as resilience gains. Results show substantial economic returns of 18.6% for the period from 1988 to 2019. The reduced downside risk of the organic cultivar is a key distinguishing factor in the analysis as organic breeding aims at providing farmers with resilient cultivars. Further investment in organic breeding appears as a promising element in the strategy for resilient and sustainable food systems.

Keywords: Economic surplus model, impact assessment, downside risk, resilience.

1. Introduction

A transition of farm systems towards agroecology relies on varieties adapted to crop management without synthetic inputs. Over the past decades, there has been a growing interest in organic crop improvement, but investments in organic seed and plant breeding remain limited. This results in a general lack of organic seed and organically bred cultivars (Döring et al., 2012). The new organic regulation in the European Union foresees the phasing out of derogations for the use of conventional untreated seed in organic agriculture by 2035 (European Parliament, 2018). While not regulating breeding as such, it recommends the use of cultivars that are well suited for organic agriculture (European Parliament, 2018). The regulation thus implies that the organic seed shortage needs to be addressed, not only through increased organic seed multiplication but also through further breeding for organic agriculture, where all breeding stages take place under organic conditions.

Modern agriculture is mainly based on varieties bred for high performance under external input systems. These generally do not perform so well under other conditions (Bharadwaj, 2016). Innovative breeding solutions are needed to face the challenges of climate change and the pollution of ecosystems. While some wheat breeding goals, such as yield increase, climate change adaptation or baking quality, are the same for conventional and organic agriculture, there are specific breeding goals that have a higher priority in organic agriculture, such as robustness and flexibility, beneficial interactions with soil organisms or disease tolerance (Lammerts van Bueren et al., 2018). In some instances, breeding goals for conventional and organic agriculture are competing. An example of this is the introduction of semi-dwarf genes for yield increase in high-input wheat cultivation that resulted in short-strawed cultivars with less weed suppression ability and reduced nutrient uptake efficiency (Lammerts van Bueren et al., 2011).

A growing interest in organic breeding raises the question of what societal benefits it can deliver. A large number of empirical studies exist that have analysed the returns to crop improvement research in conventional agriculture (some recent examples include Alene et al., 2013; Brennan & Malabayabas, 2011; Robinson & Srinivasan, 2013; Walker et al., 2015). However, there is a lack of evidence for impact at scale and returns to investment in organic cultivars. This study, therefore, aims to quantify adoption, economic impact, and rates of return to organic crop improvement research, focusing on wheat as an important staple crop. More specifically, we study the cultivar development of "Getreidezüchtung Peter Kunz (GZPK)", a non-profit plant breeding association with more than 30 years of experience in organic plant breeding. Their goal is the breeding and research of adapted varieties for sustainable agriculture as well as the maintenance, expansion and sustainable use of crop diversity. GZPK is headquartered in Feldbach, Switzerland, and operates further sites in Germany and Italy (GZPK, 2020; pers. comm.). We narrowed the scope of this study to the winter wheat variety Wiwa due to its successful adoption in Switzerland and parts of Germany. Returns to breeding conventional wheat varieties have been estimated to range from 39% (Morocco) to 41% (Mexico) and 84-105% (Nepal) by various studies (e.g. Azzam et al., 1997; Marasas et al., 2003; Thakur et al., 2007). The novelty of the present research is based on the consideration of the social benefits of organic wheat breeding, using an enhanced version of the economic surplus model. Estimated impacts relate not only to individual breeding businesses, but to the entire economy. Besides yield differences, also quality and resilience gains are considered in the analysis. The enhanced specifications are systematically compared with the standard specifications, which are usually found in the literature.

In the next section, the model background and description, as well as the data and scenarios, are explained. Subsequently, adoption, benefit-cost ratios and rates of return, just like some sensitivity tests, are presented. The last section provides some discussion of the results and the conclusions.

2. Material and methods

2.1. Conceptual background

The impact of Wiwa breeding was quantified based on an economic surplus model (Alston et al., 1995; Masters, 1996). The method is grounded in welfare economics and has been widely applied to determine the returns of crop improvement research (e.g. Alene et al., 2009; Lantican et al., 2005; Robinson & Srinivasan, 2013). It allows estimation of the total social welfare effect generated by the dissemination of a new variety, specifying economic gains for producers and consumers. Economic surplus is defined as the monetary gain obtained by producers and consumers from selling and buying at the market price. The area between the supply curve and the demand curve up to the point where they intersect (market equilibrium) describes this surplus. According to the model, adopting an improved variety triggers a downward and right shift of the supply curve, which creates economic benefit (Alston et al., 1995). This is represented by an increase in the area between the supply and demand curves. While the model is theoretically well-grounded, it is based on certain assumptions, such as the shape of supply and demand curves, the market equilibrium and the nature of the supply shift (Schreinemachers et al., 2017). According to Alston et al. (1995), the assumption of a parallel shift of the supply curve due to a new variety is very important, while the assumed functional forms of the demand and supply curves do not strongly affect results.

To estimate the welfare effect of crop improvement, it is necessary to design the supply curve in the absence of the new technology, which results in the counterfactual for the ex-post impact assessment (Marasas et al., 2003). The supply curve without the dissemination of the improved variety is unobserved in this context, but previously dominant varieties generally serve as counterfactual (Schreinemachers et al., 2017). Traditionally, the supply shift and resulting welfare effect have been modelled as a function of increased crop yields or reduced production costs from improved varieties (Masters, 1996). In addition to these effects, the present application also considers the economic benefits of crop quality and resilience improvements. This is key to capturing some of the central breeding goals related to organic crop improvement. Nutrient and processing quality were selected as quality criteria. These are rewarded by the Swiss organic certification body through premium payments. Resilience was incorporated in the analysis due to increasing concerns about climate change impacts. Resilient wheat farms will find it easier to anticipate and adapt to changing conditions. In economic terms, resilience was defined as downside risk, which accounts for years where negative deviations from average revenues occur.

The estimated welfare gains are put into relation with the breeding costs to determine the return on investment. For the entire analysis of Wiwa returns, calculations begin in 1988, the year in which varietal development was initiated, and are split into four steps: i) breeding (including pre-breeding), which lasted from 1988 to 2001, ii) registration from 2001 to 2005, iii) introduction to the market in 2005 and 2006, and iv) maintenance breeding and adoption starting in 2006. As maintenance breeding is still taking place and data were available until 2019, the impact estimations run until that year. Furthermore, to consider that welfare benefits will continue to accrue, key data for selected model variables were forecast until 2030 based on trend analysis. For the national area under organic winter wheat and the national organic winter wheat yields, future growth was linearly extrapolated from data of the past five years (2015 to 2019). For adoption trends, a logistic adoption curve was estimated, as explained in section 2.2. While Switzerland's overall organic winter wheat area is likely to continue its rapid growth over the next ten years, the upper limit on the area under Wiwa has been set only 20% above current adoption levels, in absolute terms. In relative terms, this translates to a decreasing share over the next ten years, which is deemed reasonable as experts pointed out likely resistance breaks and organic-bred wheat varieties with good potential in current trials (Agroscope, 2020; Bioland-HG, 2020; GZPK, 2020; LTZ, 2020; pers. comm.). All data and calculations for the assessment of Wiwa breeding return are available from the supplementary material.

2.2. Model specifications

Data on the area cultivated with Wiwa is not available. Following previous studies (e.g. Schreinemachers et al., 2017; Sequeros et al., 2019), seed sale figures were used to infer the area under the improved variety, as defined in Equation 1. From the introduction into the market in 2006 until 2019, yearly adoption of Wiwa A_t was estimated from observed data on the quantity of Wiwa seed S_t (in tons) sold in the Swiss market in each year t:

$$A_t = (S_t * 10^6)\, r^{-1}\, p^{-1} \tag{1}$$

where r is the seed rate (seed need for one ha in grams), and p is the seed replacement rate, which is the proportion of farmers buying new seed as opposed to using farm-saved seed (ranging between zero and unity). Both parameters are assumed constant over the calculation period. The recommendation for the seed rate remained unchanged between 2006 and 2019 (GZPK, 2020; pers. comm.). As further explained in section 2.3, the seed replacement rate is extremely high among Swiss farmers growing organic wheat (close to 100%), so most used seed is bought at the beginning of the cropping cycle (GZPK, 2020; pers. comm.).

As data equation (1) is calculated with actual data, available until 2019, a variety-specific adoption profile needed to be estimated for future projections from 2020 until 2030 by assuming a logistic curve for Wiwa uptake. This is in line with similar studies (e.g. Bantilan et al., 2005; Maredia et al., 2000; Robinson & Srinivasan, 2013; Sequeros et al., 2019) and the theory of innovation diffusion (Rogers, 2010). It postulates that uptake of innovations is initially slow and then accelerates until it reaches a plateau:

$$A_{t+19} = U / [1 + e^{-(a+b_{t+19})}] \tag{2}$$

where A_{t+19} is the total projected area planted with the crop variety in each future period $t+19$ (starting 19 years after the introduction, where our actual data ends), U is the upper adoption limit, as explained at the end of section 2.1, a is the intercept, and b is the slope coefficient measuring the rate of variety uptake. The adoption values computed with actual data in equation (1) and forecast with equation (2) are shown in Figure 2 in section 3.1.

Linear transformation creates an equation, where parameters a and b can be estimated using standard linear regression based on the existing observations for A_t and assuming a realistic value for U (Schreinemachers et al., 2017):

$$\ln [A_{t+19} / (U - A_{t+19})] = a + b_{t+19} \quad (3)$$

According to the economic surplus model, adoption of the new variety induces a shift in the supply, known as 'K-shift' (Alston et al., 1995). This shift can be determined using data on the benefits of the new variety and the estimations from equations (1) and (2). It represents technological change due to output improvements or due to a reduction of production costs once the innovation diffuses among farmers. If the new technology simply enhances yield or reduces yield variability, the producer sells more of the good in the market. If it also enhances quality, more premium goods are sold in the market. K_t defines the benefit and cost changes in year t due to technological change. Following Alston et al. (1995), the supply shift was derived as:

$$K_t = A_t [(\Delta Y/Y_t)/\varepsilon + (\Delta C/Y_t P_t)] \quad (4)$$

where ΔY represents the gain attributable to the new variety, which is assumed constant over the calculation period, Y_t is the average national reference value in year t, ε is the price elasticity of supply for the crop. ΔC is the difference in cost between the new variety and the previously dominant varieties. P_t is the selling price of the crop in each period. In section 2.5, the scenario-specific calculations of the 'K-shift' are explained.

Positive changes in K_t should boost total supply due to higher profits and a corresponding expansion of the planted area by farmers. This growth is presumed to put downward pressure on the market price, depending on the shape of the demand curve. The market mechanism is illustrated in figure 1 in section 2.5. As defined in Alston et al. (1995), Z_t describes the price effect:

$$Z_t = K_t\varepsilon / (\eta + \varepsilon) \quad (5)$$

where η is the price elasticity of demand.

Ultimately, the total welfare effect is computed by combining the supply shift K_t and the price effect Z_t. The economic surplus ΔTS (in CHF) comprises producer and consumer gains (Alston et al., 1995; Robinson & Srinivasan, 2013). It is calculated as follows:

$$\Delta TS_t = P_t Q_t (1-s) K_t (1-0.5 Z_t \eta) \quad (6)$$

where Qt represents the sold output (in tons), and s is the proportion of output reused in the next cropping season.

2.3. Data for estimating economic impact

Adoption rates

No data on Wiwa adoption is available, but comprehensive information for exact estimation could be collected. To obtain the adoption rate (A_t), it was first necessary to calculate the potential area planted with the Wiwa variety, using seed production and seeding rate information. Seed production (S) data were taken from the Swiss Seed Producers Association swisssem (pers. comm., 24/02/2020). It increased from 11 tons in 2006 to 629 tons in 2019. For the seeding rate (r), the value of 190,000 g/ha, the optimum sowing date provided by UFA Samen (2020), was chosen. We estimated the seed replacement rate (p) based on expert opinion (GZPK, 2020; pers. comm.). Semi-structured interviews were conducted with experts in wheat research, breeding, propagation and distribution of the Wiwa variety. These experts were recruited by e-mail, and all interviews were conducted one-to-one, mainly by telephone. Organisations from which key experts were recruited are listed in Table 1. Per organisation approximately 2-3 experts were interviewed.

Table 1*: Expert opinions*

Organisation	Expertise	Roles
Agroscope (Swiss Federal Centre for Agricultural Research)	Wiwa, Titlis and Runal trial data	Breeding, variety trials
Agristat (Swiss Farmers' Association)	Swiss crop statistics	Advocacy, advisory services
BFS (Swiss Federal Statistical Office)	Swiss crop statistics	Administration
Bundessortenamt (German Federal Plant Variety Office)	German crop statistics	Administration
ÖBBW (Organic Advice Baden-Württemberg)	Trial data from Germany	Advisory services
Bioland-Handelsgesellschaft (Bioland Trading Baden-Württemberg)	Organic seed multiplication and distribution	Marketing
GZPK (Cereal breeding company Peter Kunz)	Wiwa breeding stages and investments	Breeding, variety trials
LTZ Augustenberg (Centre for agricultural technology Augustenberg)	Trial data from Germany	Advisory services, variety trials

According to the experts, self-propagation of organic winter wheat seed is hardly practised in Switzerland due to the high risk of plant diseases. This is in line with our calculations, as the seed production quantity corresponds to the cultivated winter wheat area, based on a seeding rate of 1 ton per 5 hectares[1]. As a result, we consider a seed replacement rate of 99 percent as exact. Per this rate, the proportion of the harvest retained from Wiwa production to produce seed *(s)* is tiny, at 0.1%.

The total area planted of organic winter wheat in Switzerland from 2006-2019 was taken from the Swiss Federal Statistical Office (BFS, pers. comm., 10/06/2020). In this period it increased

[1] 6,001 ha total area planted organic winter wheat CH 2019 (BFS, pers. comm., 10/06/2020); approx. 1 t seeds per 5 ha; 1,503 t total organic winter wheat seed sales CH 2019 (swisssem, 2020) ≙ 7,515 ha

from 2,321 ha to 6,001 ha. Ultimately, adoption rates for 2006 to 2019 were calculated by dividing the estimated Wiwa area by the total organic winter wheat area.

Time series data of Swiss organic winter wheat crop yields (YLD_t) were estimated based on individual yield reports submitted by farmers to the Agristat system of the Swiss Farmers' Association (Agristat, 2020; pers. comm., 03/03/2020).

Wheat prices

National average wholesale prices (P_t) for organic winter wheat (franco mill grinding wheat *Knospe*[2]) for the years 2013 to 2019 were taken from the Swiss Federal Office for Agriculture (BLW, 2020). As the data for the years before 2013 were not available from official sources, the price data from 2006 to 2012 is based on reference prices obtained from Bio Suisse (pers. comm., 02/07/2020). We calculated the average price difference for 2013 to 2019 of the BLW and the Bio Suisse data. As the Bio Suisse reference prices are always lower than the actual prices, we added the average price difference of 105.90 CHF/t to the reference prices in order to determine the approximate prices for the years 2006 to 2012.

The supply elasticity (ε) in the economic surplus model was set to 0.35 following Ricci et al. (2019) findings on wheat supply elasticity in Italy. This is within the range specified by Masters (1996), indicating that supply elasticity estimates should lie between 0.2 and 1.2. The demand elasticity (η) was set to -0.7 following Abdulai (2002), who examined cereal demand in Switzerland. Sensitivity analysis was performed for both parameters to test the robustness of study results in response to elasticity changes.

Crop characteristics

As mentioned in section 2.1, a key challenge when estimating crop improvement returns is identifying a suitable counterfactual. To this end, we relied on data for two previously dominant

[2] Organic label in Switzerland

winter wheat varieties, called Runal and Titlis. These are conventional cultivars that have been widely used in the organic wheat production system in Switzerland. We selected these two varieties based on expert interviews (Agroscope, 2020; GZPK, 2020; pers. comm.) and 'swisssem' seed production data. Runal and Titlis were introduced to the market about ten years before the introduction of Wiwa. As done in similar studies (e.g. Alene et al., 2009; Sequeros et al., 2019), we assumed that, in the absence of Wiwa development, it is likely that farmers would have continued to use the dominant varieties that they were already familiar with and that corresponded to seed regulations in the organic sector. Therefore, the selected cultivars are considered to provide a valid counterfactual for our analysis.

To assess differences in yield, quality and risk between Wiwa and the two previously dominant varieties, we relied on trial data from the Swiss agricultural research centre Agroscope (see Table 2). The Research Group "Varieties and Production Techniques" has been carrying wheat trials under organic conditions for over 20 years (Agroscope, 2020). Wiwa was introduced to the market in 2006, so our analysis required times series data starting in that year and ranging until 2019.

Based on Bio Suisse payments for organic wheat, the three economically most relevant features tested in the field trials were included in our analysis. In addition to the grain yield, these are hectolitre mass (HLM) and the percentage of protein content in the grains. The protein content is a nutrient quality criterion, and a high percentage is rewarded in monetary terms. The same applies to HLM, which is a processing quality criterion. The premiums and discounts were based on the 2019 Bio Suisse purchasing conditions for bread cereals (see Bio Suisse, 2019). Trial data thus allowed a monetary valuation of the quality differences.

In addition to yield and quality differences, the risk profiles of the crops at hand were considered a critical factor in the analysis. Organic breeding aims at providing farmers with resilient cultivars. Stable financial returns are an important consideration in cultivar choice for farmers.

In this regard, rather than overall fluctuations, it is important to capture below-average performance. Negative deviations from the expected yield are most problematic for farmers. Therefore, it was decided to measure the downside risk of Wiwa as compared to that of Runal and Titlis. Downside risk has been specified as semi-deviation (Nawrocki, 1999).

***Table 2**: Key crop characteristics*

		Wiwa		Ø Runal/Titlis	
Parameters	Units	Ø 2006 - 2019	Semidev.	Ø 2006 - 2019	Semidev.
Average physical yield	t/ha	4.55		4.49	
Average sales revenues	CHF/ha	5289.70		5219.01	
Processing quality premium (HLM)	CHF/ha	18.30		4.69	
Nutrient quality premium (protein)	CHF/ha	41.42		31.48	
Total sales revenues	CHF/ha	5349.42	588.97	5255.18	642.40

Note: Own calculations based on data provided by Agroscope (2020); semi-deviation only calculated for total sales revenues.

2.4. Breeding investments

As shown in Table 3, we calculated the investment cost of 1) breeding, 2) registering, 3) disseminating, and 4) maintaining the Wiwa variety by the Peter Kunz Breeding Company (GZPK) based on the actual costs incurred for the different steps in the process of breeding winter wheat. We set the starting year for calculating the investment costs at 1988 when the breeding process of the Wiwa variety began. As the maintenance breeding is still ongoing, we predicted the same values for continuing maintenance breeding in 2020 to 2030.

We distributed the total costs among the successfully registered and marketed varieties, including seven other varieties besides Wiwa. These varieties overlap time-wise with Wiwa in at least one of the four breeding steps. The allocation of costs to the eight varieties was based on the sum of seeds sold from 2004-2019 (swisssem, pers. comm., 24/02/2020) and was calculated separately for each breeding step. Due to Wiwa's dominance in seed sales, this variety accounted for between 80 and 96 percent of total costs.

Since the Wiwa variety is successfully cultivated in Switzerland and to an even greater extent in Germany, we have allocated only 40 percent of the total costs to Switzerland. The adjustment factor calculation of 0.4 is based on seed production data and the assumption that approx. One ton of seed is needed for five hectares of land. As German data was only available from 2010-2018, the average of these years was used to allocate the share for both countries. We have taken the Swiss data from swisssem and included a seed replacement rate of 99 percent into the calculation (see 2.3). To calculate the area under Wiwa cultivation in Germany, data from the federal plant variety office on the quantity of certified seed was used (Bundessortenamt, pers. comm., 24/03/2020). However, there is some uncertainty associated with these data, as the seed may come from both domestic and foreign production. The seed replacement rate *p* for Germany is also subject to uncertainty, as it is based on the judgement of a few experts only (Bioland HG, 2020; Saatgut-Treuhandverwaltungs GmbH, 2020; pers. comm.). According to the best information we could obtain, we have assumed a value of 50 percent for *p*.

The costs and benefits were deflated (BFS, 2020) and converted to net present values by compounding historical values and discounting future values at a real discount rate of 5 percent per year, as used in comparable studies (e.g. Alene et al., 2009; Schreinemachers et al., 2017).

Table 3*: Breeding costs of the Wiwa winter wheat variety*

	Time period	Wiwa breeding costs in 1000 CHF, real 2015
Breeding	1988-2001	470.4
Registration	2001-2005	10.2
Dissemination	2005-2006	13.5
Maintenance breeding	2006-2019	52.9
Total breeding costs	***1988-2019***	***547.0***

Note: Based on GZPK, pers. comm., April 2020

2.5. Scenario development

This study tests three main scenarios, which closely build on each other. Key-informant interviews clearly highlighted the importance of yield, quality and risk differences in the Wiwa case. In addition to yield, quality and risk are key parameters for assessing economic performance, as high-quality levels are financially rewarded, and high risk implies potentially high monetary losses. Experts pointed out no differences in production costs when comparing Wiwa to the Runal and Titlis varieties (GZPK, 2020; pers. comm.). This is also confirmed by trial data (Agroscope, 2020). Therefore, the baseline scenario models the 'K-shift' primarily as a function of physical yield gain, reflecting the approach frequently found in other studies (e.g. Alene et al., 2009). The subsequent scenarios introduce aspects of quality improvement and risk reduction. From the original supply shift formula in equation (4), three scenario-specific formulas for K_t have been developed, illustrated in Figure 1.

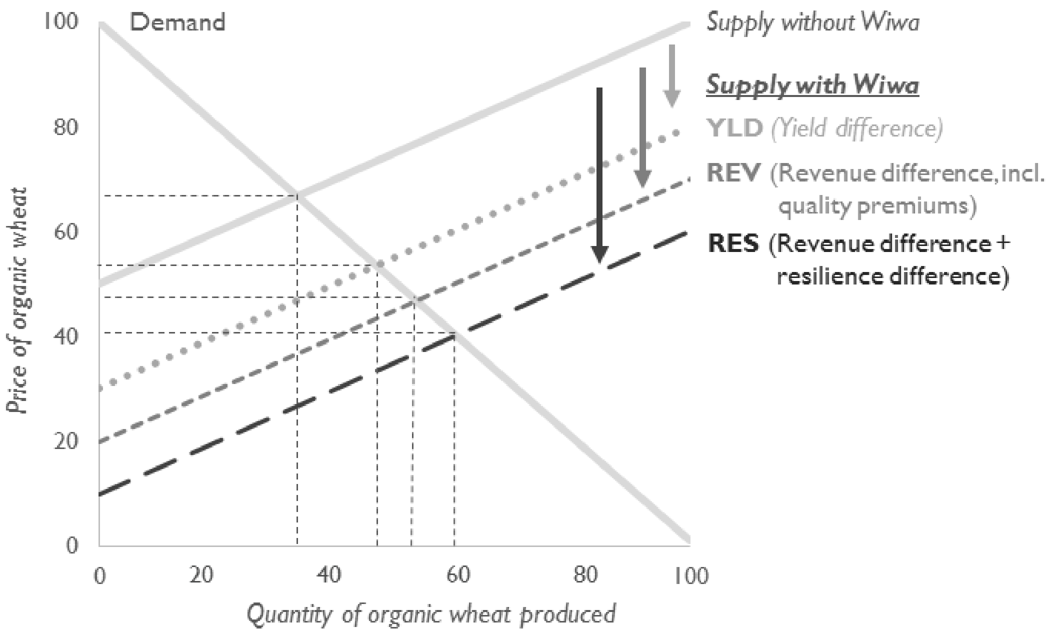

Figure 1: Conceptual frame of 'K-shift' in three different scenarios (General organic wheat price and quantity for scenario YLD, price and quantity of high quality organic wheat included for scenarios REV and RES)

In the first scenario (YLD), enhanced supply is characterised by a yield gain (in t/ha) only:

$$K_{tYLD} = A_t\,[(\Delta YLD/YLD_t)/\varepsilon] \quad (7)$$

where *ΔYLD* represents the increase in physical yield from the Wiwa variety (using agronomic data from 2006 to 2019). YLD_t is the average national reference yield for winter wheat in year t (from 2006 to 2019). The price elasticity of supply for the crop is given by ε (see section 2.2), with A_t assuring scaling following the Wiwa adoption rate.

In a second scenario (REV), the 'K-shift' is defined by a change in sales revenues:

$$K_{tREV} = A_t\,[(\Delta REV)/(REV_t)\,/\varepsilon] \quad (8)$$

where *ΔREV* represents the mean revenue change due to the introduction of Wiwa, which includes average yield gain (*ΔYLD*) valued at average organic winter wheat prices plus the average gains in Bio Suisse price premium payments described in Table 1 (Processing quality premium and nutrient quality premium, both based on a 2006 to 2019 average). REV_t is the national organic winter wheat reference revenue in each year *t* (from 2006 up to 2019). *It* is based on YLD_t parameters valued at yearly organic winter wheat prices P_t plus annual differences in quality premium payments. Wiwa and Runal/Titlis processing and nutrient quality were prized for each year using the Bio Suisse payment scheme as reference. With this, the difference in the premium payment could be computed for each year. To reflect the fact that the share of Wiwa and thus the composition of the overall organic winter wheat variety portfolio is changing over time, the annual gain in premium payments was adjusted for the Wiwa adoption rate in year *t*.

The third scenario (RES) involves an extended version of the economic surplus model. In this scenario, the 'K-shift' is characterised not only by a revenue gain but also by a reduction in downside risk. We consider that less negative divergence from the expected average yield translated into higher economic resilience of the organic wheat enterprise of the farm. The risk parameters are calculated for those years with revenues below the average revenue by subtracting the actual revenue from the average value. The resulting differences are then squared. The square root of the mean squared differences represents the semi-deviation or downside risk, a reduction of which corresponds to a gain in resilience:

$$K_{tRES} = A_t \, [((\Delta REV)/(REV_t)+(\Delta SED)/(REV_t))/\varepsilon] \quad (9)$$

where an extra term is added to equation (8), with *ΔSED* representing the difference in semi-deviation of sales revenues when comparing the new variety to the counterfactual. For each year, this value, reflecting the crop's comparative resilience, is put in relation to the overall revenues REV_t.

3. Results

3.1. Adoption profile

Adoption of the Wiwa variety started in 2006. There has been a substantial increase in the area under organic winter wheat in Switzerland, from 2,321 ha in 2006 to 6,001 ha in 2019. At the same time, the overall winter wheat area in Switzerland slightly decreased from 78,180 ha in 2006 to 72,741 ha in 2019 (BFS, pers. comm., 10/06/2020). For our projection, we assumed that this trend continues so that the organic winter wheat area reaches 11,879 ha in the final year of the forecast, which is 2030. The adoption calculations for Wiwa, as defined in equation 1 in section 2.2, resulted in an initial coverage of 58 ha, which grows to 3,344 ha in 2019, representing a 56% share. This is in line with expert opinions. We then assumed a declining share of Wiwa in the years after 2019. As explained in section 2.1, this assumption is based on likely resistance breaks and promising new organic wheat varieties. Future use of the variety was estimated based on the adoption model defined in equations 2 and 3 in section 2.2. It yielded an area of 3981 ha for the year 2030, representing a share of 34%, as shown in Figure 2.

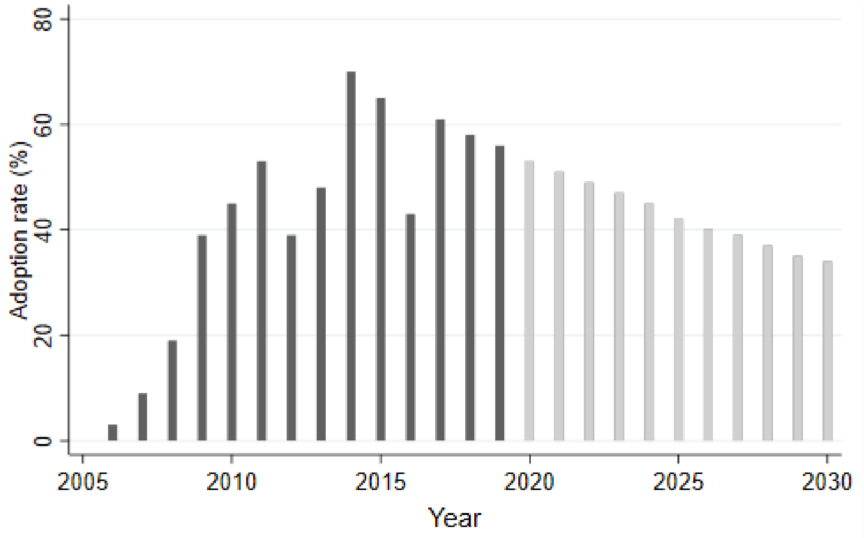

Figure 2: Adoption profile of Wiwa winter wheat, 2006 to 2030 (forecast values from 2020 onwards)

3.2. Returns to investment

The three scenarios explained in section 2.5 were evaluated for the Wiwa variety in terms of benefit-cost ratios (BCR) and the internal rate of return (IRR). While BCRs compare the aggregate net present value of the economic surplus to the aggregate net present value of the investment and maintenance costs, the IRR measures the profitability of the breeding project. It represents the discount rate that makes the net present value of all cash flows equal to zero.

Findings for the periods from 1988 to 2019 and from 1988 to 2030 are reported separately and are displayed accordingly in Figure 3. The BCR for the simple yield gain scenario (YLD) ranges between 24 and 56. Once quality differences between Wiwa and Runal/Titlis are accounted for in the revenue gain scenario (REV), the ratio increases to 37 and 85, respectively. Ultimately, downside risk aspects were included in the resilience gain scenario (RES). Here, the BCR rises to 58 for the current period and 133 once future benefits are considered. The IRR starts at 13.5% and 15.5% in the YLD scenario and reaches 16% and 17.7% for the respective calculation periods in the REV scenario. In the RES scenario, the rate lies at 18.6% for the period up to 2019 and at 20% for the period up to 2030.

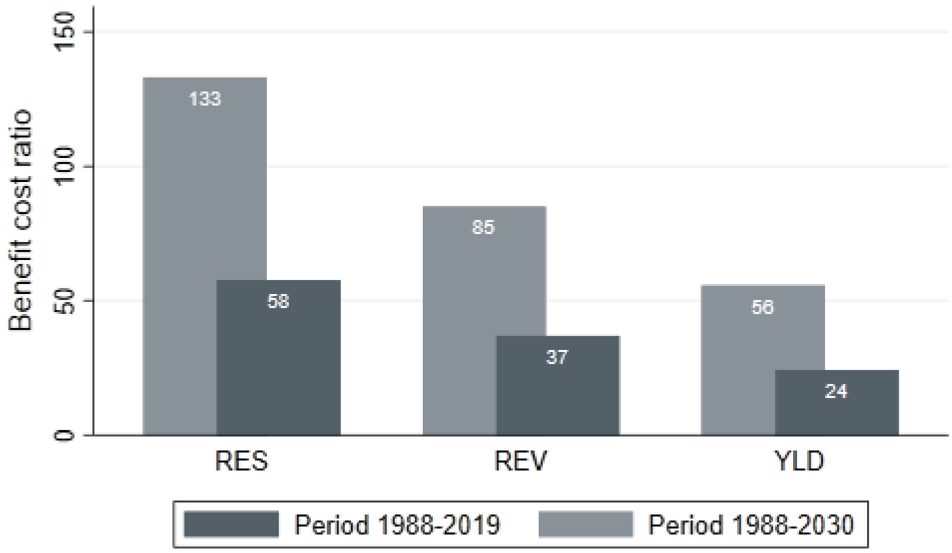

Figure 3: Benefits cost ratios for the three model scenarios by calculation period (YLD - Yield difference; REV - Revenue difference, incl. quality premiums; RES - Revenue difference + resilience difference)

3.3. Sensitivity tests

Sensitivity tests were carried out for model parameters, which are considered key leverage points and subject to a degree of uncertainty. This includes the yield difference between Wiwa and the previously dominant varieties. Here the yield premium was first reduced by 25% and then increased by 25% to tests its influence on the results. As part of the sensitivity testing, the standard discount rate of 5% was set to 3% and 8%, respectively. To reflect the fact that more than half of the entire area cultivated by Wiwa is outside of Switzerland, investment costs were adjusted downwards using a multiplication factor of 0.4, as explained in section 2.3. Here we also test adjustment factors of 0.3 and 0.5. Finally, elasticities for supply and demand were included in the uncertainty analysis. The supply elasticity of 0.35, as specified in the literature, was alternatively set to 0.2 and 0.5. Demand elasticity was reduced to -0.3 and increased to -1.5 from the ordinary model coefficient of -0.7.

In this paper, we focus on the sensitivity results for the main RES scenario. Figure 4 shows that the results for this scenario are somewhat sensitive to the specification of the discount rate, the cost adjustment factor and the supply elasticity. Especially a lower supply elasticity and a higher discount rate produce substantially higher benefit-cost ratios. For the current period up to 2019, the ratio is diminished from 58 to approximately 40 when applying a higher supply elasticity, a lower discount rate or a bigger cost share by changing the cost adjustment factor. The model appears relatively robust to changes in the yield difference. As these differences are based on highly detailed trial data, the 25% downward and upward adjustments in the sensitivity testing are considered more than sufficient to capture possible on-farm deviations from the trial results. Finally, it should be noted that model outcomes are only minimally affected by changes in the demand elasticity.

To sum up, the uncertainty analysis demonstrates that model outcomes are rather robust within certain ranges, with the highest uncertainty regarding the supply elasticity parameter (see Figure 4). As expected, sensitivity to model specifications increases with extending the calculation period. Still, trends are confirmed for the analysis until 2030. Parameter choices generally are backed up by data or literature and are deemed reasonable.

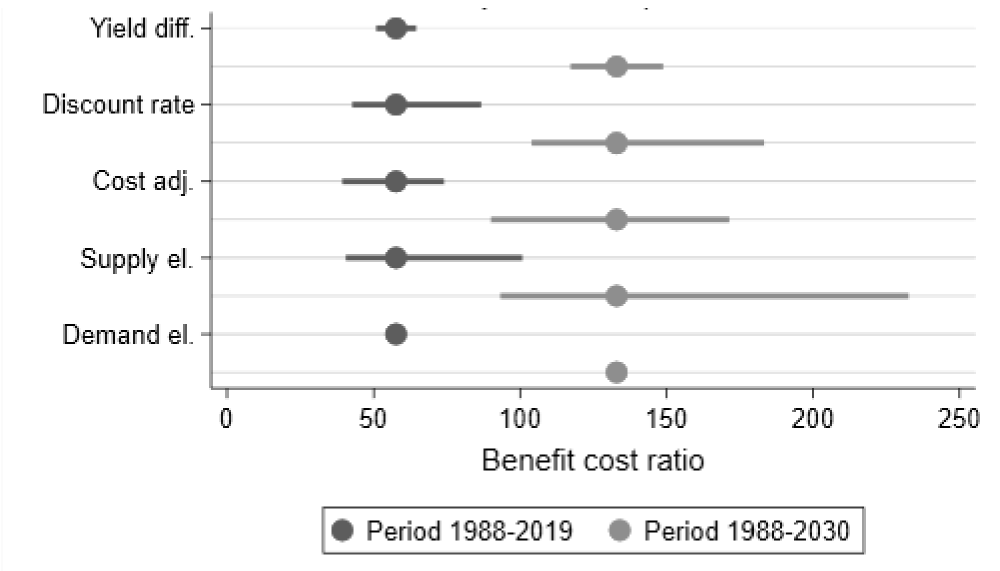

Figure 4: Sensitivity ranges for key model parameters by calculation period

4. Discussion and Conclusion

Winter wheat is one of the most important arable crops in Switzerland. While there is a substantial investment in conventional wheat breeding, the situation in organic breeding is quite different. At the same time, however, the organic winter wheat area share has almost tripled in the last 15 years, reaching 8.25% of the total wheat area (BFS, pers. comm., 10/06/2020). It is therefore important to better understand the role of crop improvement based on organic principles. This study contributes to closing the scientific gap on the economic benefits of organic wheat breeding by quantifying rates of return from a societal perspective. Considering that the organic sector is still a niche market and that R&D spending in the sector lags far behind conventional agriculture, the results show how investments in breeding the organic Wiwa wheat variety produce attractive returns.

It should be noted that this is contingent on a sizeable uptake of the variety, which has not been the case for other organic wheat varieties so far. Depending on the respective scenario, the internal rate of return ranges between 13.5% and 18.6% for the period up to 2019. Moreover, benefits from the investments significantly outweigh costs, being 58 times higher in the resilience scenario (and 133 times higher once future benefits are accounted for). Such positive returns are in line with the results of other studies that have quantified the rate of return to crop improvement research in wheat varieties (e.g. Azzam et al., 1997; Marasas et al., 2003; Thakur et al., 2007). In conventional breeding, studies generally produce higher estimates though. Concentrated know-how, economies of scale and geographical scope are all possible explanations for the gap in rates of return between organic wheat breeding and conventional wheat breeding.

The present study provides evidence that investments in organic crop improvement research can pay off, especially when quality and resilience gains are accounted for. For the Wiwa case, economic returns were estimated by valuing the grain yield, the nutrient quality (protein content), the processing quality (hectolitre mass) and the risk profiles of the varieties (semi-deviation). We consider the downside risk as a key distinguishing factor in the analysis, as a central goal of organic breeding lies in supplying farmers with robust and resilient cultivars. In the context of climate change, we expect that this breeding goal will even attain greater importance, not only in the context of organic farming. Therefore, some relevant spill-over effects from organic breeding to conventional farming are likely to happen in the future. Already in the case of Wiwa, this is happening to a small extent. A significant challenge will be to address trade-offs that exist between yield, quality and risk performance. While retailers focus mainly on quality parameters, such as protein content, farmers and policy-makers are more interested in yield stability.

Overall, organic crop improvement is still in its infancy. Existing initiatives have fragmented and insecure funding (Wirz et al., 2017). Compared to the Wiwa study, it can therefore be expected that higher benefit-cost ratios will be achieved in the future, but targeted investments into the organic crop improvement sector are required. Regarding this type of analysis, it is important to note the difference between a private business perspective and a welfare economics perspective. Considerable social gains do not imply the profitability of the breeding activities themselves but demonstrate the larger benefits of R&D investments. In fact, small breeding initiatives often struggle to cover costs. The positive findings on the broader economic welfare of organic crop improvement provide a rationale for developing creative funding solutions and boosting the sector's public and private R&D spending. Value chain partnerships and pool funding are ways of distributing the financial burden among multiple actors who benefit and collectively securing the integrity of the future organic product supply (Messmer et al., 2019; Winter et al., 2021). At the same time, there is also a case for higher R&D funding of organic breeding through public initiatives. While organic breeding companies will benefit, it will most likely also increase competition as larger seed companies enter the organic breeding market. Ultimately, a growing market should lead to a greater diversity of varieties and potentially more choices for farmers. This will help to achieve more sustainable farming systems in line with policy goals.

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Study 2: Sow what you sell: Strategies for integrating organic breeding and seed production into value chain partnerships

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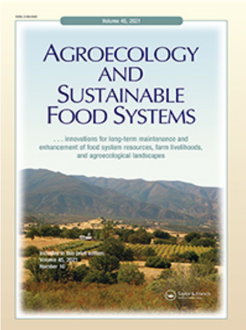

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Sow what you sell: strategies for integrating organic breeding and seed production into value chain partnerships

Eva Winter[a,b], Christian Grovermann[a], Joachim Aurbacher[b], Stefano Orsini[c], Freya Schäfer[d], Mariateresa Lazzaro[e], Francesco Solfanelli[f], and Monika M. Messmer[g]

[a]Department of Socioeconomics, Research Institute of Organic Agriculture (FiBL), Frick, Switzerland; [b]Institute of Farm and Agribusiness Management, Justus-Liebig University of Giessen, Giessen, Germany; [c]The Organic Research Centre, Cirencester, UK; [d]FiBL Deutschland, Frankfurt Am Main, Germany; [e]FiBL Europe, Bruxelles, Belgium; [f]Department of Agricultural, Food and Environmental Sciences, D3A Università Politecnica Delle Marche, Ancona, Italy; [g]Department of Crop Sciences, Research Institute of Organic Agriculture (FiBL), Frick, Switzerland

ABSTRACT

The development of an independent organic breeding and seed sector poses a significant challenge for organic agriculture in Europe. It should deliver cultivars suitable to the principles and conditions of organic farming and secure the integrity of future product supply. This study seeks to identify promising pathways to address this challenge by analyzing value chain organization. It is based on a mixed method approach combining the assessment of qualitative data from a stakeholder dialogue with an analysis of quantitative farm survey data.

The results from the stakeholder dialogue show that a value chain partnership is a promising strategy to distribute the burden for refinancing breeding, as the whole organic sector would profit from organic breeding. A cross-sector pool funding strategy is proposed for joining forces among all value chain partners of the organic sector to invest in organic breeding and collectively secure the integrity of the future organic product supply. Four success factors have been identified: a long-term commitment, a pool fund for organic cultivar development, awareness-raising on the importance of breeding, and a high level of transparency in the process. The funding strategy is backed up by findings on market channels. Farmers who market their products through long value chains use less organic seed than those marketing through short value chains. This highlights the need to better integrate long organic value chains such as processors, traders, and retailers, and seed supply. Regardless of the marketing channel, farmers consider the development of organic breeding a vital measure to achieve higher organic seed use. This indicates that overcoming organic seed shortage is more likely to be achieved when also including breeding activities.

KEYWORDS
Organic plant breeding; organic seed; value chain partnership; farmer perceptions; marketing channel

CONTACT Eva Winter eva.winter@fibl.org Research Institute of Organic Agriculture (FiBL), Frick 5070, Switzerland

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Background and objectives

The state of organic seed and breeding in Europe

In Europe, a constant reduction of public breeding programmes has taken place in the past decades (Aad Van et al. 2013). This development accompanied the privatization of the agricultural breeding and seed industry and, more recently, a substantial consolidation of the sector. Just three agrochemical firms controlled more than half of the global proprietary seed market in 2011 (Howard 2015) and this trend is ongoing. At the same time, the focus of crop improvement is increasingly targeting only a few major cash-crops for which breeding investments can be refunded through royalties on the production and sale of seed (Messmer et al. 2015). There is evidence from agroecological farming that a lack of breeding and consequently suitable cultivars is one of the main bottlenecks for crop diversification (Meynard et al. 2018; Vanloqueren and Baret 2008). These factors contribute to the decrease of agrobiodiversity in farmers' fields (Montenegro and Maywa 2016). These changes have generated public concern and may decelerate the transformation toward a more sustainable food system (Mooney 2017).

The organic farming movement emerged to find solutions for a more self-sufficient and locally adapted form of agriculture (IFOAM 2005). Many European countries are experiencing a rapid rise in the share of organic farms (Willer and Lernoud 2019). Yet, developing a strong and independent organic breeding and seed sector that addresses the needs of organic agriculture remains a key challenge. There are two bottlenecks to be overcome. Firstly, there is a shortage of seed multiplied under organic conditions (Solfanelli et al. 2019). As the phasing out of derogations for non-organic seed in EU organic agriculture by 2036 has been announced (New Organic regulation 848/2018), effective solutions need to be found which supply sufficient organic seed. Secondly, presently, for ca. 95% of all organic produce, cultivars were bred under conventional conditions (Lammerts Van Bueren et al. 2011). The new Organic Regulation recommends the use of cultivars suitable for organic agriculture. In this context, the European Commission has announced a 7-year temporary experiment to foster development and marketing of organic varieties within the scope of the EU seed marketing directives (New Organic regulation 848/2018 (39)). This experiment aims to show the suitability of organic cultivars for organic farming and to create easier market access for them. This opens a window of opportunity for the organic breeding and seed sector to become more independent of the conventional sector. Both bottlenecks could be overcome at once since there are several problems linked to both organic seed and organic breeding. With the phasing out of the derogations for non-organic seed, it is likely that many commonly used or newly developed conventional cultivars will no longer be available to organic farmers. This decrease in availability can be attributed to either the small size of the organic market or technical challenges to produce organic seed, such as high pest pressure or high costs of separate processing facilities. The commitment of the organic movement to only accept specific breeding techniques may further decrease cultivar choice, as emerging genetic engineering techniques, such as CRISPR-Cas9, could be widely adopted in future agricultural systems (BÖLW 2018).

Furthermore, organic agriculture differs from conventional agriculture with regard to agricultural crop diversity exploitation. Crop biodiversity organized in time (crop rotation) or space (crop association) is crucial in organic agriculture, which generates the need for breeding a wide range of crops with sometimes a relatively small total area. As organic agriculture aims for diverse crop species and locally adapted cultivars, it is expected that the area under production of a single organic-bred cultivar may remain relatively small, even if organic acreage share would grow rapidly in the future. Therefore, refinancing Organic Plant Breeding through a royalty system on seeds of protected cultivars will be insufficient for most crops (Kotschi and Wirz 2015). Moreover, most organic breeders do not want to protect their cultivars but motivate organic farmers to produce their own seed. This puts the prevailing system of refinancing breeding investments through royalties or seed sales to a test.

Approaches to overcome shortages of organic seed and suitable cultivars in the European organic food sector

As outlined above, alternative financing strategies to the prevailing refinancing system have to be identified for the organic sector. In reaction to this, a range of alternative crop improvement programmes have emerged, including initiatives with the aim to increase organic seed production and to facilitate organic cultivars release. In most cases, organic breeding initiatives rely on co-financing from various sources, which are often restricted to project-based or short-term engagement. For example, in Switzerland and Germany, the current common financing strategies for organic breeding initiatives are, in decreasing order of importance, pre-financing through foundations (52%), trade and processing (14%), donations from individuals (9%), public funding (8.5%), as well as other sources (Kotschi and Wirz 2015). These data reveal the fragmented nature of organic breeding funding.

However, with a current market volume of 37.3 billion euros in Europe in 2017, the organic food sector has become an essential part of the overall food industry. Organic products, both fresh and processed, can be found at farmers markets as well as in big retail outlets. The majority is marketed through supermarkets (Willer and Lernoud 2019). All organic value chain actors will be affected if there is a shortage of organic seed and cultivars. Thus, it is in the interest of a wide range of industry actors to acknowledge and address the individual challenges of the organic sector, such as the provision of organic seed and cultivars suited for organic agriculture. Furthermore, there is case study evidence that downstream value chain actors influence organic farmers' seed and cultivar choice. For example, two studies show that in France, organic vegetable growers tend to use more organic seed if they market their produce directly rather than through longer value chains (Le Doaré 2017; Rey et al. 2013). The same tendency was found in a study conducted in Canada (Levert 2014). This shows that a closer link to the end-consumer facilitates organic seed use. Furthermore, it is likely that given the current mainstream standards of longer value chains, e.g., with respect to uniformity and visual quality is still easier to meet market requirements when using cultivars from conventional breeding. The importance and influence of marketing channels on various farm management aspects, such as input and crop choices, has been established in numerous studies (Navarrete 2009; Schipmann and Qaim 2011; Xaba and Masuku 2013). As more traditional approaches, like refinancing breeding costs through royalties or seed sales, cannot be applied to many crops in organic agriculture, insights into the influence of marketing channels on seed and cultivar choice are important for encouraging and steering activities in value chain partnerships and designing public policies. These efforts will help achieve the targets for organic seed use and organic breeding promotion, set by the new Organic Regulation.

Approaches focusing on value chain partnerships

With declining public funding for breeding, institutional innovation seems to be an entry point for enhanced breeding activities. Both researchers and decision-makers acknowledge the importance of developing interventions that target collaborations along the agri-food value chain (Healy and Dawson 2019; Henriksen et al. 2010; Matopoulos et al. 2007). This involves for instance improved information flows about needs and challenges at different value chain stages and coordinated problem-solving mechanisms. It also often requires a reconfiguration of power distribution along the value chain. Rossi, Bui, and Marsden (2019) argue that equity can lead to substantially more sustainable agri-food systems. They outline a case of power shift from global to local value chain actors in wheat breeding. Another example is better linking seed producers and breeders to downstream value chain actors by establishing collaborative structures, that focus on addressing the needs of both sides (Altaye and Mohammed 2013). Chable et al. (2020) demonstrated the usefulness of participatory breeding approaches linked with local short supply chains to enrich biodiversity from farm to fork. There are some small-scale examples where partnership-based value chain solutions in the organic seed and breeding value chain have succeeded in establishing sufficient organic seed and cultivar supply in Europe (Naturata International 2015; Verrière, Nuijten, and Messmer 2019). Other larger scale examples can be found in the textile industry, i.e. the Organic Cotton Accelerator, that supports organic cotton breeding through a pool funding by value chain actors (Messmer, Joshi, and Riar 2019). Additionally, a pool-funding strategy is considered to tackle other challenges of the agricultural sector in Europe, such as animal welfare issues (Initiative Tierwohl 2020).

Objectives and research questions of this study

In this study, we focus on developments in the EU organic seed and breeding sector. We outline novel models for financing the growth of organic breeding through the development of value chain partnerships. In addition, we advance the understanding of the role of downstream value chain actors, regarding their influence on organic seed use and farmers' perception of breeding needs for the organic sector. Our research is the first to conduct a multi-step stakeholder dialogue to develop a model that could boost the organic seed and breeding sector, based on value chain collaboration, underpinned by an analysis of marketing channel effects using a large sample of organic farmers across Europe. Marketing channels are used as a proxy for the effect of downstream value chain actors on farmers' organic seed use. Through the combination of this data, we aim at giving a comprehensive overview of the perspectives of the most relevant actors of the seed and breeding value chain stages in European organic agriculture, i.e., breeders, seed producers, farmers, and downstream actors.

In particular, our study was based on the following research questions:

(i) Which financing strategies for breeding for the organic sector exist, what are their bottlenecks and potentials for upscaling?

(ii) Against this background, what would a promising intervention targeting value chain collaboration look like to boost organic breeding and seed production?

(iii) What effect do organic marketing channels currently have in terms of organic breeding and seed use at the farm level? How do they influence farmers' perception of the importance of organic seed and breeding?

Materials and methods

An integrated research approach was applied in this study by combining and analyzing different data types, including (i) qualitative data from two multi-actor workshops, (ii) qualitative semi-structured interviews with key breeding and seed experts in Europe and with market players of the food processing and retailer sector and (iii) quantitative data from a multi-country online farmer survey in Europe. The integrated research approach allowed us to exploit the most suitable data sources for answering the above-stated research questions.

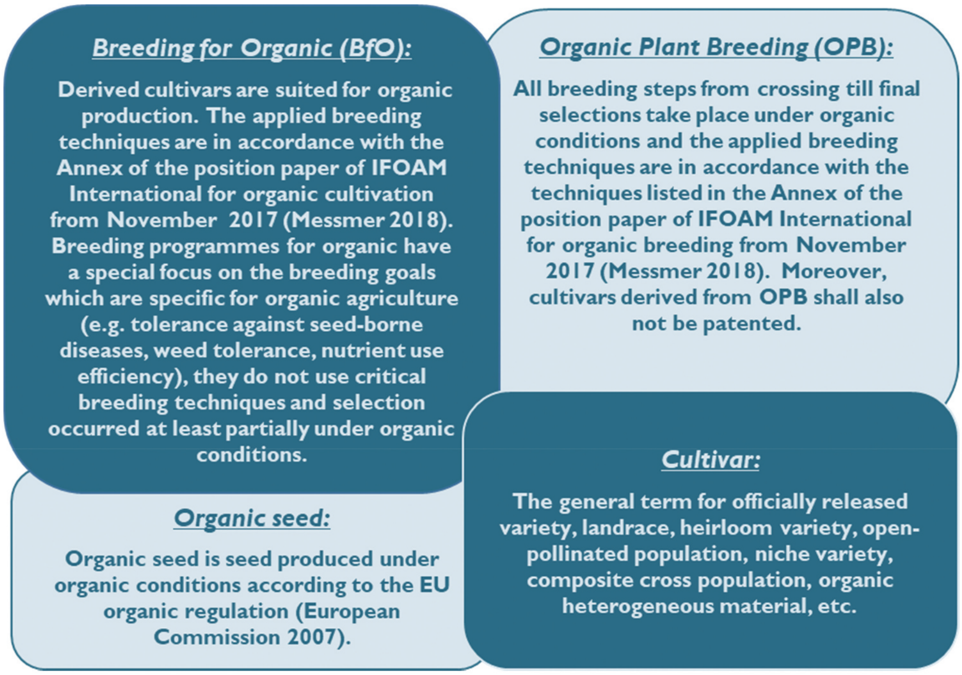

Figure 1. Definitions for organic cultivar development and organic seed.

The study relies on the definitions of organic breeding, breeding for organic, cultivar and organic seed as outlined in the Horizon2020 project LIVESEED (Figure 1) (LIVESEED 2020).

Assessment of multi-step stakeholder dialogue on strategies for integrating organic breeding in value chain partnerships

Data collection

A multi-step stakeholder dialogue (Dodds and Benson 2012) was carried out between 2018 and 2019 comprising (1) explorative interviews with breeders and seed producers in Europe and (2) two formal participatory workshops with all relevant stakeholders and (3) bilateral meetings of scientists with selected stakeholders, including organic breeders, farm advisors, seed producers, researchers, processors, retailers, organic farming associations and donation agencies targeting the refinement of the workshops' outcomes. The objective of the stakeholder dialogue was to identify existing financing strategies for organic breeding and to develop a long-term, large-scale financing concept for organic breeding that represents the views of all relevant stakeholders.

At first, twenty-five explorative key informant interviews representing public breeding institutions, breeding initiatives, and breeding and seed companies of the conventional and organic breeding and seed sectors in 12 European countries were conducted. This allowed a better understanding of how organic breeding is financed at present. On this basis, we identified promising financing strategies for organic breeding, as gray and scientific literature is scarce. Among the 25 interview partners, 19 interviewees represented entities directly involved in organic seed production and/or breeding or breeding for organic. The financing strategies of these actors were identified and analyzed (see next sub-section for further information about the analysis) as to their potential for upscaling and their shortcomings. Key informants and relevant actors for the interviews were identified with additional support of the LIVESEED project partners and its stakeholder platform.

The interview results were used as the basis for discussion in two workshops (September 2018 and February 2019) and bilateral meetings between scientists and selected stakeholders aiming to co-develop criteria for a cross-sector pool funding strategy and establish framework conditions that can be applicable at the European level. During the workshops and bilateral meetings, key issues regarding organic breeding integration into value chain partnerships were discussed. The included actors were organic breeders, farm advisors, seed producers, researchers, processors, retailers, organic farming associations and donation agencies that already fund organic breeding.

The first workshop targeted organic value chain stakeholders from Germany. In this country, several organic breeding initiatives and small-scale experiences of value chain collaborations for financing breeding are already in place. Comments from seed and breeding experts (21), processors (4), retailers (7), associations (10), foundations (3), and communication experts (2) were collected. The second workshop was used to expand the discussion with breeders, researchers, retailers and organic producers active at the European level. Twenty-three participants from eight countries from Central and Eastern Europe attended the workshop. The participants were breeders (7), researchers (7), NGOs (2), seed producers (3), retailers (2), organic farmers (1), and organic associations (1).

To summarize the process, based on existing financing strategies and experiences as well as ideas for the improvement of breeders that had already built a relationship with value chain partners, a core group of natural and social scientists developed essential criteria for a cross-sector financing strategy. During the outlined workshops and bilateral meetings, the identified criteria for long-term collaboration along the value chain were validated and additional criteria identified and integrated as a multi-actor effort.

Data analysis

The material from the interviews, meetings and workshops was qualitatively analyzed using content analysis. Content analysis aims to obtain a broad and condensed description of phenomena. As an outcome, concepts or categories are derived (Elo and Helvi 2008). Specifically, organizational models and financing strategies for organic breeding were described and analyzed as to their advantages, shortcomings and resulting potential for scaling up or out. With this knowledge as a basis, further interviews, and workshops concerning a financing strategy and organization model for organic breeding at a European level were conducted. As a part of this process, we developed a strategy proposal for including organic breeding in value chain partnerships. This strategy proposal operationalizes the knowledge collected and generated during the stakeholder dialogue, and builds on experiences of previous examples of similar approaches. Potentials and challenges of such a strategy for boosting the organic breeding sector were identified.

Analysis of farmers' behavior and downstream value chain interactions

Data collection

To complement the findings from the key-informant interviews and stakeholder dialogue, data from an online survey targeting organic farmers was analyzed. The survey was conducted between November 2018 and June 2019 and distributed through the networks of partners involved in the Horizon2020 project LIVESEED, including 23 breeding & research institutes, seven breeding companies, eight seed companies, and 11 organic associations.

752 complete entries by farmers from 20 countries from Central, Northern, Southern, and Eastern Europe could be used from the 1,475 total accesses to the survey. Since neither the information needed for probability nor for cluster sampling of the organic farm population was readily available due to privacy restrictions, non-probability opportunity sampling was applied. This is a widely used sampling strategy in rural sociology to tackle the challenge of data collection at the farm-level (Abdu-Raheem 2014; Ferguson and Kepe 2011; Sangkapitux et al. 2017). In our case, all farmers fulfilling the requirement for participation (i.e., that they grow at least one of 19 specified important crops organically) could complete the survey. The investigated crops are, apples (*Malus domestica*), grapes (*Vitis vinifera*), pea (*Pisum sativum*), grain maize (*Zea mays*), barley (*Hordeum vulgare*), oats (*Avena sativa*), lupine (*Lupinus angustifolius*), potatoes (*Solanum tuberosum*), cauliflower (*Brassica oleracea* var. botrytis), carrots (*Daucus carota*), onion (*Allium cepa*), tomatoes (*Solanum lycopersicum*), soft wheat (*Triticum aestivum*), soybeans (*Glicine max*), alfalfa (*Medicago sativa*), durum wheat (*Triticum durum*), strawberries (*Fragaria* x *ananassa*), olives (*Olea europea*), and a forage mixture.

Respondents could indicate multiple marketing channels they use in the survey, i.e. marketing via supermarkets, processors or traders, specialized organic retailers, cooperatives and direct marketing. To obtain groups that are large enough for meaningful econometric analysis, we re-coded the variable to match our outcome of interest, i.e. the comparison of responses grouped as short *vs* long value chains. This resulted in two groups: (1)

Farmers predominantly marketing through supermarkets, traders, and cooperatives (a proxy for long value chains); (2) Farmers marketing directly to consumers (a proxy for short value chains).

Out of the 25 questions in the survey, five outcome variables were of interest for this study:

(i) *Attitude toward organic breeding*: This is a 5-point Likert-scale statement 'more breeding for organic farming would increase organic seed use with 1 indicating strong disagreement and 5 strong agreement. It is an indicator of the farmer's attitude toward the potential of increasing organic seed use through more targeted breeding in the organic sector. Thus, this outcome variable shows if, according to the farmer's perception, increasing the availability of organic cultivars would encourage the use of organic seed.

(ii) Organic seed use per farm: This outcome variable is calculated as a percentage of organic seed use of the overall seed use at the farm level. It is an indicator of the organic farmers' actual behavior in terms of their use of organic seed.

(iii) Buyer expectation: The variable is specified as a 5-point Likert-scale statement 'my buyer expects me to use organic seed', with 1 indicating strong disagreement and 5 strong agreement. It captures the farmers' perception of their buyers' expectations about organic seed.

(iv) Farmers' attitude toward organic seed: This variable is a 5-point Likert-scale statement 'the use of organic seed is important for the integrity of organic farming', with 1 indicating strong disagreement and 5 strong agreement This outcome variable displays the attitude of the organic farmers toward organic seed.

(v) Farmers' perception of the organic seed price: This variable is a 5-point Likert-scale statement 'the organic seed price is prohibitive' with 1 indicating strong disagreement and 5 strong agreement. This outcome variable indicates if farmers find the organic seed prices too high.

Data analysis

The comparative analysis of marketing channels required data pre-processing to overcome the unbalanced composition of the two groups (responses grouped as short *vs* long value chains) arising from the opportunity sampling strategy used. The sampling strategy may have caused a bias toward a higher response rate from farmers who are motivated to use organic seed, even if it is not compulsory. We applied various weighting methods to address the bias that will be explained in the following. Through the application of these weighting methods, the dataset can still yield relevant results, e.g. explaining differences in quantity of used organic seed between different farmer groups.

To control for confounding factors (e.g., gender, age, farm size, crop specialization of farm depicted by the percentage of area on which vegetable grown (on remaining area, arable crops are grown), education of farm manager, received trainings, and location), we employed a doubly robust data pre-processing approach in our comparative analysis. This technique combined inverse probability weighting and regression adjustment, using the treatment effects routine in STATA 15 (Cerulli 2017; Drukker 2016). These confounders were selected to ensure the inclusion and balance of the most relevant independent farm and farmer characteristics. At the same time, model convergence was still warranted. To maximize the predictive power of the chosen model, quadratic terms of the continuous variables were included and sufficient balancing was tested and confirmed with the overidentification test. Standard errors are specified to allow for intragroup correlation with the country indicator as the cluster variable. A similar approach was applied, for example, to compare different levels of farmers' value chain integration and their effect on farm household food security in Tanzania (Kissoly, Faße, and Grote 2017) and to determine the impact of marketing through agricultural cooperatives on farm household income in the Sichuan province, China (Liu et al. 2019). We adjusted our sample of observational data through the use of probability weights. These were calculated based on the known number of organic farmers per country. Adjusting the sample by country is the best suited approach, as the regulations regarding organic seed are implemented at national level, and thus differ significantly between countries. As the number of observations in each country was not directly indicative of the total number of organic farms per country or in the entire population, the number of observations in each country was weighted in the model using the probability weights routine in STATA 15. Here, the inverse probability of the selection of a farmer in a given country helped to reflect more adequately the importance of individual sampling units.

In Table A2 in the Appendix, a substantial improvement of covariate balance for the selected control variables by the ipwra balancing strategy can be observed. In most cases, the standardized differences of the weighted covariates moved closer to zero, and the variance ratios moved closer to one. A perfectly balanced covariate would have a standardized difference of zero and a variance ratio of one. The overidentification test for covariate balance shows that the pre-processing method ipwra sufficiently balanced the samples (chi-squared value of 14.4 with 12DF, p-value of 0.27). The compared subsamples were re-weighted from 317 to 378.4 in the case of the subsample of farmers using longer chains, and from 435 to 373.6 in the case of the subsample using short chains.

To verify the robustness of results, we additionally applied the method of propensity score matching for comparison. However, probability weights and standard errors allowing for intragroup correlation with the country indicator as the cluster variable are not implemented in the treatment effects routine in

STATA 15; thus, the results are not as accurate as inverse probability weighting combined with regression adjustment (ipwra). Moreover, if the propensity score model is miss-specified, there is no control mechanism as in ipwra (Liu et al. 2019).

Results

Multi-step stakeholder dialogue on strategies for integrating organic breeding in value chain partnerships

A number of different actors, including commercial companies, nonprofit organizations, and public institutions, conducts breeding activities. The breeding programmes in the organic farming domain can be grouped in Breeding for Organic (BfO, Figure 1) and Organic Plant Breeding (OPB, Figure 1). Most Organic Plant Breeding activities are currently taking place in Central Europe (36), with 12 activities present in Southern Europe, 7 in Northern Europe, and only 3 found in Eastern Europe. An actor mapping confirmed these numbers (Nuijten, Vonzun, and Messmer 2019). Breeding for Organic (BfO) activities usually integrate breeding goals of the organic sector into their running breeding programme. For example, in Austria, Latvia, and Hungary, there are BfO initiatives in which crosses and early generation selections are performed under conventional conditions, and selection at later generations and cultivar testing are conducted under organic conditions.

Based on interviews with 23 key informants of both conventional and organic seed and breeding sector, the following financing strategies and linked organizational models for breeding for the organic sector could be identified and their potential for scaling up or out assessed. An overview of advantages and shortcomings of the combinations of financing strategies and organizational models is presented in Table 1.

Refinancing through seed sales or royalties, with mostly shared organic and conventional programmes, was mentioned as the most used financing strategy for medium-sized conventional seed companies (Breeding for Organic, Figure 1). By combining their activities for the conventional and organic sector they can harness synergies in the breeding process, be more cost-efficient and cross-finance the investment into organic breeding goals via conventional seed sale. Upscaling would be readily possible if the organic market continues growing and the usage of organic seed is enforced by the new organic regulation. The main bottleneck, which would affect Breeding for Organic, are restrictions in breeding techniques by the organic sector. However, Breeding for Organic is a compromise that cannot always adequately address all breeding goals relevant for the organic sector, as not all selection steps are conducted under organic conditions. The introduction of semi-dwarf genes for yield increase in high-input wheat cultivation is a salient

Table 1. Existing financing strategies and organizational models for breeding for the organic sector, advantages and shortcomings for scaling up or out (based on interviews with stakeholders).

Financing strategy Organizational model	Refinancing through seed sales or royalties	Pre-financing through public funding	Pre-financing through donations	Pre-financing through food trade actors
Medium-sized conventional seed company with combined breeding programmes for organic and conventional farming (Breeding for Organic)	**Advantage**: -Resource-efficient breeding process -Upscaling possible if organic market increases **Shortcoming**: -Organic breeding goals cannot be fully addressed, because the breeding process is mainly conducted under non-organic conditions -Possible restriction in breeding techniques due to organic regulation (Interviewed actors: 7)	-	-	-
Small organic breeding company or initiative (Organic Plant Breeding)	**Advantage**: -Can cover part of an investment **Shortcoming**: -Insufficient return on investment due to small production areas and farm-saved seed (Interviewed actors: 3)	**Advantage**: -Transparent distribution -Supports collaboration with researchers and other breeders **Shortcoming**: -Only short-term research-focussed funding -Practical breeding work is not publicly funded -High administrative burden (Interviewed actors: 2)	**Advantage**: -Low administrative costs **Shortcoming**: -Unstable source of income for breeder -Only a few foundations provide substantial support to Organic Plant Breeding -Difficult to transfer to other countries (Interviewed actors: 3)	**Advantage**: -Stable source of income for breeder -Transparent distribution -Close collaboration between breeders, processors and traders to contribute to determining breeding goals **Shortcoming**: -High voluntary commitment of food value chain actors needed (Interviewed actors: 4)

(*Continued*)

Table 1. (Continued).

Financing strategy Organizational model	Refinancing through seed sales or royalties	Pre-financing through public funding	Pre-financing through donations	Pre-financing through food trade actors
Farmer-breeders organization (Organic Plant Breeding)	**Advantage**: -Added value and partial return of investment through direct marketing or short value chains **Shortcoming**: -High financial risk of farmer -Upscaling to reach longer value chain and larger geographical coverage (e.g. to European level) is difficult (Interviewed actors: 4)	-	**Advantage**: -Low administrative costs **Shortcoming**: -Unstable source of income for farmer breeders (Interviewed actors: 2)	-
Public breeding institute (Organic Plant Breeding, Breeding for Organic)	-	**Advantage**: -Secure long-term funding based on the needs of society **Shortcoming**: -Public funding has been declining -Practical breeding work is only funded in a few countries, mainly focused on conventional farming (Interviewed actors: 4)	-	-

example for competing breeding goals between organic and conventional agriculture. This resulted in cultivars with short straw and consequently, a reduced weed suppression ability and reduced nutrient uptake efficiency (Lammerts Van Bueren et al. 2011). Most of the key informants interviewed agree that Organic Plant Breeding activities cannot be entirely refinanced through seed sales, considering the characteristics of organic farming. These include diverse crop rotations and therefore a high breeding demand for small crop areas. Moreover, many Organic Plant Breeding initiatives are nonprofit organizations that refrain from variety protection and breed with open-pollinated cultivars that can be multiplied by farmers (Wirz, Kunz, and Hurter 2017).

Decentralized farmer-breeders organizations were mentioned as a relevant organizational model using a refinancing strategy via direct sale or short value chains, as well as donations. Small-scale local farmer-based breeding initiatives are ongoing in France (Réseau semences Paysannes), Italy (Rete Semi Rurali), Spain (Red de semillas) and Portugal (Associação Zea Mais). However, scaling up or out such initiatives to supply also long value chains and to a European level would require establishing extensive decentralized structures with a very high degree of voluntary farmer involvement in breeding activities.

Public funding and donations play a significant role in financing companies conducting Organic Plant Breeding. **Public funding** is in general based on research-driven projects (e.g. H2020 DIVERSIFOOD, LIVESEED, ECOBREED and BRESOV), which contribute to breeding research but do not cover the cost for the close-to-market practical breeding work. Although public breeding programmes in Europe have been reduced and replaced by commercial enterprises, they still play a major role in several countries (e.g., Hungary, Romania, Latvia, Italy, Switzerland). However, their engagement in organic breeding is still in its infancy but could be upscaled if political decisions toward independent and sustainable agriculture and food production in Europe were made.

Private foundations with specific funds dedicated to organic breeders, such as *Zukunftsstiftung Landwirtschaft* in Germany, currently play a major role facilitating the activities of the forerunner organic breeding initiatives in Central Europe. However, in many cases, upscaling or scaling out to other countries is difficult as foundations are often committed to specific geographic regions and prefer start-up financing. Available finances also depend on the interest rates of the foundation capital and other arising social challenges. These limitations constrain the sustainable growth of the organic breeding sector across Europe.

Many interviewees listed the involvement of **value chain actors** as a promising financing strategy for scaling up or out as the whole sector is profiting from organic breeding. This distributes the burden of refinancing breeding, now solely carried by breeders and farmers, amongst the value chain partners. There are several examples on a rather small scale where a close collaboration of value chain actors has led to the use of an organically bred cultivar or a cultivar particularly suited to organic conditions and fair compensation of breeders and farmers. These initiatives are described in the following paragraphs. Further, the success factors of these initiatives are explained, as emerged from the interviews.

The *Fair-Breeding®* initiative is an example of a small-scale pool-funding model based on value chain collaboration in Germany, where food trade actors can contribute a percentage of their revenue of organic product sales to fund organic breeding. Value chain actors identify a breeding need and guarantee funding for a 10-year duration. With this fund, three new open-pollinated cauliflower cultivars could be bred since 2008 by Kultursaat e.V. The main marketing channel are organic shops (Wirz, Kunz, and Hurter 2017).

In 2013, the *Organic Seeds Sunflower* initiative was founded by 10 organic companies to support the breeding organizations GZPK and Sativa in developing organic high-oleic sunflower cultivars in Switzerland. Financing was secured through the organic companies joining the partnership (AOT 2020). All supply chain members are involved; farmers, oil producers and distributors, contributed together with the organic breeders at developing sunflower cultivars suitable for organic agriculture. The success factors that could be deducted from these examples are longer-term funding, a clear breeding goal, excellent communication among breeders, and downstream value chain actors, and a marketing strategy (Verrière, Nuijten, and Messmer 2019).

Additional case study evidence from the Netherlands, France, and Switzerland on the introduction of individual disease-resistant apple and potato cultivars into the organic market through value chain partnerships, show the importance of a good communication structure, shared values of value chain actors, and a clear marketing strategy (Nuijten et al. 2018).

However, these funding options are fragmented and by far do not cover the investment needed for organic plant breeding for a broader range of crop species in different European countries (Kotschi and Wirz 2015). Moreover, the annual acquisition and reporting binds resources of breeders and prevents new actors from committing themselves to organic breeding. Therefore, a broader and more sustainable funding is needed for organic breeding, which is vital for the future integrity and development of the organic sector.

The multi-stage stakeholder dialogue comprised of several bilateral meetings and two workshops allowed to consult different organic value chain actors and enriched the information collected with the qualitative interviews. This activity aimed at systematizing the opportunities for integrating organic breeding in value-chain partnerships and developing a strategy for pool funding of organic breeding in Europe (Figure 2).

The central concept of the pool funding is that all value chain partners of the organic sector join forces to invest in organic breeding to secure the integrity

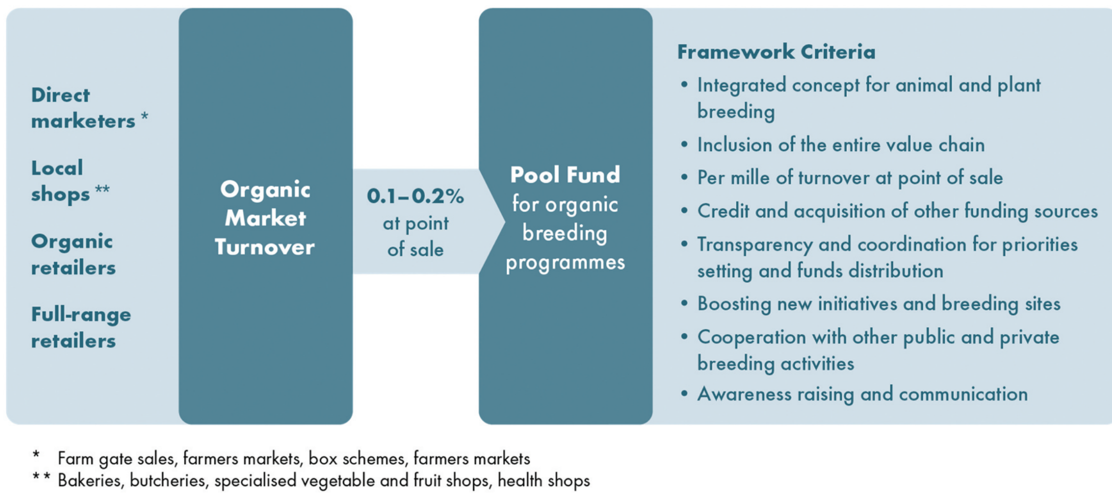

Figure 2. Cross-sector pool funding strategy.

of their future supply. For example, one or two per mille of turnover at the point of sale of all organic products and market chains would feed a pool fund, which is coordinated and distributed to individual organic breeding initiatives (Figure 2). In the following, the framework criteria that emerged from the multi-stakeholder dialogue listed in Figure 2 are further explained.

Integrated concept for animal and plant breeding: The outcomes of the multi-step stakeholder dialogue showed that high demand for organic breeding exists equally in animal and plant production at the European level. Therefore, an overarching pool funding strategy is proposed to facilitate the development of an integrated concept for animal and plant breeding which avoids competition and promotes cooperation between both organic breeding sectors.

Inclusion of the entire value chain: The whole value chain should be involved in the cross-sector pool funding to ensure that the needs of the sector for adequate cultivars and animal breeds are covered and that all actors take responsibility to achieve sufficient funding. Mutual benefits of the pool funding concept for all value chain actors were identified and will have to be clearly communicated when upscaling efforts. Organic breeding can support processors and traders to provide continuous innovation to the market (e.g., with cultivars for a particular use such as grain legumes for meat-free protein meals). The investment on the integrity of the products including breeding and cultivar choice can be used as a commercial narrative to differentiate the organic sector for a long-term investment perspective and for the commitment toward ensuring future food security, food quality and climate robust agriculture. Increase in food diversity, nutritional value and taste of the products are additional aspects that can motivate retailers.

Per mille of turnover at point of sale: Licenses at the product level tend to lead to distortions of competition or disproportionate price increases; therefore, a flat rate at the point of sale is foreseen as a better funding option. Here, extracting a percentage of the organic turnover (similar to a VAT) at the point of sale as engagement from market partners of the organic sector is proposed. An amount in the order of 0.1–0.2% of organic turnover is seen as affordable by food trade actors and has a substantial impact on the financing of organic breeding activities when looking at the European organic turnover. For example, the sales volume of organic products in Germany was 10.9 Billion € in 2018 (Willer, Helga, Bernhard Schlatter, Jan Tràvnìcek, Laura Kemper, and Julia Lernoud. 2020. The World of Organic Agriculture 2020), and 0.2% would amount to 21.8 Million €. With an approximate annual breeding budget need for a new cultivar of 200,000 €, over 100 new cultivars could be produced, if food trade actors in Germany committed to participating in the pool funding concept for around 10 years. An acute breeding need for around 50 plant cultivars and 50 animal breeds was identified during the stakeholder process.

This type of standardized funding would allow a collective pre-commercial investment and long-term commitment of the food industry to facilitate the organic breeding sector in ensuring a constant supply of cultivars and animal breeds.

Credit and acquisition of other funding sources: Existing commitments of organic associations, processors and trading companies in organic breeding through donations or other well-functioning structures should not be curtailed. Moreover, funding contributions already made could be credited (e.g. via blockchain) and included in the transparency management of the pool funding strategy. In addition, more public funding could be attracted, and public-private cooperation could be developed if there is evidence of financial participation by the sector.

Transparency and coordination for priorities setting and funds distribution: Transparency of fund allocation and of the definition of breeding goals was identified as a key factor to a successful upscaling of value chain partnerships in organic breeding. Therefore, an independent coordination office for these purposes should be set up. Value chain actors (traders, processors, farmers, advisors, organic associations) should be involved in the strategic management, and an advisory committee of breeders and experts should be consulted for matching the requirements of all stakeholders in breeding priorities setting and programme selection. Criteria and methods for transparent allocation of funds need to be developed together with independent monitoring protocols of the breeding programmes financed to ensure that impact objectives are achieved.

Boosting new initiatives and breeding sites: In addition to existing initiatives, new initiatives and breeding sites should also be financed, and active promotion of young breeders must be pursued.

Cooperation with other public and private breeding activities: Close collaboration with other public and private breeding organizations to improve performance is advisable. Increased cooperation between organic breeders and breeders who consider organic breeding goals ("BfO"), both in the animal and plant sector, could create positive synergies. By forging and maintaining alliances, e.g. with animal protection organizations, breeding associations and other breeders' initiatives using organic breeding, existing networks can be strengthened, expanded professionally and the efficiency of organic breeding can be boosted.

Awareness-raising and communication: The importance of breeding for ensuring the independence of the organic sector and the integrity of organic products emerged as a crucial framework issue to be addressed. The communication of the commitment toward organic breeding and the reasons for this choice should be shared with consumers. It was suggested by stakeholders that the use of simple slogans, such as "We promote organic breeding", could strengthen the competitiveness and meet customers'

Table 2. Farm-level covariates of respondents of farmer survey for the two groups of short and long value chains.

Conditioning variables	Short value chain	Long value chain
n	**435**	**317**
	mean (standard deviation)	**mean (standard deviation)**
Gender of respondent (female = 1)	0.34 (0.22)	0.22*** (0.17)
Age of respondent (years)	47.9 (11.2)	47.4 (12.9)
Farm size (ln[ha])	2.62 (1.85)	3.96*** (1.44)
Time since conversion to organic farming (ln[years])	2.21 (1.05)	2.22 (0.95)
Received training in the last 10 years (yes = 1)	0.77 (0.18)	0.74 (0.20)
Crop specialization (% of vegetable area, on remaining area, arable crops are grown))	0.54 (0.44)	0.32*** (0.4)
Education of respondent	**n %**	**n %**
None	91 20.9	64 20.2
Apprenticeship	133 30.6	118 37.2
College/university degree	211 48.5	135 42.6

Differences of means tested using a two-sample t-test with equal variances
Significance levels * $p < .05$, ** $p < .01$, *** $p < .001$.

expectations for fully independent organic production without distorting the market.

As a summary, we propose a cross-sector pool funding strategy to support the development of an independent organic breeding sector that addresses the breeding needs of organic agriculture. Identified major success factors are long-term commitment of food trade actors to invest in a pool fund, awareness-raising on the importance of breeding, centralized coordination and administration of the pool fund, and a high level of transparency in the

Table 3. Average treatment effects (**ATE)** of marketing channels on organic seed use, buyer relations and farmers' attitudes toward organic seed using ipwra.

Outcome variables	PO mean of short value chain (VC)	PO mean of long VC	ATE of long VC as compared to short VC	Significance level	ATE as % of PO mean
Organic seed use per farm (Proportion)	0.75 (0.02)	0.65 (0.03)	−0.10	***	−13.3
Farmers' attitude toward the need of organic breeding to improve organic seed use (Agreement 1–5)	3.71 (0.09)	3.72 (0.06)	0.01	n.s.	0
Farmers' perception of buyer expectation to use organic seed (Agreement 1–5)	3.90 (0.13)	3.77 (0.19)	−0.13	n.s.	−3.4
Farmers' attitude toward organic seed to improve integrity of organic farming (Agreement 1–5)	4.42 (0.06)	3.93 (0.12)	−0.49	***	−11.1
Farmers' perception of too high organic seed price (Agreement 1–5)	3.17 (0.15)	3.33 (0.11)	0.16	*	5.1

Note: Significance levels * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in brackets; Agreement scale: 1 = strongly disagree to 5 = strongly agree; PO = Potential outcome process. In the following, these results are complemented with some insights into organic farmers' behavior and attitudes regarding organic seed and breeding according to their main marketing channels. We chose to include these results as farmers have a central role in the development of agricultural value chains, and especially in seed and cultivar choice.

Insights into farmers' behavior and downstream value chain interactions

Farmers are at the center of agricultural value chains and thus, taking into account their perspective is of undeniable importance when analyzing the role of value chain actors on seed and cultivar choice. The two groups of farmers (short *vs* long value chain) in the sample differ significantly in terms of gender, farm size, crop specialization (Table 2), and geographic area (Appendix Table A1). Minor differences were observed for age, training, and education level. Descriptive statistics on the number of crops per farm and location can be found in Table A1.

After the correction of sample imbalance through ipwra, we estimated the average treatment effects (ATE) of marketing channels on farmers' actual use of organic seed and this attitude and perception related to organic seed (Table 3). The most striking difference is that farmers who market to a supermarket, trader, or to a cooperative use 10% less organic seed than farmers marketing directly to consumers (short value chain). On average both groups consider the need for organic breeding as an essential measure to increase the use of organic seed across several important crops (rated as medium to high), with no significant differences between the two groups (Table 3). The farmers' perception of the buyers' expectation regarding their use of organic seed was comparably high for short (3.9) and long value chains (3.8). In contrast, farmers' attitude toward the importance of organic seed for the integrity of organic farming differed significantly between the two groups (Table 3). Farmers' marketing to short value chains strongly agree that the use of organic seed is vital for the integrity of organic farming (4.4 ± 0.06), whereas farmers marketing to longer chains agree significantly less with this statement (3.9 ± 0.12). High priced organic seed is seen as an obstacle by both groups; however, the farmers marketing through long value chains agree significantly more with this statement (Table 3). Results have been confirmed using Propensity score matching. We can thus ensure certain robustness of our results.

Discussion and conclusion

Overall, interviews with key informants and a stakeholder dialogue involving organic breeders and food trade actors revealed that collaboration between food trade actors and organic breeders in the form of a cross-sector pool funding concept could potentially tackle organic seed and cultivar shortage. Based on literature and our interviews some smaller-scale value chain partnership-based solutions already exist and have proved to be successful (Naturata International 2015; Verrière, Nuijten, and Messmer 2019). Furthermore, there is much evidence that close collaboration of agricultural supply chains has a positive impact on their functioning (Altaye and Mohammed 2013; Naspetti et al. 2011). The coordinated strategy that we propose as multi-actor group as result of the stakeholder dialogue would support to overcome the current limitation of segmented donations. A pool funding concept coordinated by the Organic Cotton Accelerator, has already been realized in 2017 for participatory organic cotton breeding ("Seeding the Green Future") supported by the textile industry (e.g., C&A, H&M, Inditex, Tchibo, Eileene Fisher, Kering) (Messmer, Joshi, and Riar 2019).

Moreover, a strategy similar to the pool funding that we propose for the breeding sector is also discussed for addressing other challenges of the agricultural sector in Europe. For example, in Germany a similar concept is proposed for addressing animal welfare issues at the national level (Initiative Tierwohl 2020). However, the current cases of value chain partnership-based breeding strategies are concentrated in Central Europe and focus on single breeding programmes. Tackling these challenges requires increased investments into organic breeding on the European level, shared responsibility along the value chain and a strategy for cross-sector collaboration that allows for pool funding collection and redistribution according to the needs and requirements of the involved actors.

From our interviews emerged, (i) different regional development level of the organic breeding sector (scattered presence of organic breeding programmes), (ii) different organizational and financing models (public sector, public-private cooperation, decentralized participatory programmes), and (iii) different regional importance for current funding sources (research funds, private donations, community contribution in-kind). These differences need to be taken into account to exploit and adapt the cross-sector pool funding strategy in different contexts. Framework criteria of the pool funding strategy might need to be refined for practical implementation, and local adaptation of the strategy for integration based on regional organic sector peculiarities should be considered.

These regional differences may be found at different levels. For example, at national level, the implementation of EU legislation may differ or some marketing channels may be of greater importance than others, e.g., if organic production is mostly exported. Furthermore, some types of organizational models for breeding in organic farming may be more common in some regions than in others (e.g. decentralized farmer-breeder networks in Southern Europe). These aspects need to be identified and incorporated when the pool funding is extended to a new region, e.g., Eastern Europe.

Over the last decades, there has been a reluctance to invest in organic breeding and seed multiplication (Döring et al. 2012). The proposed strategy should also contribute to overcoming this lock-in and facilitate more investment. There is a risk that the most aware actors do not compromise for a long-term, substantial financial commitment assuming that other firms would not join (Ostrom 1998). In a long-term perspective, all actors in the organic value chain can substantially benefit from investments in organic breeding and seed multiplication. However, as long as there are no binding agreements between the actors to invest, they may prefer to maximize their short-term interests. The awareness-raising and communication element of the pool funding strategy is a crucial framework condition to mitigate this risk. The increasing consolidation and dependence on few multinational breeding and seed companies and increased applications of new breeding techniques not in line with organic principles might result in increased consumer demand for organic from seed to fork. Consumers' expectation and buying behavior can have a significant impact on setting priorities for the organic value chain, as our results from the analysis of farm survey data suggest. In order to promote acceptance of a pool funding concept for organic breeding, the other key framework conditions must be met, and the background measures for facilitating collaboration along the value chain put in place. The most important aspects are a clear definition of how funds would be distributed, how the breeding needs and milestones for fulfillment would be determined (according to which rules) and how the property rights of produced cultivars would be managed. Transparent communication and decision structures will have to be established along with the commitment of market players to provide financing resources. Regarding the last aspect, ensuring that the financial burden is not shifted back to other value chain actors is crucial. In Germany, a pilot project began in 2020 to further elaborate and implement such a pool funding model under the guidance of the federal association of organic food industry (BÖLW).

To overcome the organic seed shortage, it is often argued that a phasing out of the derogations would be a sufficient market stimulant. However, earlier attempts at phasing out derogations of non-organic seed either resulted in a severe shortage of organic propagation material and the subsequent need to re-introduce the derogation regime. For example, derogations for juvenile fish in EU organic aquaculture were phased out in 2018 without a sufficient reaction of juvenile fish producers, resulting in a severe shortage of organic juvenile fish (Personal communication with Timo Stadtlander, an organic aquaculture expert). For organic seed in the EU, this was attempted in 2004 and then extenuated into promoting measures at country level as a first step, because a seed shortage was anticipated. Since then, the area organically farmed in Europe has increased dramatically, while the organic seed market has not grown at the same pace, resulting in an increased number of derogations in many countries for many crops (Solfanelli et al. 2019). Hence, the mere phasing out of derogations may not necessarily stimulate seed production enough. On the other hand, this example shows that there is a high level of political insecurity, as policy measures announced by the European commission are not necessarily implemented. This is likely to stop seed producers to invest into organic seed early. Furthermore, this study shows that finding sustainable solutions for an independent organic seed sector seems to include breeding activities targeted at the organic sector, as seed production and breeding are strongly interlinked.

The insights into the effect of value chains organization on current organic seed use back up the need for a pool funding model in the following ways. Firstly, there seems to be an urgency to increase awareness and involve processors, traders, and retailers when developing interventions to increase organic seed and cultivar use: Organic farmers embedded in short value chains use more organic seed compared to farmers using long value chains for marketing their produce. This outcome shows that farmers with closer contact with their end-consumer deem organic seed as an integrity attribute of organic farming. As most organic produce is, however, marketed through long value chains, targeting these value chains is of substantial importance when aiming at increasing organic seed use (Willer and Lernoud 2019). There is further evidence in literature that collaboration in prevailing organic value chains is low, and that the functioning of organic value chains is increased where there is a high level of collaboration and trust, as well as a cost and benefit sharing between value chain actors (Naspetti et al. 2011).

Secondly, the fact that farmers, especially those marketing through longer value chains, stated that the higher organic seed price is prohibitive for organic seed use, shows that the traditional financing strategy of breeding is challenged in organic agriculture. Depending on the crop, organic farmers use 8% to 28% farm-saved seed (Solfanelli et al. 2019) as they have difficulties affording the high priced seed. Thus, a change in attitude and behavior of downstream value chain actors toward supporting organic seed use and organic breeding may be necessary.

Thirdly, organic farmers in Europe, independently from their market channel, advocate for more investment in organic breeding to increase the use of organic seed, as opposed to only phasing out derogations. Thus, the goal of phasing out of derogations for non-organic seed in EU organic agriculture by 2036 (New Organic regulation 848/2018) is more likely to be achieved and to have a successful impact on the whole sector, if translated into an opportunity for implementing a sustainable and independent breeding sector. Therefore, two new types of cultivars, "organic heterogeneous material" and "organic varieties suitable for organic production", are promoted in the New Organic Regulation. Both should contribute to enhanced genetic diversity, disease resistance or tolerance and adaptation to diverse local soil and climate conditions while providing cultivars adapted to the principles and practices of organic farming.

Our findings regarding the influence of marketing channels on organic seed use are in line with former research, indicating that longer chains negatively impact organic seed use (Le Doaré 2017; Levert 2014; Rey et al. 2013). The perception of organic seed as an essential element for maintaining organic farming integrity is supported by a survey conducted in the US, where the highest agreement of all farmers was obtained for this statement (Hubbard and Zystro 2016). The finding that a higher price of organic seed being an obstacle, especially for farmers marketing through long value chains, cannot be confirmed by other studies (Hubbard and Zystro 2016; Levert 2014). However, as the price difference does not count as a viable reason for receiving a derogation, farmers are likely to be hesitant to report it. Looking at breeding and more suitable cultivars as a solution for more organic seed use, farmers often mention a lack of suitable cultivars multiplied under organic conditions in other research (Bocci, Ortolani, and Micheloni 2012; Hubbard and Zystro 2016). These results highlight the link between breeding and multiplication and show that the problem of organic seed shortage is more likely to be solved when also including breeding activities.

As a conclusion, to increase the availability of organic cultivars suitable for organic production for meeting the vision of the new Organic Regulation, a strong organic breeding sector is needed. Our results indicate that organic seed use and farmers' belief that organic seed use is crucial for the integrity of the organic chain are less prevalent in long value chains than in short. Further, the organic seed price is perceived as a stronger obstacle in long chains. Thus, as long value chains prevail in European organic agriculture, an intervention where downstream value chain actors, especially those active in longer value chains, are actively involved in overcoming the organic seed and cultivar shortage seems advisable to stimulate the market from both the supply and demand side. There are successful case studies of value chain supported pool funding for organic breeding for individual crops and breeding initiatives. Still, no examples exist where such a collaboration model between organic breeders and food trade actors has been established at a larger scale, nor has the long-term impact been evaluated. Such an evaluation after the implementation of the model would be a valuable avenue for research in the organic seed and breeding sector.

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Appendix

Table A1: Descriptive statistics of farm level variables of the respondents of the farmer survey

Variables	**Total**	**Short value chain**	**Long value chain**
	mean (standard deviation)	**mean (standard deviation)**	**mean (standard deviation)**
Number of crops per farm	3.715 (1.42)	3.94 (1.36)	3.40 (1.44)
Geographical area	**n %**	**n %**	**n %**
Central Europe	309 41.1	202 46.4	107 33.8
Eastern Europe	130 17.3	69 15.9	61 19.2
Northern Europe	124 16.5	51 11.7	73 23.0
Southern Europe	189 25.1	113 26.0	76 24.0

Table A2: Covariate balance summary of standardized differences between the long and short value chain groups of the farmer survey before (Raw) and after (weighted) applying ipwra

Covariates	**Standardized differences**		**Variance ratio**	
	Raw	**Weighted**	**Raw**	**Weighted**
Gender of respondent (female = 1)	−0.25	0.07	0.78	1.06
Age of respondent (years)	−0.04	−0.08	1.32	0.92
(Age of respondent)^2	−0.004	−0.09	1.28	0.87
Farm size (ln[ha])	0.81	0.22	0.61	1.03
(Farm size)^2	0.661	0.223	0.903	1.02
Years since conversion to organic farming (ln[years])	0.01	0.02	0.82	0.79
(Certification duration)^2	−0.04	−0.04	0.80	0.81
Education of respondent:	0.14	−0.03	1.10	0.98
-Apprenticeship	−0.12	0.11	0.98	1.01
-College/university degree				
Received training	−0.09	−0.06	1.10	1.08
Crop specialization (% of vegetable area (on the remaining area, arable crops are grown)	−0.52	−0.05	0.82	1.03

Study 3: The effects of interventions targeting increased organic seed use – The cases of perennial ryegrass in England and durum wheat in Italy

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Corrigendum: Please note the following corrections: The value of the subsidy in Scenario 8 of the case “Durum wheat in Italy” amounts to 1 €/ha instead of 15 €/ha. This value is mentioned on pages 11 (Table 3), 13, and 17.

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The Effects of Interventions Targeting Increased Organic Seed Use—The Cases of Perennial Ryegrass in England and Durum Wheat in Italy

Eva Winter [1,2,*], Christian Grovermann [1], Stefano Orsini [3], Francesco Solfanelli [4] and Joachim Aurbacher [2]

1 Department of Socioeconomics, Research Institute of Organic Agriculture (FiBL), 5070 Frick, Switzerland; christian.grovermann@fibl.org
2 Institute of Farm and Agribusiness Management, Justus-Liebig University of Giessen, 35390 Giessen, Germany; joachim.aurbacher@agrar.uni-giessen.de
3 The Organic Research Centre, Trent Lodge, Stroud Rd, Cirencester GL7 6JN, UK; steorsini@outlook.com
4 Department of Agricultural, Food and Environmental Sciences (D3A), Università Politecnica delle Marche, 60131 Ancona, Italy; f.solfanelli@agrecon.univpm.it
* Correspondence: eva.winter@fibl.org

Abstract: To meet policy goals targeting increasing the share of organic agriculture, an organic seed needs to be provided. Currently, this is far from being the case. This study investigates two cases of important crop country combinations in organic agriculture, namely perennial ryegrass in South-West England and durum wheat in Italy. A novel multi-agent value chain approach was developed to assess public and private-sector interventions aiming at increasing organic seed use. Phasing out of derogations for non-organic seed comes with 2–7% gross margin losses at the farm level. Seed producers and breeders profit by 9–24%. Mitigating measures can be subsidies of 28 €/ha or price premiums of 12 €/ton at the farm gate for durum wheat, in the case of durum wheat in Italy, and subsidies of 13 €/ha or price premiums of 70 €/ton for lamb meat, in the case of perennial ryegrass in England. Further mitigating measures are the promotion of farm-saved durum wheat seed and investments in breeding for better nitrogen efficiency in organic perennial ryegrass seed production.

Keywords: organic seed; value chain analysis; agent-based modelling; policies; farm to fork strategy

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1. Introduction

The governmental goal to increase the organic land area in Europe has become a priority in the European Union (EU) policy agenda to facilitate a sustainable food system transformation. An example is the Farm-to-Fork strategy of the EU [1], which sets the ambitious goal to increase the organic land area in Europe by 25% by 2030. An essential aspect in the organic value chain that needs to be tackled simultaneously is the increase in organic seed use by organic farmers: a key principle of organic farming is that inputs need to be organic, including seeds. This is an unresolved challenge of the organic sector since organically multiplied seed use remains the norm for a small share of organic farmers. For example, the use of non-chemically treated (NCT) non-organic seeds for important cereals like barley and maize across the EU still lies between 25 and 44%; for legumes like soybean and lucerne, the percentage ranges between 34 and 47% [2]. Addressing the unresolved issues relating to the organic seed sector has become as relevant as the new Organic Regulation (EC/848/2018), which will come into force from 2022 and envisages that all derogations for non-organic seeds will be phased out by 2036 [3].

Insufficient organic seed supply has been a challenge since the implementation of the EU organic regulation in 1992. To mitigate this, a derogation system (This system comprises three different categories in which crop species and sub-species can be classified according to their availability in organic quality: Category I = no derogations are possible; Category II = single derogations are possible if desired cultivars are not available in organically multiplied quality; Category III = a general derogation applies, and the application for the use of non-organic seed is not necessary.) was put into action, allowing farmers to apply for the use of non-organic seeds. Although this permits the EU organic regulation to be functional, it hampers at the same time the development of a market for organic seeds [4]. In 2004, an attempt at phasing out the derogation system was made but not followed through, as the risk of a severe seed shortage was apparent. Although it seems that the organic sector generally acknowledges the need for coordinated interventions [5], it seems unclear which interventions should be preferred.

In this paper, we shed light on the situation regarding organic seeds by focusing on two key crops in two selected countries and the effects of seed system interventions targeting increased organic seed use and production. After a descriptive analysis of the status quo for the two case studies, we simulate and analyse potential policy and market interventions as to their capacity to increase organic seed use and production. We focus on specific crops and countries because the implementation of the EU organic regulation concerning the derogation system regarding the categorisation of species and sub-species differs between countries [4]. The chosen crops and countries are organic durum wheat in Italy and perennial (per.) ryegrass intercropped with white clover in England. These case combinations were selected for their importance in the respective organic crop sectors, i.e., cereals and forage. Although the United Kingdom (UK) is no longer part of the EU and the strategy regarding derogations has not yet been decided upon, the results of this study can still serve as guidance to other countries with a large forage sector and similar climatic conditions. A third case, which is beyond the scope of this paper, involves carrots in Germany; this investigation examines the vegetable sector (for further information, see [6]).

Currently, durum wheat is not in Category 1 in any country and is in Category 3 in Italy. In recent years, there has been a strong increase in derogations for untreated conventional seeds, which is also related to the increase in the area used to grow organic durum wheat. However, throughout the EU, the trend regarding derogations has been increasing disproportionally (+55%) compared to the organic land area (+39%) [7]. Next to the control and command measure of phasing out derogations, some policy schemes are in place which voluntarily support organic seed use and production. The Estonian government supports the use of certified organic seeds for cereals with a 20% premium, with which the EU Common Agricultural Policy (CAP) area payments are topped up for the area where organic seeds are used. In the Czech Republic and Slovenia, similar measures have been put in place. In Lithuania, organic seed production is supported with additional payments under the Rural Development Program (RDP) scheme. In Latvia, training on seed production is offered to organic farmers [8]. For cereal seed production, an additional endorsement of €273 per hectare is paid [7]. Issues arising when targeting increased organic durum wheat seed production and use are the lack of suitable cultivars, pests and diseases in organic seed production (e.g., common bunt), the derogation system itself, and a lack of farmers' training to produce farm-saved seeds [7]. One prospect to make organic seed use more attractive could be the promotion of cultivars specifically bred and thus particularly suitable for organic agriculture. An example of such a cultivar group is Organic Heterogeneous Material (OHM). Some studies show that OHM can have high yield stability and low external input needs, making them particularly suited for low input systems [9,10].

As for the forage sector, forage crops are normally sown as mixtures, but there is not a common rule across Europe: some countries consider the organic content in the seed mixture as a whole, whilst others consider the organic content of each seed component individually. In most countries such as the UK, Switzerland, France, Germany, and Belgium, it is currently sufficient that an established share of seeds in the forage mixture is organic (usually 70%) for the whole mixture to be considered organic. Perennial ryegrass is in Category 1 only in Belgium, whereas no country has placed white clover in Category 1. Perennial ryegrass is widely used in forage mixtures across Europe. It is often mixed with clover species. Data on derogations are provided as pooled data with derogation data for Italian ryegrass. The aggregate data indicates the highest increase in derogations (ca. 90%) for the two crops from 2014 to 2016 within the European forage sector [7]. Production of organic forage seed is very limited in the United Kingdom, and most organic forage seed is imported from Denmark and the Netherlands [7]. White clover in forage mixtures is widely used across Europe too. Data on derogations, aggregated with red clover, indicate a substantial increase of 72% from 2014 to 2016 [7]. Mentioned challenges that hamper the increase in organic seed production and use are lower seed yields, less nitrogen efficiency, and high prices for organic perennial ryegrass seed, compared to NCT. Additionally, political insecurity concerning a potential phasing out of derogations is an issue. Lastly, crops with a small share in mixtures are judged to be economically unviable to be produced in organic quality [7]. The above-mentioned measures and bottlenecks serve as examples for interventions towards increased organic seed use and production.

The evidence laid out above shows that challenges and, at the same time, promising interventions to boost organic seed production and use are found at different levels of the value chain, namely breeding, seed multiplication, farming, food industry, and governmental level. Thus, a value chain perspective and analysis approach are needed to test these interventions. Furthermore, a quantitative ex-ante approach can deliver a sound economic assessment of different seed and breeding value chain interventions. Results based on simulation models far outweigh the accuracy of extrapolation from existing data [11]. Lastly, the decision-making of actors in the seed and breeding value chain, e.g., which seed to use or produce, seems vital to analyse which intervention would trigger such an uptake. The present study aims to close the knowledge gap on such methods, which are lacking in the current science of analysis of value chains [12,13].

We, therefore, developed a systematic ex-ante value chain approach based on simulation modelling and economic decision-making to assess the effects of interventions aiming to increase organic seed use and production. Moreover, as individual actors with competing interests make the most relevant decisions in the seed and breeding value chain, we depict those actors in a simplified multi-agent system. To summarise, this study addresses a dual research gap: first, it presents a novel approach for quantitative ex-ante value chain analysis; second, this approach is applied to test interventions aiming at increased organic seed use and production, a topic where little information is currently available, and which is of growing importance in the light of changing policies. This study is, to the best of our knowledge, the first to model these issues in a systematic way to provide actors with advice on the consequences of interventions in the organic sector.

The following section explains the model development in further detail, and data collected for the agents and interventions are considered. The modelling results are then presented. A discussion of the results and their implications on the organic seed sector closes the paper.

2. Materials and Methods

2.1. Conceptual Framework of Modelling Approach

Europe's organic seed value chain usually comprises five to seven stages, i.e., breeding, seed multiplication, seed trading, farming, processing, wholesale, and consumption, mainly depending on the crop of interest. For the simulation model, we focus on three value chain stages: breeding, multiplication, and farming, as they are likely to be the stages where the most important decisions take place. As a result, the following decisions taken at these three stages are modelled endogenously:

- Farming stage: crops grown in the crop rotation and type of seed used, i.e., NCT/organic seed, and from organic cultivar in some cases.
- Multiplication stage: type of seed and amount produced, i.e., NCT/organic seed, and from organic cultivar in some cases.
- Breeding stage: the amount of basic seeds for conventional, NCT, or organic seeds produced and marketed.

Policy and food industry measures such as an introduction of a subsidy, or the decision of the food industry to pay a higher product price, have been included as exogenous factors in the model through scenarios. As regards the individual actors at each value chain stage, only the enterprise processes for either wheat or forages are modelled as opposed to the entire farm or company. This is most suitable for this model, as it is more resource-efficient and focuses on relevant business branches and activities.

2.1.1. Decision Making of Actors

Breeding, seed production, and farming are activities conducted by actors driven by economic considerations. Therefore, for each actor in the chain, a mathematical programming-based algorithm is implemented with the goal of optimising individual agents' gross margins. We consider that gross margin optimisation as the main decision-making driver is a valid assumption for the two cases at hand.

Mathematical Programming (MP) is used to simulate economically sound decisions within a process [14–16]. An example for a simple linear programming (LP) model (Equations (1)–(3)), as implemented for the value chain actors in this study, is demonstrated below:

$$\text{Objective function (Gross Margin): max! } z = \sum_j c_j\, x_j \tag{1}$$

$$\text{Side constraint: } \sum_j a_{i,j}\, x_j \leq b_i \text{ for all i} \tag{2}$$

$$\text{Side constraint: } x_j \geq 0 \text{ for all j} \tag{3}$$

The objective value is 'z', in this case, the gross margin that is maximised as the sum product of 'c' and 'x'. The activities are represented by 'x' (such as growing different crops, buying inputs, etc.), and 'c' represents costs and revenues of activities over the index 'j', indicating the different possible activities. The objective function is subject to several side constraints, represented by inequalities of the products of activities and technical coefficients 'a' (e.g., the amount of labour needed for one hectare of growing potatoes) and 'i' given resource endowments b (e.g., land or labour endowment).

Optimised objective values for the farming and seed-producing agents are the gross margins of organic carrot production and other crops in the crop rotation at the farm level and gross margins of carrot seed production at the seed multiplication level. At the breeding level, breeding agents optimise their breeding budget. The breeding budget is 10 to 30% of the seed sales revenue, depending on the typical actor. The yearly breeding budget enters the model as objective value at the breeding level because the typical breeding actors we identified do not consider the gross margin at the breeding level but require a constant breeding budget for research and development [6,17,18].

Exemplary LP decision tables for agents of each value chain level can be found in the Appendix C, Tables A4–A6. An LP decision tableau is a standard method to represent sets of equations in an LP model [14]. In these tableaux, decision variables ('x') are shown in the first line, parameters representing technical coefficients ('a') can be found starting from column 4, line 5, farm gate prices and costs ('c') (e.g., last two lines), and right-hand side values ('b') (last column) are indicated. Values in round brackets are adjusted inside the model. Bold values are agent specific. The tables give a comprehensive overview of the type of data used in the model, as well as on the variability of parameters.

2.1.2. Interactions between Value Chain Stages and Actors

The simulation model is time-dynamic so that we can observe developments over time. Eight modelling years are considered, which makes it possible to realistically model e.g., a stepwise phasing out of derogations. Interactions between actors of different value chain stages are based on sales of basic seeds. Compatibility of market sizes between the different value chain stages is ensured through scaling factors, which consider economies of scale. Furthermore, adaptive expectations [19] are implemented at the basic seed and seed production levels. The seed producers and breeders adapt their sales expectations and their basic seed and seed for farmers production based on former experiences. For this, growth expectation factors need to be calculated. These factors contain the value by how much seed production can be increased after one modelling year, based on how much was sold in that year. The growth expectation factors to allow seed producers to meet organic seed demand have been obtained by a calibration process. In the case of durum wheat, the seed producer can, at most, triple their production in one year, while the perennial ryegrass seed producer can double their production each year. This calibration was conducted using scenario 2 *[Derog]* (for more information, see Section 2.6, scenario development). This can be justified by seed expert judgment that organic seeds could match demand in a stepwise phasing out derogations scenario to leave enough time to identify suitable cultivars for organic seed production. This calibration was then used for the further scenarios, as the pace of the sector development can be assumed to be similar.

A sensitivity analysis was conducted by letting the model run ten times per scenario with different seed values and triangular distributions of crop yields (wheat case, no data available for per. ryegrass case) and prices (wheat and per. ryegrass case). The input data for these distributions can be found in the Appendix A, Tables A1–A3. A basic chart of the value chain model can be seen in Figure 1. This chart shows the different decision levels and feedback loops in one modelling year.

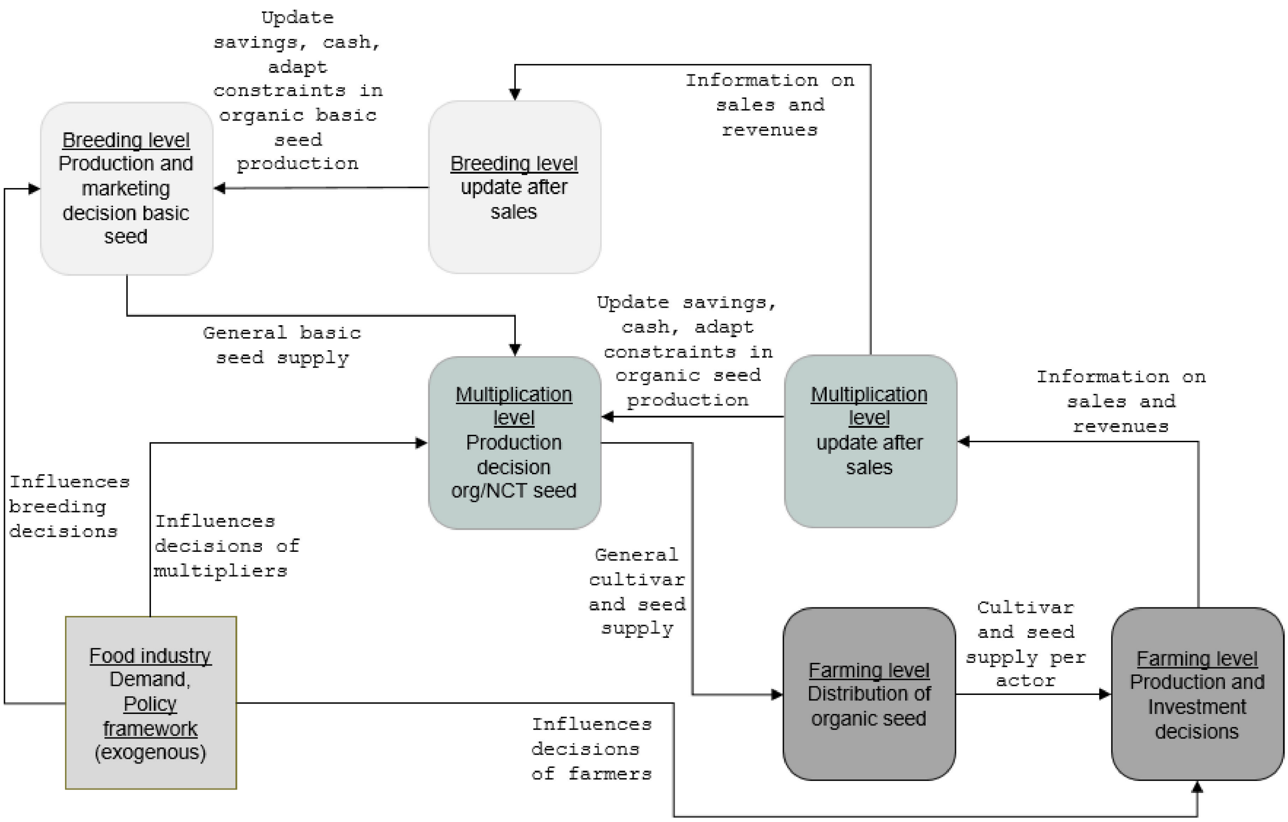

Figure 1. Conceptual chart of value chain simulation model.

2.2. *Typical Actors at Farm Level*

As data availability at the farm level for durum wheat in Italy and perennial ryegrass in England was limited, the published and established typical farm approach used by the *Agri Benchmark* network managed by the Thünen Institute of Farm economics was used to identify two typical production systems per case study crop [20,21]. "Typical" can be described also with "representative" or "most common". This means the described typical farm exists in reality and is not e.g., an artificial average of all farms [21]. In statistical terms, this is called the mode; the farm type that occurs the most in a distribution [22]. Moreover, we established that at least approximately 50% of the focus crop should be produced on these farm types in the selected regions.

This approach has several advantages over other commonly used approaches. For example, the issue of particularities and lack of generalization of individual farm data with small or biased samples can be avoided [21]. Furthermore, it mitigates the issue of aggregation bias that occurs when using average data for model parameterisation [22]. Generally, the approach strives to combine sufficient data depth, consistency, and accuracy with reasonable time and resource input for data collection [21].

We endeavoured to test the effects of policy and market interventions on typical organic producers, covering at least the minimum of heterogeneity represented by two different production systems for each of the two case study crops. To identify typical production systems, the Standard Operational Procedure (SOP) as proposed in the typical farm approach was applied as far as the identification and data collection of farm types are concerned.

Firstly, regions and production systems were selected according to the following criteria. A relevant region is a region with a large share of the agricultural area dedicated to producing the focus crop or a high density of farms that produce the crop. More precisely, the three indicators were considered to identify the area:

- Total area (ha) of organic focus crop production in the region.
- Share of organic focus crop area of total agricultural farm area in the region.
- Share of organic focus crop area per 100 ha surface area in the region.

One medium-sized and one slightly larger enterprise, both with gross margin or sales revenue per focus crop farm enterprise close to the average of the farm population, were chosen. For all the above-mentioned points, we proceeded hierarchically, i.e., starting with the most specific (e.g., area of perennial ryegrass), and if this data was not available, we verified the area of ryegrass in general, and so on. Subsequently, the further steps of SOP data collection, data processing, and data cross-checking were conducted. The main criteria after the identification of the regions where most of the focus crops are produced were typical farm size, typical crop production system (crop rotation, input use), and typical marketing channels. A more detailed description of the chosen typical systems can be found in Section 2.5.

2.3. Defining Typical Companies and Initiatives at Seed Production and Breeding Levels

In both cases, typical breeding and seed production entities were identified. The approach to depict typical processes was selected considering data availability and the limited willingness of actors to share financial data. We defined a typical entity as a company or initiative with a large market share in organic seed production and, if existing, organic breeding. Typical economic entities were chosen as opposed to average entities to avoid aggregation bias. Here, again, the mode of the distribution of existing firms, as opposed to an artificial average firm, is identified [22]. Companies and initiatives that differ in size, target market, financing strategy for organic breeding can be observed. The firm with the most common combination of these criteria (mode) was chosen from these types.

2.4. Data

Typical farm data was collected through a series of stakeholder and expert interviews between 2017 and 2020. Data from the Italian and English Farm Accountancy Data Network (FADN) was reviewed and integrated, where appropriate (e.g., farm sizes and crop areas). Similarly, typical breeding and multiplication data were obtained through stakeholder and expert interviews between 2017 and 2020. An overview of the seed and breeding value chain landscape of Italian organic durum wheat and English organic perennial ryegrass production was obtained through a value chain mapping with the help of expert interviews.

In the case of Italy, this mapping revealed that several medium-sized companies and cooperatives are involved in providing seed for Italian organic durum wheat production. Two breeding and seed production companies shared detailed information on costs and revenues, inputs and outputs of durum wheat breeding and multiplication, as well as bottlenecks in seed production, promising breeding goals, and scenarios to boost the organic seed and breeding sector.

In the case of South-West England, the value chain actor mapping showed that around eight companies are involved in providing seed for organic ryegrass growers (sheep farms). These companies exhibit similar characteristics, so one typical company for the sector in England was identified [7]. The identified companies and initiatives were contacted for interviews. One internationally active breeding and seed production company with a significant market share in the UK in perennial ryegrass seed production shared detailed information on costs and revenues, inputs and outputs of breeding and multiplication, as well as bottlenecks in seed production, promising breeding goals, and scenarios to boost the organic seed and breeding sector.

2.5. Case Study Description

2.5.1. Case 1, Durum Wheat in Italy

Durum wheat was chosen as a case study focus crop since it is the key cereal crop produced in the Italian organic sector with an extensive production area. In Italy, most seed demand by organic farmers is met by untreated conventional seed, especially for the most widespread arable crops, particularly durum wheat. The major providers of seed and cultivars for the organic sector are international players, medium-sized breeding and seed producers that are most active in Italy, and, to a limited extent, public institutions. Farm saved seed plays a role as well as seed provision through farmers' associations [7]. The area of organic durum wheat production in Italy amounts to around 141,129 ha [23]. According to an estimate, about 40% of the organic farmers in Southern Europe declare to use their own seeds as a principal source of cereal seed for their farms [24]. More detailed data for the case of Italy and durum wheat was not available at the point of time of our data collection.

Farming: Based on the available data provided by the Italian (IT) Ministry of Agriculture, two farms were selected: one typical farm for Southern and Central Italy. Based on the available data provided by the Italian (IT) Ministry of agriculture, two main criteria were used to select regions and locations. First of all, the IT regions in which the major part of organic cereals is produced were identified. For this, regional distribution of organic land under cereal production (%) was generated. Most of the organic cereal land is located in the Southern and Central parts of Italy, with three regions (Apulia, Sicily, and Basilicata) covering almost 50% of the total land dedicated to organic cereal in Italy. We also considered the regions with little organic cereal agricultural land but a high degree of specialisation in organic cereals production, which were identified based on the share of organic cereal in the total agricultural land (%). The most critical regions are Basilicata, Sicily, Apulia, Marche, and Tuscany. Based on the results reported above, two main IT macro-regions were identified for our analysis: macro-region 1, which includes two neighbouring regions located in the Southern part of Italy (Apulia, Basilicata), and macro-region 2, which includes two regions in Central Italy (Marche and Tuscany). Once the macro-regions were identified, we explored three main parameters related to the production system: farm size, main enterprise, and farm performance. The chosen Southern Italian farm has a 60 ha total farm size. This is the typical size for the chosen region, it is however relatively large compared to Italian farms in other regions. The crop rotation is narrow: durum wheat, faba bean, durum wheat, chickpea, green manure, durum wheat. The share of durum wheat can reach up to 50% of the farm's agricultural area. The main marketing channel is selling to four or five big pasta manufacturers. In organic pasta production, one big company dominates the market, and there are also a few smaller organic pasta makers.

Regarding the Central farm type, the farm size is smaller and the crop rotation wider. The medium-sized farm is about 30 ha. The typical crop rotation includes alfalfa, emmer, faba bean, durum wheat, sunflower, soft wheat, clover, and chickpea. Land for durum wheat represents around 6 ha. The typical central farm type is more likely to be associated with cooperatives. There are two particularly successful cooperatives in encouraging organic seed use that have the following measures in place: (a) collective seed purchase reducing seed price, and (b) a pre-financing scheme where seed costs have to be paid only once the durum wheat has been sold. These measures increase farmers' liquidity. Other administrative burdens are also taken from farmers and organised collectively, such as choosing appropriate cultivars [25].

Seed multiplication: The organic arable seed sector is characterised by small to medium-sized companies that multiply organic seed and sell it to retailers or directly to farmers' cooperatives. In some cases, the same company also undertakes breeding, which is often observed for medium companies handling soft and durum wheat (examples can be found in Denmark, Germany, and Italy) [7].

The chosen company type for the simulation model for durum wheat seed production has the following profile according to the criteria defined in Section 2.3. The governance model is a shareholder-owned company, and its financing strategy for seed and breeding is re-financing its breeding activities through commercial seed sales. The target market is primarily national. Not chemically treated and chemically treated organic seed is produced. It has an integrated breeding department. More information on the seed production and breeding type can be found in Appendix B.1.

2.5.2. Case 2, Perennial Ryegrass in England

Forage crops (grass, clover, and herbal crops) represent an important crop sector in the UK, with temporary pasture being the second most important crop grown after permanent pasture, on about 92,000 ha and 330,000 ha, respectively [26]. The production of organic forage seed is limited in the United Kingdom. Most organic forage seed is imported from a few foreign companies operating internationally. Furthermore, organic breeding and breeding for organic in the forage sector is very limited. Conventional breeding is conducted by the private and public sectors alike.

In this case study, an intermediate product in the form of forage is investigated, meaning that there is no farm gate price of the product, i.e., perennial ryegrass, used to feed livestock. Changes in the farm-gate price for milk or meat or the price of alternative feed sources can be used to model farmers' decisions. In this case, we use the price for organic lamb meat. Ryegrass was considered and modelled in a less complex mixture with white clover, often used in England's rotational grazing. More information on the procedure can be found in Appendix B.2.

Farming: Farmers usually grow mixtures of several forage species and varieties, making it challenging to find organic seed for all the crop species and varieties needed in the mixture. We decided to focus on perennial ryegrass grown in a mixture with white clover since, based on expert interviews, perennial ryegrass is one of the most common grasses grown throughout the UK. It is most likely to find organic perennial ryegrass in the South West of England because of the high concentration of organic farms and pasture [26]. Therefore, the main counties considered are Devon, Dorset, Somerset, and Cornwall. The total organic grazing area in these four counties amounts to around 6000–7000 ha, and the number of organic sheep farms is about 500–600 with a total of 200,000 sheep [26]. We adopted an established system for this study to discriminate the grazing farming systems, which distinguished between lowland (LL) and upland (UL) grazing systems. The main differences between the two chosen typical sheep meat production systems are the following. The typical LL grazing system has a farm size of 88 ha, of which 81 ha is dedicated to grazing. It holds 73 grazing livestock units. The typical UL grazing system has a farm size of 194 ha, of which 176 ha is dedicated to grazing, holding 126 grazing livestock units. LL grazing systems have a higher seed need than UL grazing systems as they need to be re-planted every three years, whereas UL can be re-planted after five years. Furthermore, organic lamb meat produced in UL grazing systems can obtain a slightly higher price than lamb meat produced in an LL grazing system. Both systems are common in the chosen area and thus are represented in the simulation model.

Seed multiplication: The company considered in this study for data collection and modelling for ryegrass seed production has the following profile according to the criteria defined in Section 2.3. The governance model is a shareholder-owned company, and its financing strategy for seed and breeding is re-financing of own breeding activities through commercial seed sales. The size of the company is large, and its target market is international. Not chemically treated and chemically treated organic seed is produced in the breeding department. More information on the seed production and breeding type can be found in Appendix B.2.

2.6. Scenario Development

Promising scenarios were identified during stakeholder interviews in the period of 2018 to 2019 and a workshop with organic crop experts for the respective cases for scenario development [7]. Scenario identification, assumptions, and data collection for scenarios were part of the stakeholder interview, as explained in more detail in Section 2.4. The chosen scenarios per case and the assumptions that are made are as follows:

Durum wheat:

- Stepwise phasing out of derogations for the use of non-organic seed at farm level (one-year steps) ***[Derog-Wheat].***
- Organic durum wheat farm gate price premium per ton of organic seed use at farm (product) level ***[Prce-Wheat].***
- Subsidy for organic seed use at farm (hectare) level ***[Subs-Wheat].***
- Promoting organic farm-saved seed use ***[SavedS].***
- Promoting the use of organic heterogeneous material (OHM) and testing a price premium with the option to use OHM ***[OHM].***

Perennial ryegrass:

- Stepwise phasing out of derogations for the use of non-organic seed at farm level (one-year steps) ***[Derog-Forage].***
- Organic lamb meat farm gate price premium per kg for organic seed use at farm (product) level ***[Prce-Forage].***
- Subsidy for organic seed use at farm (hectare) level ***[Subs-Forage].***
- Breeding goal "10% organic seed yield increase": Investment in breeding for higher nitrogen efficiency at perennial ryegrass seed production level, e.g., funded through a public-private partnership ***[HseedY].***

For each scenario, some assumptions were made, as shown in Tables 1 and 2 below:

Table 1. Scenarios and assumptions of Case 1.

	Scenario	Assumptions
1.	Baseline ***[Bsl-Wheat]***	
2.	Stepwise phasing out of derogations at farm level to use organic seed ***[Derog-Wheat]***	Adaptive expectations mechanism: Growth expectation factor equals 3 Stepwise phasing out of derogations for NCT seed Yearly steps: Year 1: 80% NCT seed allowed per farm, year 2: 50%, year 3: 30%, year 4: 0%
3.	Organic durum wheat farm gate price premium per ton for organic seed use ***[Prce-Wheat]***	Adaptive expectations mechanism: Growth expectation factor equals 3 Different levels of price premiums are tested. The goal of this process was to identify price premium levels that induce farm agents to adopt organic seed
4.	Subsidy for organic seed use at farm (ha) level ***[Subs-Wheat]***	Adaptive expectations mechanism: Growth expectation factor equals 3 Different levels of subsidies are tested. The goal of this process was to identify subsidy levels that induce farm agents to adopt organic seed

Table 1. *Cont.*

	Scenario	Assumptions
5.	Promoting organic farm saved seed use ***[Bsl-Wheat] + [SavedS]***	Own seed production at farm level is possible with a seed replacement rate of 0.3
6.	Scenario 2 *and* 5 ***[Derog-Wheat] + [SavedS]***	No new assumptions
7.	Scenario 3 *and* 5 ***[Prce-Wheat] + [SavedS]***	No new assumptions
8.	Scenario 4 *and* 5 ***[Subs-Wheat] + [SavedS]***	No new assumptions
9.	Promoting organic farm saved seed use in OHM ***[Bsl-Wheat] + [SavedS] + [OHM]***	Own OHM seed production at farm level is possible with a seed replacement rate of 0.3
10.	Scenario 3, 9 and 12 ***[Prce-Wheat] + [SavedS] + [OHM]***	No new assumptions

The unique scenario names are bold and in italics.

Table 2. Scenarios and assumptions of Case 2.

	Scenario	Assumptions
1.	Baseline ***[Bsl-Forage]***	
2.	Stepwise phasing out of derogations at farm level to use organic seed ***[Derog-Forage]***	Adaptive expectations mechanism: Growth expectation factor equals 2 Stepwise phasing out of derogations for NCT seed Yearly steps: Year 1: 80% NCT seed allowed per farm, year 2: 50%, year 3: 30%, year 4: 0%
3.	Organic lamb meat farm gate price premium for organic seed use ***[Prce-Forage]***	Adaptive expectations mechanism: Growth expectation factor equals 2 Different levels of price premiums are tested. The goal of this process was to identify price premium levels that induce farm agents to adopt organic seed
4.	Subsidy for organic seed use at farm (ha) level ***[Subs-Forage]***	Adaptive expectations mechanism: Growth expectation factor equals 2 Different levels of subsidies are tested. The goal of this process was to identify subsidy levels that induce farm agents to adopt organic seed
5.	Condition "10% organic seed yield increase" ***[Bsl-Forage] + [HseedY]***	Farm level: Seed price reduction of 8.7% for the organic mixture Multiplication level: Accomplishment of 10% seed yield increase of organic perennial ryegrass seed as a breeding goal
6.	Scenario 2 *and* 5 ***[Derog-Forage] + [HseedY]***	No new assumptions
7.	Scenario 3 *and* 5 ***[Prce-Forage] + [HseedY]***	No new assumptions
8.	Scenario 4 *and* 5 ***[Subs-Forage] + [HseedY]***	No new assumptions

The unique scenario names are bold and in italics.

3. Results

The modelled organic crop area is held constant over the eight years modelled so that effects of interventions can be compared to the baseline without having to account for crop area increase. Thus, the effects of a growing organic area are excluded from the following results presented.

The results on gross margins and breeding budgets presented in this section are calculated from the last three years modelled (years six to eight). The organic seed amounts indicated are also the averages of these years.

The levels of subsidies and price premiums were calculated in an iterative process of simulation model results. This process aimed to identify subsidy and price premium levels that would lead farm agents to adopt organic seed or cultivars.

3.1. Modelling Results of Case 1, Durum Wheat in Italy

Scenario 1: Baseline.

We use a simplified model including only two farm agents. Thus, we implemented a baseline of zero organic seed use for both farm agents. This represents the majority of farms, as around 65% NCT seed is used across the farm population of the overall seed use. The average yearly gross margins (GM) at the farm enterprise level is € 26,528, the yearly average gross margin at multiplication level for conventional untreated seed (seed production only, excluding processing and marketing, etc.) is € 247,208, and the average yearly breeding budget for durum wheat is € 248,477. These figures are close to the figures collected from the companies and thus act as realistic baseline values to compare scenario outcomes. In Table 3, the results of different scenarios can be seen relative to the baseline.

Table 3. Summary of results using key outcome variables for Case 1.

	% Δ GM/Farm Enterprise	**% Δ GM/Seed prod. org. Seed and NCT Seed**	**% Δ Breeding Budget Organic, NCT and CT Seed**	**% Δ Organic Seed Use**	**Costs of Intervention in €**	**Cost Effectiveness (Ton Organic Seed/€)**
Scenarios (#)	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
Without farm saved seed						
Stepwise phasing out of derogation (2)	−1.54%	14.82%	10.44%	100.00%	n/a	n/a
Organic seed price premium (12 €/t) (3)	5.75%	15.87%	10.44%	100.58%	2,465,428.62	0.01
Subsidy (28 €/ha) (4)	21.19%	17.76%	10.23%	101.12%	1,937,063.92	0.01
Farm saved seed with a 3 year replacement rate with organic seed						
Stepwise phasing out of derogation (6)	−2.52%	10.38%	10.44%	98.23%	n/a	n/a
Organic seed price premium (0.3 €/t) (7)	0.47%	9.33%	10.39%	99.24%	63,848.18	0.24
Subsidy (15 €/ha) (8)	0.47%	9.33%	10.39%	99.24%	63,848.18	0.24
Introducing OHM as innovation						
OHM price premium on durum wheat with own farm saved seed use (13 €/ton) (9)	18.99%	110.77%	13.86%	96.67%	1,152,591.70	0.01

Scenario 2: Command and control approach to derogation phasing out.

If derogations were to be phased out in three steps (Year 1: 80% NCT seed allowed per farm, year 2: 50%, year 3: 30%, year 5: 0%), the farmers would still have to bear the burden of additional seed costs. This would cause an average 1.5% loss in gross margin at the farm enterprise level. If 100% organic seed is achieved, the typical seed producer has an increase in gross margin by 15% and the breeding department by 10%. The estimated development of the organic durum wheat seed taken up under such a derogation scheme can be seen in Figure 2. The results shown in this figure are scaled up to the regional level and therefore need to be considered cautiously, as we only modelled the decision-making of the two typical farms.

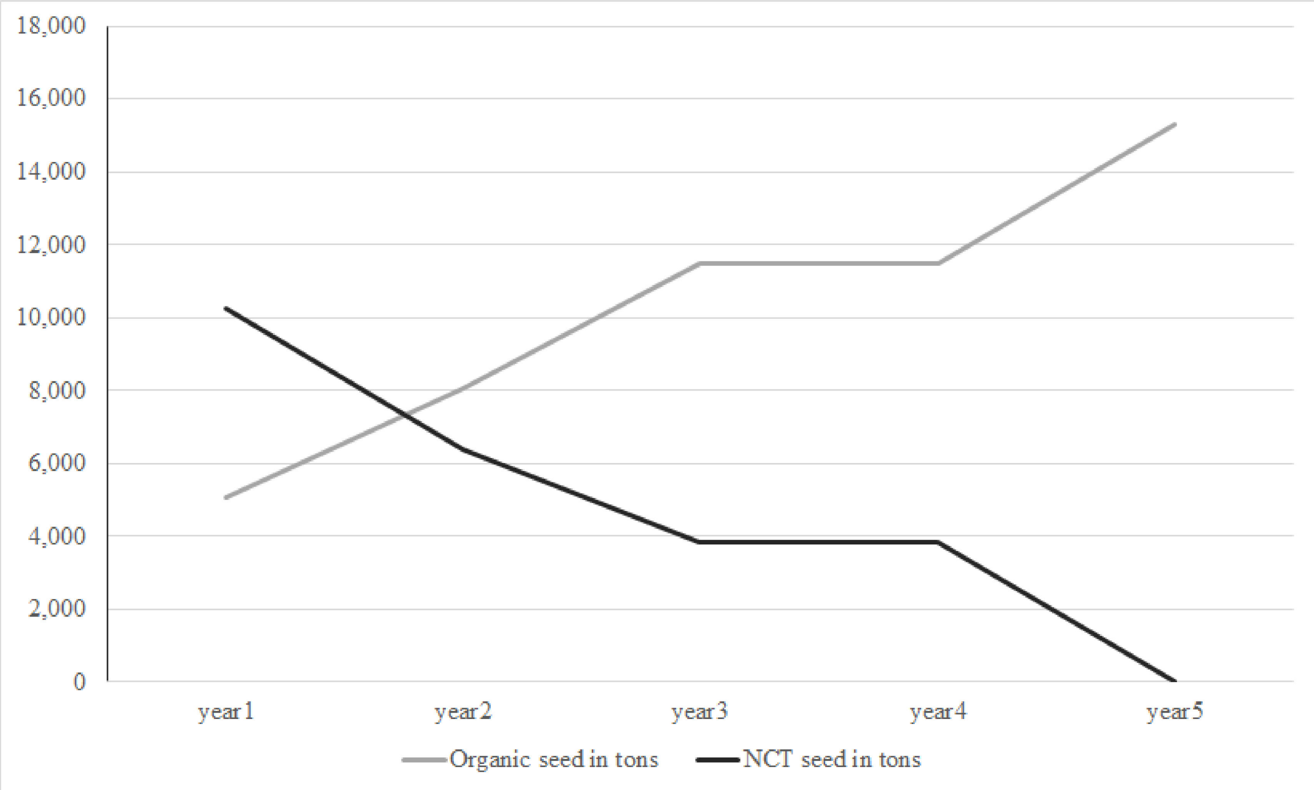

Figure 2. Scenario 2: Development of organic seed use in a modelling period of five years under a stepwise phasing out of a derogations scheme.

Scenarios 3 and 4: Voluntary measures to incentivise organic farmers to use organic seed.

Measures to support farmers to bear the additional costs for organic seed in the short term can be increasing farm-gate prices or providing farm subsidies. The outcomes of these scenarios can be seen in Table 3, rows 2 and 3. With a €12 increase per ton of organic durum wheat sold, both farm types would be compensated for the additional seed costs.

The same effects along with the durum wheat seed and breeding value chain are obtained with an area subsidy for using organic seed of €28 per hectare for both farm types. Regarding the cost-effectiveness of these interventions, on average, 7.7 kg per € subsidy can be incentivised, up to 100% organic seed use by both farm agents considered here.

These measures could smooth a transition to 100% organic durum wheat use. There are no losses because of seed shortages. According to the expert interviewed, organic durum wheat seed production is not substantially restrained by technical difficulties. However, some time needs to be allowed to find suitable varieties for organic agriculture, so an immediate 100% phasing out is not advisable.

Scenario 5: Farm saved organic seed.

Farm saved seed is an essential part of the strategy to obtain 100% organic seed. This is especially relevant in crops where farmers' own seed production is relatively straightforward, such as many kinds of cereal. However, pests and diseases like smut in cereals pose some challenges for on-farm seed production. Training for own seed production, pest management, and promotion of smut-resistant cultivars should be considered. On-farm seed production represents a realistic option to decrease costs for farmers and boost organic seed use. If appropriate measures are taken, farmers would have the know-how to manage pests and diseases and the necessary processing and storage facilities.

Within the model, if the two typical farms are given the option to produce and use farm-saved seed, both types produce their own seed. As we assumed a seed replacement rate of around 0.33 (see Table 1), the typical farms buy the necessary seed from the seed and breeding actors, choosing NCT seed. The average yearly gross margin (GM) at the farm enterprise level is €26,695, which is slightly higher than the baseline value without the option to use and produce farm-saved seed. The yearly average gross margin at multiplication level for conventional untreated seed (seed production only, excluding processing and marketing, etc.) is €247,208, and the average yearly breeding budget for durum wheat is €248,477. These figures are close to the figures collected from the companies during interviews. The figures are thus realistic baseline values against which scenario outcomes can be compared.

Scenario 6: Command and control approach for non-organic seed use with the option for the farmer to save own seed (farm-saved seed).

If derogations were to be phased out in three steps (Year 1: 80% NCT seed allowed per farm, year 2: 50%, year 3: 30%, year 5: 0%), the farmers would have to bear the burden of additional seed costs, which would amount to an average of 2.5% loss in gross margin at the farm enterprise level. Even though this loss through organic seed use is bigger in percentage than the loss through organic seed use without own seed production, the total gross margin is nevertheless higher with own seed production. If 100% organic seed is obtained, the typical seed producer and the breeding department both have a 10% increase in gross margin.

Scenarios 7 and 8: Voluntary measures to incentivise organic farmers to use organic seed when promoting farm-saved seed with organic seed.

Measures to support farmers with the additional costs in the short term can be increasing product prices or providing farm subsidies. The outcomes of these scenarios can be seen in Table 3, rows 5 and 6. With a €0.3 increase per ton of organic durum wheat sold, the farms would be compensated for the additional seed costs.

The same effects along with the durum wheat seed and breeding value chain could be obtained with subsidies for using organic durum wheat basic seed and producing their own organic seed of €15 per hectare for both farm types. Regarding the cost-effectiveness of these interventions, 0.24 tons per € subsidy on average can be incentivised up to 100%.

Scenario 9: Introduction and promotion of Organic Heterogeneous Material and farm-saved seed.

A further proposed intervention is the encouragement to use organic heterogeneous material (OHM). OHM is broadly defined in the New Organic Regulation 2018/848/EU as 'material with a high level of genetic diversity, intended for the market and for which DUS criteria (Distinctness, Uniformity, and Stability) are not applicable (New Organic regulation 848/2018). OHM is generally more resilient in low input systems, as there is high yield stability and fertilisers are unnecessary. According to our case study data collection, however, overall yields associated with OHM are 10% lower than the yield of prevalent non-OHM cultivars. It is supposed that farmers choosing OHM would save their own seed for re-planting. Furthermore, it seems most realistic that a price premium for OHM seed use would be implemented by a trader or a cooperative instead of a subsidy implemented by the government. The results from the modelling of this scenario in Table 3, row 7 show that, if farmers were to produce OHM seed themselves, a price premium for OHM durum wheat of € 12 per ton (with a seed replacement rate of 0.3) would be sufficient to incentivise farmers to use OHM seed. For seed producers, this would mean a substantial increase in gross margin (Table 3, row 7, column 2), which makes producing OHM seed quite attractive if the two typical farms are incentivised to grow OHM through the price premium. In Figure 3, the GMs at the farm level across all scenarios can be seen.

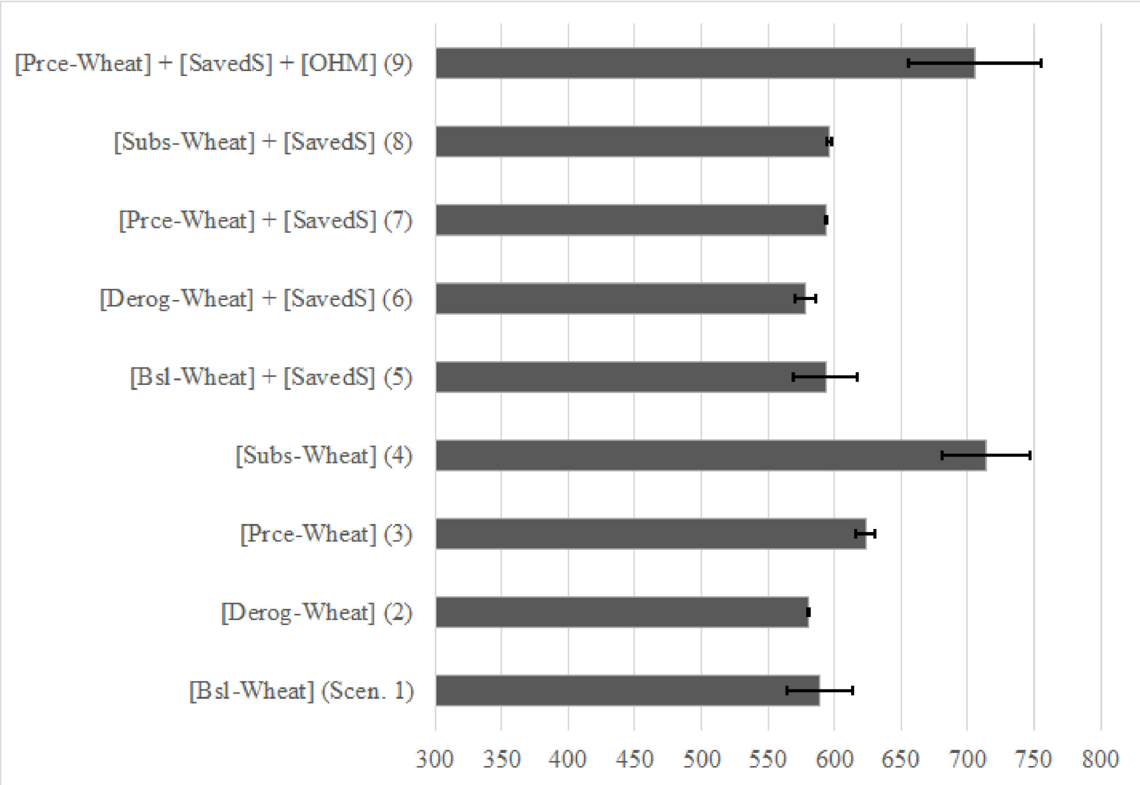

Figure 3. Average gross margins in € per ha and confidence intervals (95%) calculated by sensitivity analysis (ten model runs with triangular distributions over yields in ton/ha and farm gate prices €/ton at farm level).

3.2. Modelling Results of Case 2, Perennial Ryegrass in England

Scenario 1: Baseline.

In the baseline scenario, none of the simulated actors produce or use organic seed. The average yearly gross margin at the farm enterprise level is € 48,410. The gross margin at multiplication level for conventional untreated seed (seed production only, excluding processing and marketing, etc.) is €28,577,976, and the breeding budget for perennial ryegrass is €1,013,487. These figures are close to the figures obtained during data collection and are therefore acceptable as baseline values.

Scenario 2: Command and control approach to derogation phasing out.

In Table 4, the results of different scenarios can be seen relative to the baseline. As shown in the first row of Table 4, if derogations were to be phased out in three steps (Year 1: 80% NCT seed allowed per farm, year 2: 50%, year 3: 30%, year 5: 0%), the farmers would have to bear the burden of additional seed costs, which would amount to an average of 7% loss in gross margin. If 100% organic seed use is achieved, the typical seed producer increases gross margin by 23.5% and the breeding department by 13.7%. This shows that producing organic seed for perennial ryegrass can be an attractive business opportunity if seed usage is controlled by regulatory instruments such as a mandatory phasing out of derogations (even with a stepwise approach). The estimated development of the 70% organic seed mixture taken up under such a derogation scheme can be seen in Figure 4. The results shown in this figure are scaled up to region level.

Scenarios 3 and 4: Voluntary measures incentivising farmers to use organic seed.

Measures to support farmers to afford the additional seed costs in the short term can be increasing farm-gate prices or providing farm subsidies. As indicated in rows two and three of Table 4, with a 6-pence price increase of lamb meat, both farm types would be compensated for the higher seed price, leading to an approximate 90% increase in organic seed use. The same effects along with the perennial ryegrass seed and breeding value chain can be achieved with an area subsidy of €13 per hectare for both farm types for 70% organic seed use in the mixture containing white clover and perennial ryegrass. With a € 1 subsidy or higher product price, 1.62 tons organic mixture can be incentivised up to 90% of the entire pasture area (rows 2 and 3, column 7).

Table 4. Summary of results using key outcome variables for case studies.

	% Δ GM/Farm Enterprise	**% Δ GM/Seed prod. org. Seed and NCT Seed**	**% Δ Breeding Budget Organic, NCT and CT Seed**	**% Δ Organic Seed Use**	**Costs of Intervention in €**	**Cost Effectiveness (Ton Organic Seed/€)**
Scenarios (#)	Mean	Mean	Mean	Mean	Mean	Mean
Stepwise phasing out of derogation (2)	−6.61%	23.54%	13.68%	100%	n/a	n/a
Organic seed price premium (0.07 € per kg lamb) (3)	34.91%	21.18%	12.31%	90%	62,634	1.62
Subsidy (13 €/ha) (4)	34.91%	21.18%	12.31%	90%	62,634	1.62
Higher nitrogen efficiency 10% organic seed yield increase at multiplication level (and then translated into a lower seed price at farm level)						
Without further intervention (5)	0.00%	0.00%	0.00%	0%	n/a	n/a
Stepwise phasing out of derogation (6)	−3.33%	10.61%	11.09%	100%	n/a	n/a
Organic seed price premium (0.04 € per kg lamb) (7)	21.36%	10.61%	11.09%	90%	33,930	2.99
Subsidy (6 €/ha) (8)	21.36%	10.61%	11.09%	90%	33,930	2.99

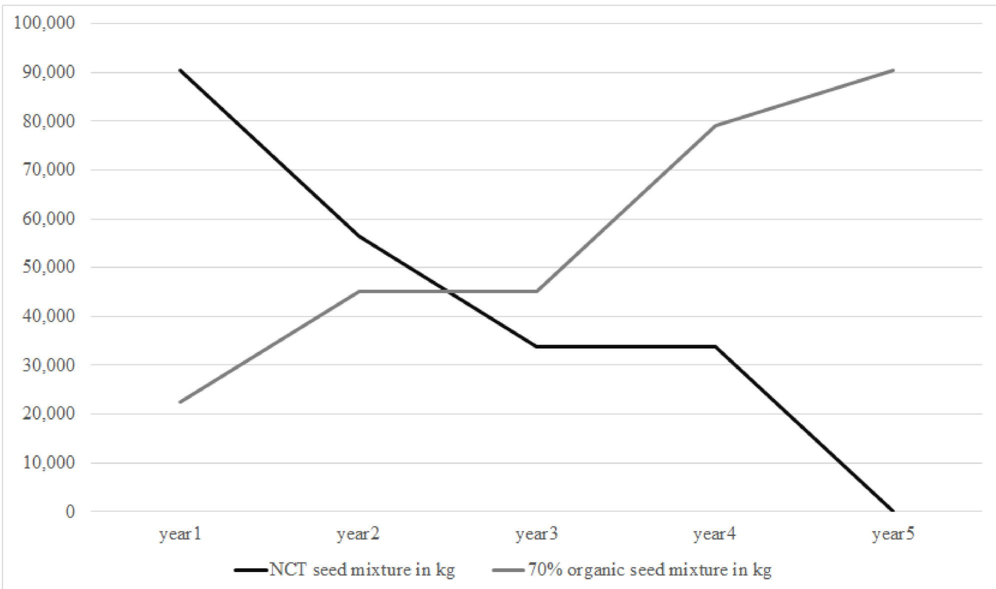

Figure 4. Scenario 2: Development of organic seed use in a modelling period of five years under a stepwise phasing out of derogations scheme.

These measures would smooth the transition to 70% of organic seed use in 100% of the seed mixtures purchased and sown by the organic farmers in the region considered. No substantial losses are expected because of seed shortages, according to the experts interviewed. In the used mixture, only perennial ryegrass must be organic, and only 70% of it. Ryegrass makes up 87.5% of the entire mixture. Compared to other crops such as many vegetable crops, perennial ryegrass seed production seems less restrained by technical difficulties. The typical seed producer and breeder are expected to achieve a gross margin increase of around 20%.

Scenarios 5 to 8: Higher nitrogen efficiency in the seed multiplication stage as a breeding goal.

In order to find solutions for the longer term, seed yield increase through improved nitrogen utilisation at seed production level was identified as a key breeding goal (Condition: "10% organic seed yield increase"). This could have the effect of reducing organic seed prices. The results of these scenarios are in Table 4, rows 4 to 7.

Regarding the financing strategy for such a breeding program, Switzerland has one example of a public-private partnership that makes it possible to pursue breeding goals specifically for organic agriculture. Based on expert interviews, we assume that improved nitrogen utilisation at the seed multiplication stage would bring about a 10% organic seed yield increase, a price reduction of organic seed mixture at farm level of 8.7%, and a 10% reduction for organic ryegrass seed price (revenue per seed) at the multiplication level. As the resulting price reduction of 8.7% would not be sufficient to lead farmers to adopt organic seed use voluntarily, some policy schemes are justified.

In this scenario, a phasing out of derogations would only amount to a loss of around 3.3% in gross margin at the farm level. The gross margin and breeding budget would increase less than without this investment in breeding, but still, they would increase substantially.

If the breeding goals were successfully implemented, the farm subsidy and price premium to achieve 90% organic seed use would be substantially lower than the other scenarios, corresponding to € 6 per ha or 4 cents per kg of lamb meat. The measures would be approximately twice as cost-effective as the measures without the seed yield increase. In Figure 5, an overview is provided of the average farm enterprise gross margins per ha and year across the scenarios. Regarding the seed producer, there is still an increase of around 10% in their gross margin with the reduced seed price.

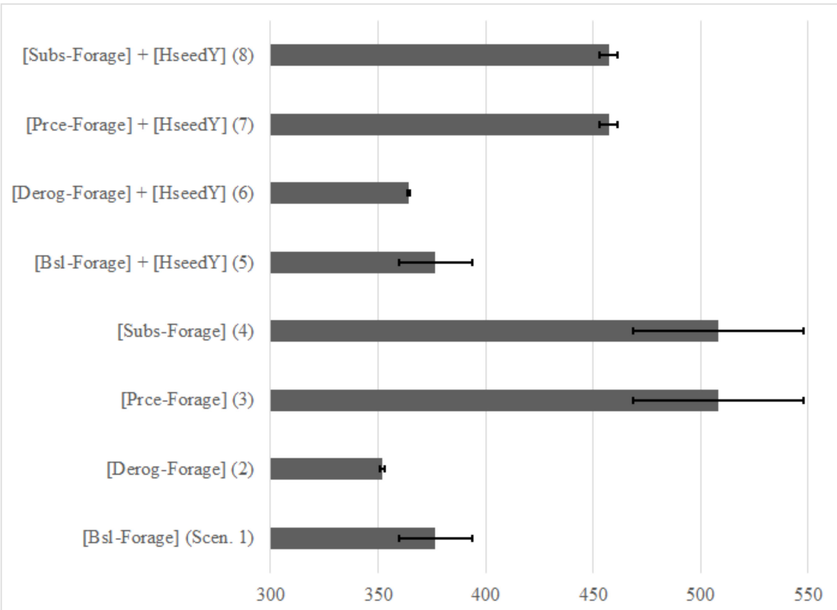

Figure 5. Average gross margins in € per ha and confidence intervals (95%) calculated by sensitivity analysis (Ten model runs with triangular distributions over lamb prices in €/ha at farm level).

4. Discussion

Organic durum wheat model: According to our results relating to the organic durum wheat case study in Italy, phasing out of derogations within a few years seems to be a realistic policy goal. Seed companies would likely be able to supply a sufficient amount of organic seed. Nevertheless, a former study [7] emphasises that some time is likely to be necessary for the transition to find suitable cultivars for different climatic conditions and soil types. Therefore, derogations should be phased out gradually. Furthermore, farmers should be supported in farm seed production. Measures providing farmers with training for their own seed production, pest management, and the promotion of smut-resistant cultivars are recommended to support the transition to 100% organic seed use [7]. If farmers can produce at least part of their own seed need, 100% organic seed, or nearly 100%, can be achieved without substantial loss in gross margins at the farm enterprise level (2.5% on average if farmers produce with a 0.3 seed replacement rate). Moreover, a subsidy of €15 per hectare of durum wheat to incentivise own organic seed production could support the transition further. In both Southern and Northern Italian farm types, the current level of subsidies for durum wheat ranges from a minimum of €220 per hectare to a maximum of €258 per hectare [27,28].

Some studies argued that the use of OHM could be a promising way to move towards organically bred cultivars well suited for organic agriculture. OHM has high yield stability and a low external input need, which is advantageous in low input farming systems and is particularly suited for climate change adaptation [9,10]. However, it is likely that the approach used in this study does not show all the possible advantages of OHMs as only two farms of an average to high productivity are examined in accordance with the Agribenchmark approach [20]. The advantages of OHM are likely to be seen more clearly if farms in more marginal regions and consequently of lower productivity were considered. As yields are somewhat lower on average in the investigated typical farms, the uptake at the farm level would need to be incentivised with a price premium for durum wheat OHM of € 13 per ton if farmers produced most of their own OHM seed. Implementing such a measure at the cooperative level seems more realistic, as cooperatives in the sector are widespread in Italy, and there are already examples where they promote the use of particularly suitable cultivars and seed types.

According to our modelling results, the investigated organic durum wheat seed multiplier can increase their gross margin by 9–18% if they produced organic seed as opposed to NCT seed and by 110% if they produced OHM seed as opposed to NCT seed. However, definite political commitment to increasing organic seed use is critical for seed producers [29]. Next to policies at the country level, promoting cooperation or POs are promising policy instruments to induce farmers to use organic seed and cultivars and induce breeders to breed for organic agriculture [30]. Furthermore, some medium-sized breeding companies have taken up OHM breeding, indicating that this could be a way forward for more breeding for the organic sector. It seems to be a profitable business branch for seed producers if demand at the farm level is stimulated.

Organic perennial ryegrass model: Implementing a farm subsidy of €13 per ha of pasture would encourage farmers to start using organic seeds for perennial ryegrass voluntarily in the short-term, covering the additional costs for organic seeds. Phasing out of derogations would substantially increase costs for organic lamb producers, on average by 6.6%. In the longer term, the inclusion of a seed yield increase as a breeding goal of around 10% is recommended to reduce organic seed costs by 50%.

According to expert estimations, perennial ryegrass seems to be sufficient availability or at least the capacity to produce enough organic seed. However, an identified difficulty seems to exist concerning the rest of the grass mixture. Clovers may also still be sufficiently available, but there is a trend towards more diversified mixtures that are more resilient than simpler mixtures in terms of climate robustness or similar issues [31]. With very small shares in the mixtures of some crop species and cultivars, financing organic seed production and breeding activities for minor crops would be a challenge. Consequently, there is a trade-off between obtaining 100% organic seed in forage mixtures and resilient grazing systems. At least for the short to middle term, a solution is to continue allowing 70 to 90% of organic seed in the mixture. According to our modelling results, the investigated organic perennial ryegrass seed multiplier can increase their gross margin by 21–24% if they produced organic seed as opposed to NCT seed.

A public-private partnership like that in place in Switzerland could be a promising approach to fund organic breeding for perennial ryegrass and other components in forage seed mixtures. This financing strategy could facilitate achieving breeding goals, such as a higher nitrogen efficiency, as was modelled in this study. In this financing model, costs and tasks are shared by a public institution and a medium-sized seed company [32]. It could further be important if organic breeding for crops with a very small share in the seed mixtures should be taken up. In general, an increase in public investment in organic plant breeding seems advisable. Other promising financing strategies that have been identified for organic breeding, such as a value chain pool funding financed by the food industry, or funding by cooperative structures, rely heavily on the voluntary engagement of value chain actors [33] and are thus uncertain.

Some limitations of this study need to be mentioned. In the baseline, none of the simulated actors produce or use organic seed. Selling organic seed would be more profitable for the seed company; however, there is no demand on the farm side. Thus, the seed company does not produce any organic seed. This does not reflect the actual situation, as around 35% of organic seed use by organic durum wheat producers has been estimated in Italy. However, the simplified model structure does not allow for calibration according to organic seed use across the farm population, as only two farms are considered. The simplified model structure needed to be adopted due to data limitations. Such a calibration could be conducted if the entire farm population was modelled [6]. Furthermore, although the decision-making of all typical actors in the seed and breeding value chain is captured, the model cannot depict much heterogeneity at the different levels. This could be solved by including a full agent-based approach where all actors are modelled individually. However, this is only possible where a high level of detail in data is available, which was not the case in this study. Constant market size and distributions of yields and prices over the modelling period are further simplifications. This means that possible external market effects or unexpected shocks are not considered in the study. As these effects are challenging to predict with any reasonable certainty and beyond the research interest, they are disregarded for the sake of parsimony.

To the best of our knowledge, this is one of the first studies to integrate all three levels of the seed value chain (farming, seed multiplication, and breeding) for the organic sector into one consistent optimisation-based simulation model. The results of this study are particularly relevant as the New Organic Regulation 848/2018, which enters into force in 2022, and derogations for the use of non-organic seed in Europe are planned to be phased out by 2036. This is the first study to systematically analyse the consequences of these planned interventions in the necessary degree of detail. Moreover, to be able to realise ambitious policy goals, as formulated in the farm to fork strategy, where a 25% increase of the organic agricultural land share is the aim by 2030 [1], the availability and use of organic seed must be considered essential [29].

5. Conclusions

Our modelling study proves that the phasing out of derogations for the use of NCT causes gross margin losses at the farm level, however, the gross margins remain positive in the two case studies investigated. At the same time, an increase in gross margin at seed production and breeding levels can be observed in both cases. The extent of these losses or gains differs based on several factors such as seed price of the crop and cultivar, and how difficult producing seeds under organic conditions is. For example, seed companies could incur losses with seeds that are more difficult to produce organically than wheat or ryegrass. An example of this is represented by wash/storage carrots in Germany, where we conducted a similar study using the same modelling approach [6]. Overall, as results are very much crop and country-dependent, future research based on case studies that take these unique aspects into account is valuable in developing a roadmap to increase organic seed use.

Another important conclusion of our study is that a combination of public interventions is justified and needed to smooth the transition to increased organic seed use. The market alone is not likely to deliver 100% organic seed use. Amongst the public interventions that we looked at, the provision of farm subsidies is advisable to compensate farmers for their losses. The support of farm-saved seed through training and research in breeding is also recommended to improve organic seed production and supply capacity. From a market perspective, a price premium can help farmers bear the additional costs of organic seeds. However, price premiums are subject to a willingness to pay by the downstream actors and are therefore recommended in association with the voluntary use of organic cultivars and private labels. To the best of our knowledge, this study is the first to analyse the economic performance of typical seed and breeding value chains in two case studies with a novel multi-agent value chain approach. The results of this study furnish evidence-based insights into changes resulting from planned policy interventions in the rapidly growing organic sector.

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Disclaimer: The opinions expressed and arguments employed herein do not necessarily reflect the official views of the EC and the Swiss government. Neither the European Commission/SERI nor any person acting behalf of the Commission/SERI is responsible for the use which might be made of the information provided in this study.

Appendix A

Table A1. Wheat case: Farm gate prices in €/ton (Modi, minima, maxima) used for sensitivity analysis.

Farm Type		Durum Wheat	OHM Durum Wheat	Faba Beans	Chickpea	Soft Wheat	Alfalfa	Sunflower	Barley	Emmer
Southern	Min	337.92	337.92	295.68	580.80				337.92	
Southern	Mode	422.40	369.60	422.40	726.00				726.00	
Southern	Max	464.64	464.64	406.56	798.60				464.64	
Central	Min	360.00	360.00	28.00	370.00	360.00	70.00	400.00		420.00
Central	Mode	450.00	450.00	480.00	450.00	450.00	90.00	30.00		90.00
Central	Max	500.00	500.00	34.00	800.00	500.00	110.00	550.00		560.00

Table A2. Wheat case: Yields in ton/ha (Modi, minima, maxima) used for sensitivity analysis.

Farm Type	Yields t/ha	Durum Wheat	OHM Durum Wheat	Faba Beans	Chickpea	Soft Wheat	Alfalfa	Sunflower	Barley	Emmer
Southern	Min	2.3	1.6	1.5	1				2.1	
Southern	Mode	2.8	2.3	1.8	1.4				3.3	
Southern	Max	4.5	2.7	2.6	2				4.4	
Central	Min	3	2	1.5	1.2	2	5	1.4		2
Central	Mode	3.5	2.7	2	1.5	2.5	7	1.8		2.5
Central	Max	4	3.4	2.5	1.8	3	8	2.2		3

Table A3. Perennial ryegrass case: Farm gate prices for lamb in €/ha pasture (Modi, minima, maxima) used for sensitivity analysis.

Farm Type	Low Land	Upland
Min	603.1	621.1
Mode	768	786
Max	896.89	914.89

Appendix B

Appendix B.1. Additional Information on the Typical Actors of Case 1, Durum Wheat

Seed multiplication: Data was collected from one company representing this type. Reported differences in costs between NCT and organic seed are mainly at the seed production level, as organic seed production has 40% lower yields. However, with the possibility to charge a higher price for organic seed, the company finds it slightly more profitable to sell organic than NCT seed.

Breeding: The majority of the breeding companies focus their activities on the needs of conventional farmers, and the selection is conducted solely under non-organic conditions (i.e. no particular breeding program for organic) or the breeding program for organics is shared with conventional. Nevertheless, as some of these varieties may perform relatively well under organic conditions, the breeding companies are usually investing in post-release organic variety testing to understand which varieties may be selected for multiplication under organic conditions.

There is a yearly breeding budget of around €200,000 for durum wheat, both non-organic and organic. Breeding activities are usually re-financed through royalties or levied on the seed price of a protected variety. The company produces around one new durum wheat cultivar yearly to stay competitive. It needs around 55,000 ha of durum wheat to re-finance its operations. The organic market it currently supplies makes up about 20% of this area. This shows that breeding activities solely for organic agriculture could not be sufficiently financed.

There are no organic breeding activities so far in Italy. However, some initiatives are likely to be started in the near future (e.g., a cooperation with the Swiss organic cereal breeding initiative Getreidezüchtung Peter Kunz and the CREA-CER: Centro di ricerca per la cerealicoltura). However, there are some attempts at breeding heterogeneous material, which is considered especially suited for organic agriculture.

Appendix B.2. Additional Information on the Typical Actors of Case 2, Perennial Ryegrass

Seed multiplication: Seed multiplication for perennial ryegrass occurs mainly in Northern and Central European countries, representing the most commonly used forage grass in many pasture seed mixtures. It is often sown in short-term leys (temporary grassland) together with clover and other forage species.

The interviewees reported some technical/agronomic issues in the multiplication of perennial ryegrass under organic compared to non-organic conditions. One of the essential problems is the difficulty to provide adequate nutrient supply, especially nitrogen, resulting in lower seed yields. Thus, this aspect was taken up as a scenario in this study. [34]. Overall, seed companies reported between 20% and 40% lower yields for organic compared to non-organic production, with reductions. The scientific literature on this is limited to research conducted in Denmark years ago, which reports a yield reduction in organic perennial ryegrass seed production of approximately 25% compared to conventional [34,35].

The chosen company type represents an important player in the UK organic forage seed market. Reported differences in costs between not chemically treated and organic seed are mainly at seed production level because of lower seed yields. Furthermore, higher labour costs for manual weeding in organic seed production is another critical factor. However, with the possibility of charging a higher price for organic seed mixtures, the company finds it more profitable to sell organic than NCT seed provided that they are able to match the demand in terms of seed amount and variety request.

Breeding: A few multinational seed companies fund their own (non-organic) breeding programs for forage through seed sales. This is the case of the non-organic breeding activities carried out for the most common species (particularly perennial ryegrass, white clover and red clover), which have the biggest market share within the forage sector. The only European breeding programs for organic farming in the forage sector we were able to identify are conducted by a public research institute in Switzerland. These organic breeding programs include both clover and grass species. The programs' goals focus on disease resistance, competitiveness against weeds, high yields under low nitrogen inputs. The financing model of this specific case is based on a partnership between the research institute and a small-medium seed company, where the research institute is responsible for the fundamental breeding work. The company then organises the registration, enlisting in the national variety list, and the basic seed production. Public funding and revenues from royalties constitute the basis of the breeding and registration of varieties. The seed of the most suitable varieties is multiplied under organic conditions and commercialised. As mentioned above, in the UK, most grass mixture seed is imported from larger seed production and breeding companies. Thus, such an actor was chosen in the simulation model. Breeding is part of the seed company. There is a yearly breeding budget of around 1 Mio € for perennial ryegrass, both conventional and organic. There are no specific breeding activities for organic ryegrass production. The company produces three to five new perennial ryegrass cultivars yearly to stay competitive. It needs around 2.67 Mio ha of perennial ryegrass to re-finance its operations. The organic market it currently supplies makes up 17% of this area. This shows that breeding activities solely for organic agriculture could not be sufficiently financed.

Appendix C.

Table A4. Simplified matrix overview of the MP decision-making model at farm level.

			Activities X1 to Xn																																			
	Yrs	U	CR	G FC NCT	G FC O	G FC OC	B S FC NCT	B S FC O	B S FC OC	G C1	G C2	G GG	M FC NCT	M FC O	M FC OC	M C1	M C2	C.T.	TGM	CR	G FC NCT	G FC O	G FC OC	B S FC NCT	B S FC O	B S FC OC	G C1	G C2	G GG	M FC NCT	M FC O	M FC OC	M C1	M C2	C.T.	TGM	Rel.	RHS b_1 to b_n
Years			yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2		
Unit			ha	ha	ha	ha	t	t	t	ha	ha	ha	t	t	t	t	t	€	€	ha	ha	ha	ha	t	t	t	ha	ha	ha	t	t	t	t	t	€	€		
Obj. function			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
Land constr.	yr1	ha	1																																		≤	**R**
Main CR constr.	yr1	ha	−1	1	1	1				1	1	1																									≤	0
Specific CR constr. 1	yr1	ha	**−A**	1	1	1																															≤	0
Specific CR constr. 2	yr1	ha	**−A**							1																											≤	0
Specific CR constr. 3	yr1	ha	**−A**								1																										≤	0
Specific CR constr. 4	yr1	ha	**A**									−1																									≤	0
Labour constr.	yr1	PH		**A**	**A**	**A**				**A**	**A**	**A**																									≤	**(R)**
S requ. NCT	yr1	t		**A**			−1																														≤	0
NCT S restr.	yr1	t																																			≤	0
S requ. organic	yr1	t			**A**			−1																													≤	0
O S restr.	yr1	t						1																													≤	**(R)**
S requ. OC	yr1	t				**A**			−1																												≤	0
OC S restr.	yr1	t							1																												≤	**(R)**
Yield O FC NCT	yr1	t		**(−Y)**									1																								≤	0
Yield O FC O	yr1	t			**(−Y)**									1																							≤	0
Yield O FC OC	yr1	t				**(−Y)**								1																							≤	0
Yield O C1	yr1	t								**(−Y)**						1																					≤	0
Yield O C2	yr1	t									**(−Y)**						1																				≤	0
Account open	yr1	€		**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**						1																			≤	**R**
Account close	yr1	€																																			≤	0
Land constr.	yr2	ha																		1																	≤	**R**
Main CR constr.	yr2	ha																		−1	1	1	1				1	1	1								≤	0
Specific CR constr. 1	yr2	ha																		**−A**	1	1	1														≤	0
Specific CR constr. 2	yr2	ha																		**−A**							1										≤	0
Specific CR constr. 3	yr2	ha																		**−A**								1									≤	0
Specific CR constr. 4	yr2	ha																		**A**									−1								≤	0
Labour constr.	yr2	PH																			**A**	**A**	**A**				**A**	**A**	**A**								≤	**(R)**
S requ. NCT	yr2	t																			**A**			−1													≤	0
NCT S restr.	yr2	t																																			≤	0
S requ. organic	yr2	t																				**A**			−1												≤	0
O S restr.	yr2	t																							1												≤	**(R)**
S requ. OC	yr2	t																					**A**			−1											≤	0
OC S restr.	yr2	t																								1											≤	**(R)**
Yield O FC NCT	yr2	t																			**(−Y)**									1							≤	0
Yield O FC O	yr2	t																				**(−Y)**								1							≤	0
Yield O FC OC	yr2	t																					**(−Y)**								1						≤	0
Yield O C1	yr2	t																									**(−Y)**						1				≤	0
Yield O C2	yr2	t																										**(−Y)**						1			≤	0
Account open	yr2	€											**(−C)**	**(−C)**	**(−C)**	**(−C)**	**(−C)**	−1.03			**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**						1		≤	**R**
Account close	yr2	€																												**(−C)**	**(−C)**	**(−C)**	**(−C)**	**(−C)**	−1.03	1	≤	0

Note: Yrs = Years, U = Unit, CR = Crop Rotation, G = Grow, FC = Focus Crop, C1= Crop 1 in crop rotation, S = Seed, B = Buy, O = organic, OC = Organic Cultivar, GG = Green Manure, M = Market, C.T. = Cash Transfer, TGM = Total Gross Margin, Rel. = Relation, PH = Person-hours, E = Expected values, C = price coefficients, Y = Crop yields, A = Technical coefficients, R = Available resources. Values in round brackets are adjusted inside the model. Bold values are agent-specific.

Table A5. Simplified matrix overview of the MP decision-making model at seed multiplication level.

	Yrs	Unit	Activities X_1 to X_n																						Relation	RHS b_1 to b_n
			P S NCT	P S org.	P S org. cult.	B BS NCT	B BS org.	B BS org. cult.	M S NCT	M S org.	M S org. cult.	Cash T.	Tot. GM	P S NCT	P S org.	P S org. cult.	B BS NCT	B BS org.	B BS org. cult.	M S NCT	M S org.	M S org. cult.	Cash T.	Tot. GM		
Years			yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2		
Unit			t	t	t	t	t	t	t	t	t	€	€	t	t	t	t	t	t	t	t	t	€	€		
Obj. function			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
Typical organic market size constr.	yr1	ha	**A**	**A**																					≤	**Typical organic market size**
Typical organic cultivar market size constr.	yr1	ha			**A**																				≤	**Typical organic cultivar market size**
Basic seed requ. NCT	yr1	t	**A**			**−1**																			≤	0
Basic seed requ. organic	yr1	t		**A**			**−1**																		≤	0
Basic seed requ. organic cultivar	yr1	t			**A**			**−1**																	≤	0
Basic organic seed constr.	yr1	t					**1**																		≤	**(R)**
Basic organic cultivar seed constr.	yr1	t						**1**																	≤	**(R)**
Seed yield NCT	yr1	t							**1**																≤	**($E_{NCT\ seed\ sales}$)**
Seed yield organic	yr1	t								**1**															≤	**($E_{organic\ seed\ sales}$)**
Seed yield organic cultivar	yr1	t									**1**														≤	**($E_{organic\ cultivar\ seed\ sales}$)**
Expected organic seed sales	yr1	t																							≤	0
Expected organic cultivar sales	yr1	t																							≤	0
Account open	yr1	€	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	1													≤	**R**
Account close	yr1	€																							≤	0
Typical organic market size constr.	yr2	ha												**A**	**A**										≤	**Typical organic market size**
Typical organic cultivar market size constr.	yr2	ha														**A**									≤	**Typical organic cultivar market size**
Basic seed requ. NCT	yr2	t												**A**			**−1**								≤	0
Basic seed requ. organic	yr2	t													**A**			**−1**							≤	0
Basic seed requ. organic cultivar	yr2	t														**A**			**−1**						≤	0
Basic organic seed constr.	yr2	t																**1**							≤	**(R)**
Basic organic cultivar seed constr.	yr2	t																	**1**						≤	**(R)**
Seed yield NCT	yr2	t	**−Y**																	**1**					≤	0
Seed yield organic	yr2	t		**−Y**																	**1**				≤	0
Seed yield organic cultivar	yr2	t			**−Y**																	**1**			≤	0
Expected organic seed sales	yr2	t																			**1**				≤	**($E_{organic\ seed\ sales}$)**
Expected organic cultivar sales	yr2	t																				**1**			≤	**($E_{organic\ cultivar\ seed\ sales}$)**
Account open	yr2	€	**C**	**C**	**C**				**−C**	**−C**	**−C**	−1.03		**C**	**C**	**C**	**C**	**C**	**C**	**−C**	**−C**		1		≤	0
Account close	yr2	€												**C**	**C**	**C**				**−C**	**−C**		−1.03	1	≤	0

Note: Yrs = Years, P = Produce, S = Seed, B = Buy, BS = Basic Seed, org. = organic, cult. = cultivar, M = Market, T. = Transfer, Tot. = Total, E = Expected values, C = price coefficients, Y = Crop seed yields, A = Technical coefficients, R = Available resources. Values in round brackets are adjusted inside the model. Bold values are agent-specific.

Table A6. Simplified matrix overview of the MP decision-making model at breeding level.

			Activities X_1 to X_n																	
	Yrs	Unit	P BS org.	P BS org. cult.	M BS CT	M BS NCT	M BS org.	M BS org. cult.	Cash T.	Tot. GM	P BS org.	P BS org. cult.	M BS CT	M BS NCT	M BS org.	M BS org. cult.	Cash T.	Tot. GM	Relation	RHS b_1 to b_n
Years			yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr1	yr2	yr2	yr2	yr2	yr2	yr2	yr2	yr2		
Unit			t	t	t	t	t	t	€	€	t	t	t	t	t	t	€	€		
Obj. function			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
Typical market size constr.	yr1	ha			**A**	**A**	**A**												≤	**Typical market size**
Typical organic market size constr.	yr1	ha				**A**	**A**												≤	**Typical organic market size**
Typical organic cultivar market size constr.	yr1	ha						**A**											≤	**Typical organic cultivar market size**
Basic seed yield	yr1	t	**−1**		**1**	**1**	**1**												≤	0
Basic organic cultivar seed yield	yr1	t		**−1**				**1**											≤	0
Expected organic basic seed sales	yr1	t					**1**												≤	**($E_{organic\ basic\ seed\ sales}$)**
Expected organic basic cultivar sales	yr1	t						**1**											≤	**($E_{organic\ cultivar\ basic\ seed\ sales}$)**
Account open	yr1	€							1										≤	**R**
Account close	yr1	€																	≤	0
Typical market size constr.	yr2	ha											**A**	**A**	**A**				≤	**Typical market size**
Typical organic market size constr.	yr2	ha												**A**	**A**				≤	**Typical organic market size**
Typical organic cultivar market size constr.	yr2	ha														**A**			≤	**Typical organic cultivar market size**
Basic seed yield	yr2	t									**−1**		**1**	**1**	**1**				≤	0
Basic organic cultivar seed yield	yr2	t										**−1**				**1**			≤	0
Expected organic basic seed sales	yr2	t													**1**				≤	**($E_{organic\ basic\ seed\ sales}$)**
Expected organic basic cultivar sales	yr2	t														**1**			≤	**($E_{organic\ cultivar\ basic\ seed\ sales}$)**
Account open	yr2	€			**−C**	**−C**	**−C**	**−C**	−1.03								1		≤	**R**
Account close	yr2	€											**−C**	**−C**	**−C**	**−C**	−1.03	1	≤	0

Note: Yrs = Years, P = Produce, BS = Basic Seed, org. = organic, cult. = cultivar, M = Market, T. = Transfer, Tot. = Total, E = Expected values, C = price coefficients, Y = Crop seed yields, A = Technical coefficients, R = Available resources. Values in round brackets are adjusted inside the model. Bold values are agent-specific.

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Study 4: Assessing seed and breeding interventions for organic farming using a multi-agent value chain approach

This manuscript is currently under review in Agricultural and Food Economics by SpringerOpen. The appendix and the ODD-Protocol can be found on the CD enclosed in this thesis.

Assessing seed and breeding interventions for organic farming using a multi-agent value chain approach

Eva Winter[1,2], Christian Grovermann[1], Monika M. Messmer[1], Joachim Aurbacher[2]*

[1]Research Institute of Organic Agriculture (FiBL), Ackerstrasse 113, 5070 Frick, Switzerland,

[2]Institute of Farm and Agribusiness Management, Justus-Liebig University of Giessen, Senckenbergstraße 3, 35390 Giessen, Germany

*Corresponding author: eva.winter26@gmx.de

Abstract

According to the EU organic regulation, the use of organic seed is generally binding in organic farming. Due to organic seed shortage, exceptions (called "derogations") to use not chemically treated non-organic seed can be obtained. By 2036 the EU plans to phase out these derogations and achieve 100% organic seed for the sector. Previous attempts to phase out the derogations have failed in the past. Ensuring organic seed supply is of particular EU-wide importance to meet EU policy goals such as the farm-to-fork strategy. To assess the impact of measures to smooth this transition, we developed the VAL-MAS model *(VALue chain Multi-Agent System)*. It is a multi-agent model based on a heterogeneous agent population and mathematical programming, which can provide new insights into the performance of different seed system interventions. We selected organic carrots for the fresh market in Germany for their importance in the national and European organic sector as example case. Our model suggests that the end of the derogation system poses a big challenge for the seed value chain in terms of seed supply and farm incomes. The most effective mitigation solution is an investment into improved pest control during seed multiplication, accompanied by a step-wise phasing out of derogations for the use of non-organic seed. However, with the given technology, alternatively a subsidy of 500 €/ha organic carrot production or a price premium of 10 €/t organic carrots for the use of organic carrot seed at farm level were necessary to avoid farm income trade-offs after the end of derogations.

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

1. 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 (Organic Regulation 848/2018). This principle ensures the integrity of organic agriculture along the value chain. However, in the case of seed, this requirement is largely unmet, even though it is at the heart of the farming system. In fact, there is a lack of sufficient organic seed supply in the EU due to 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 (Döring et al. 2012). By 2036 the EU plans to phase out the derogations and achieve 100% organic seed for the sector (Organic Regulation 848/2018). A strategy is still missing on how to secure sufficient organic seed supply. This is of particular importance to meet EU policy goals, as formulated in the farm-to-fork strategy (European Commission 2020). The envisaged increase in organic land share to 25% will create a higher demand for organic seed. Previous attempts to phase out the derogations have failed, because the phasing out was not accompanied by a strategy to build up the organic seed sector first, leading to seed shortages.

Organic seed production and use vary substantially among countries and crops (Solfanelli et al. 2020). Thus, there is a need to identify crops of high importance for the organic sector for which organic seed is difficult to produce or where organic seed use at the farm level is still very low to implement measures towards more organic seed production and use. In this study, we examine the case of organic carrots for storage and fresh markets in Germany, where little organic seed is used so far (around 10%). Growers are granted a general permission to use NCT seed (Herstatt 2017), and seed producers are confronted with substantial challenges in organic seed production: a lack of effective pest management (Wohleb 2019), limited access to suitable production areas, and a low number of farmers willing to produce this type of seed. The selected case is also of interest because organic carrots are among the most produced and consumed organic vegetables in Germany (Destatis 2018).

Very few measures have been implemented by European countries to encourage organic carrot seed production and use. Only in France, on-going attempts are made to phase out derogations for organic carrots in a step-wise process (Orsini et al. 2019). Furthermore, in five EU countries, derogations to use NCT carrot seed have to be individually requested. Overall, the NCT seed amount granted through derogations in 2016 has increased on average by 96% compared to the year 2014 in EU countries 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 that focus on obstacles in organic seed use and production and that systematically analyse the effects of interventions to overcome these obstacles along the value chain from breeding to farming. To this end, models are needed that portray enabling factors, decision-making and interactions of actors along the seed value chain so that feasible solutions for boosting organic seed use can be identified for the sector. 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 and offer solutions for the organic seed market. Consequently, all 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 conducted to analyse seed and other agricultural value chains (Bellù 2013; Mulugeta et al. 2010; Kumara et al. 2012; Senyolo et al. 2018; Das and Roy 2021; Mallick et al. 2017). These methods can be complemented by more sophisticated assessment approaches, which can give more in-depth insights into system dynamics. 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, which is still true today. Therefore, they recommend system dynamics and agent-based models to conduct quantitative ex ante policy assessments of value chains.

Ex-ante policy assessment via simulation models is a useful means of testing policy instruments that could smooth the transition period and deliver long-term solutions to increase organic seed production and use. A large number of studies exist where agricultural policies and private sector interventions are tested ex-ante through simulation modelling. Existing models mostly assess policy implications at the farm or sector level, while the assessment of entire value chains has so far been neglected (Janssen and van Ittersum 2007; Grovermann et al. 2017; Häring 2003; Bunte and Galen 2015; Schreinemachers and Berger 2011; Appel et al. 2019; Heckelei et al. 2012). Applications often relate to farm-level input choices under varying conditions (Schreinemachers and Berger 2011; Grovermann et al. 2017; Berger et al. 2017). There is an urgent need to capture input supply decisions alongside farmer behaviour in agricultural simulation models.

This study proposes the VAL-MAS model *(VALue chain Multi-Agent System)*, a mathematical programming and agent-based value chain simulation model for the ex-ante assessment of seed system interventions. It represents a novel integrated modelling approach that can generate better insights into the production and use of organic seed as well as into the effects of organic seed policies in the EU. On the basis of the VAL-MAS model, our study aims at answering the following research questions:

- Which policy or private sector measures can increase the use and production of organic seed, and what are the economic implications for the actors in the organic seed value chain?
- Which quantitative value chain analysis can provide robust and systematic ex-ante evaluation of policy interventions targeting value chains, where analysis has so far mainly been limited to qualitative assessments?

Materials and methods are explained in the next section, followed by the results. Finally, discussions, policy implications and conclusions are presented.

2. Materials and Methods

2.1 Conceptual background of the modelling approach

2.1.1 Definition of research question and quantitative outcome variables

The primary quantitative outcome variables that we will assess are the use and production of organic seed. A secondary outcome variable is the gross margin of different value chain entities. A number of factors can influence these variables. The main factors as well as the nature of their influence are presented in Table 1. Furthermore, in the last column of this table, the model implementation of influencing factors in relation to outcome variables is briefly outlined.

Table 1: Seed system context and model implementation

Outcome variable	Influencing factors	Nature of influence	Model implementation
Production of organic seed	-Demand	Currently, demand for organic seed is low. This hampers its production.	Expectations on seed demand are endogenously adapted each year by seed producers based on past sales.
	-Ease of production	For some crops, organic seed production is technically challenging, and thus holds it back. For some cultivars, it is so far not possible to produce organic seed from.	Seed production activities are modelled in detail, as well as with an upper limit on production increase.
	-Cost of production	Organic seed production is in almost all cases more expensive than non-organic production. This results in a higher price for organic seed and lower demand.	Costs and revenues of seed production activities are modelled.
	-Policy framework	Derogations allowing for the use of NCT seed hampers organic seed production.	The current situation is reflected in the baseline, while changing regulations are modelled in scenarios.
Use of organic seed	-Availability of organic seed	There is currently only a limited range and amount of organic seed available.	The baseline is calibrated according to the current use of organic seed. This is the starting point in scenarios aiming at a production increase. An upper limit reflecting a realistic growth rate ensures a realistic increase.
	-Quality of seed	In some cases, organic seed is of lower quality (e.g. regarding the germination rate). This does not make it a farmer's first choice.	Crop production activities are modelled at an input and output level disaggregated to seed requirement and price at hectare level.
	-Suitability of cultivars	Only a limited number of cultivars are available as organic seed. The cultivars are sometimes not the preferred choice of the organic farmer.	Individual cultivars are not modelled, but average characteristics of cultivars available in NCT seed, organic seed, or organic cultivars[1].
	-Policy framework	s. above	s. above
	-Attitudes and expectations from down-stream value chain actors	Currently, there is limited awareness and emphasis on the use of a specific kind of seed. This does not induce the farmer to use organic seed.	The behaviour of down-stream value chain agents are not endogenously modelled. Scenarios including a higher farm gate price are modelled exogenously.
	-Cost of seed	Organic seed is generally more expensive for farmers than NCT seed.	Crop production activities are modelled in detail, disaggregated to seed

[1] In this study, organic cultivars are organically bred cultivars where the entire breeding process is conducted under organic conditions. The seed multiplication process is also conducted under organic conditions.

		This is a major constraint for farmers to switch to organic seed.	requirement and price at hectare level.
	-Attitudes and expectations from organic farmers	Attitudes about the importance and need for organic seed varies among organic farmers and can be strong (de)motivators.	An individual excess willingness to pay for organic seed per farmer was estimated and included as exogenous parameter in the model.

2.1.2 The VAL-MAS model

As explained in the introduction, our ex-ante impact assessment of seed system interventions relies on the VAL-MAS value chain model, in which a system of agents in the seed and breeding value chain (comprising breeding, seed production, and farming agents) take decisions based on mathematical programming and heuristics. Agent-based systems are a valuable tool when modelling the behaviour of different actors in a heterogeneous population, where each entity takes individual decisions and reacts to the decisions of other entities (Gjerdrum et al. 2010; Schreinemachers and Berger 2006). In this study, actors always refer to real-world actors, while agents are their representatives in the modelling context. The term value chain level is used to summarise all actors or agents active in the respective value chain level: Breeding, Seed multiplication, and farming.

Since the actors along the organic seed value chain and the actors within one level of the seed value chain are highly heterogeneous with respect to their decision-making behaviour (Orsini et al. 2019), a multi-agent system is well suited when modelling the vertical and horizontal complexity of the seed value chain. Therefore, we chose an approach representing individual decision making and not an aggregate modelling approach. In this study, an entire agent population with individual decision making per agent is considered at the farm level. At multiplication and breeding levels, typical seed supply actors are represented by decision-making agents.

Mathematical optimisation models are often used in agricultural economics to find optimal solutions for economic decisions, such as the optimal production plan at the farm level under given resource constraints. Generally, either production costs are minimised or gross margins maximised, taking these constraints into account (Hazell and Norton 1987). Based on standard microeconomic theory, optimisation models allow to model the behaviour of individual agents that have a vast range of decision options and objectives to choose from. This makes optimisation models particularly suitable for modelling detailed input decisions, such as seed use (Schreinemachers and Berger 2006, 2011). Therefore, optimisation is central in the VAL-MAS model.

Clearly, not all decisions by actors are taken "rationally" as described by micro-economic theory and follow an optimisation logic. Therefore, this has to be complemented with so-called "Heuristics", where decisions are taken based on a pre-defined decision-tree, which offers far less flexibility in choices than optimisation, but can capture behaviours that are not fully rational from an economic perspective. Schreinemachers and Berger (2006) argue that a combination of agent-based systems, optimisation and heuristics is advisable for realistic modelling of decision-making behaviour at the farm level. Consequently, 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 for example an excess willingness to pay (WTP) for organic seed at the individual farm level. This is further explained in Subsection 2.2.

When simulating processes (e.g. breeding and farming) with different time horizons in one model, a dynamic model approach is essential to capture developments emerging under different model scenarios. Moreover, once activities in a particular year are fixed by the agents, a feedback loop is needed between the value chain levels. As a consequence, the start values of a certain period need to be the end values of the previous period. We thus deemed it most suitable to embed in the model a positive recursive-dynamic decision-making algorithm based on a combination of optimisation and heuristics. A complete documentation of the VAL-MAS-model in ODD-Protocol format is available in the supplementary material.

2.1.3 Case study selection and description

As derogations for NCT seed are tied to the country's legislation and to the specific crop, the boundaries of our case study were defined accordingly. The analysis is limited to one country and to one specific crop at the farm level. The case of wash/storage carrot production for the fresh market (rather than for e.g. processing) was selected for its importance in the organic sector in Germany and the EU as a whole (Orsini et al., 2019). Most of these carrots are marketed through long value chains, where organic seed use is less prevalent than in shorter value chains (Orsini et al. 2020; Winter et al. 2021). Moreover, it represents the challenges faced across a range of high-value crops in the EU, i.e. a great lack of organic seed and cultivars in the value chain. This situation is owed to the derogation scheme as well as prevailing technical difficulties, which require considerable investments to be overcome. This also means that policies and private sector interventions can make a real difference in scaling up use and availability in such situations. Another primary criterion for case selection was data availability so that the model can be fully parameterised. Availability of detailed production information was one of the most significant bottlenecks for this study, as economic data on breeding, multiplication, and organic farming is scarce and often confidential. There are approximately 800 organic carrot producers in Germany cultivating around 2,100 ha with a resulting seed demand of approximately 4,200 Mio seeds per year (Destatis, 2018). Expert estimates indicate that around 50% of organic carrots produced in Germany are for the fresh market segment and belong to the cultivar group "wash/storage". Around ten relevant seed companies produce carrot seed used in organic agriculture, based in the Netherlands and Germany, most of which have a breeding department in addition to seed production. These companies are primarily international players that produce seed and cultivars for conventional and organic vegetable producers. Furthermore, some organic breeding and seed production initiatives exist. These initiatives produce open-pollinated (OP) cultivars and are mostly only active in Germany and relatively small (Orsini et al., 2019). For all input data, Value Added Taxes are excluded and deflated with real interest rates, where relevant. All direct payments or subsidies are excluded from calculations unless specifically mentioned, so that effects of scenarios can be observed applying the ceteris paribus assumption.

2.2 Data collection and parameterisation of the VAL-MAS model

2.2.1 Input data and definition of 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 the limited willingness of actors to share economic data. We defined a typical entity as a 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 were then obtained through a series of stakeholder and expert interviews between 2017 and 2020. The mapping revealed that around nine 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). These nine companies and initiatives were contacted and face-to-face interviews with identified actors willing to participate in our study were conducted (Anonymised information about the companies and initiatives can be found in Appendix A.1). 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 organic seed from organic cultivars. This type will be referred to as type II. We interviewed three companies corresponding to the first type and three companies or non-profit initiatives corresponding to the second. 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 seed multiplication, bottlenecks in seed production, promising breeding goals, and scenarios to boost the organic seed and breeding sector. Family-owned companies constitute the governance model in type I, with a financing strategy for seed and breeding through commercial seed sales. The size of the companies is large with a yearly total sales revenue of above 150 Mio €. Their target markets are both national and international. Organic, NCT and CT vegetable seed is produced. Type II represents companies that specialise in organic vegetable seed and only produce open-pollinated (as opposed to hybrid) organic cultivars. They are small sized (yearly sales revenue below 10 Mio €) shareholder-owned companies and with target markets mostly in Germany and Switzerland. Seed production costs are covered with seed revenues. However, breeding does not need to be re-financed, as cultivars are provided by a breeding initiative, described further in the next section.

As regards the implementation in the simulation model, two breeding types are also represented in the simulation model. Type I is defined as the breeding department of an internationally active company that also produces 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. Eight to ten new carrot cultivars are placed on the market each year to stay competitive. They have a life span of around 12 years. To re-finance the breeding programmes, 13,545 ha of carrot production area need to be planted with the company's seed. The organic area share is 1,505 ha, 11% of the total area, while the yearly fresh market carrot breeding budget is estimated to be around 30% of the revenue. Type II characterises a company specialised in breeding organic cultivars, which exclusively develops open pollinated cultivars. The governance model consists of a breeding initiative with fragmented funding. Pre-financing of breeding activities happens through voluntary contributions from seed multipliers, alongside donations and sponsorship. We assume that around 10% of the total seed sales from the company's cultivars is voluntarily returned to it for re-financing purposes. A complete list of the input and output parameters of the VAL-MAS model can be found in the Appendix A.2.

To be able to model the entire wash/storage carrot seed production enterprise of both agents, scaling factors were implemented in the model. These ensure compatibility between the actual seed sales market and the available German organic carrot production area.

If this were omitted, economies of scale would not be realised. The cultivated area in the case study would not be interesting enough as a seed market for the larger of the two typical seed producers. As the present agent-based value chain model is the first to simulate the seed value chain fully, 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 2015b; Gibbons and Ramsden 2008). In this study, scaling factors are used to connect the three value chain levels to match supply and demand. For example, one of the interviewed carrot seed producers has a market size of 1,505 hectare organic carrot production, while according to German statistical data, the organic carrot producers in Germany cover 2,100 ha (Destatis 2018), of which around 1,200 to 1,400 ha are covered by carrots for main production and storage (German organic carrot expert estimation). Consequently, the scaling factors from seed multiplier (Type I) to farmers varies from 0.8 to 0.93, depending on the random seed value for the generation of the agent population, and from farmers to multiplier it ranges between 1.1 and 1.25.

2.2.2 Input data and creation of an agent population at the farming level

In order to generate the agent population of organic carrot producers in Germany, we relied on the farm accountancy data ("Agrarstrukturerhebung") of the year 2016, provided by the national statistical office in Germany (RDC 2016). The organic wash/storage carrot farm agent population for carrots has been generated and verified with 100 agents. However, there are around 325 farmers in reality (Destatis 2018). The results did not differ significantly, while the more parsimonious specification of the agent population allowed speeding up the modelling runs substantially. To ensure compatibility, there is a scaling factor of 3.25 that scales up the farming level to reality.

A copula approach was used to estimate a joint distribution between selected key farm characteristics, following the procedure proposed by Troost and Berger (2015a). The aim of this was to obtain combinations of characteristics of individual observations and their frequencies. For the joint distribution, farm characteristics variables were divided into quintiles (a higher resolution was not possible due to privacy restrictions). Subsequently, matrices were created from the combinations of quintiles along the farm characteristics of each observation in the dataset. This is illustrated in Figure 1. The observed frequencies within the multidimensional space served as empirical copula from which the agents for the agent population were drawn. An approach with several copulae including total agricultural area as main matching variable and other important farm characteristics was adopted to avoid the barring of values in the copulae due to privacy restrictions. One copula included total agricultural area, farm area, organic vegetable area in rotation with other vegetable and with arable crops, and available labour per farm. Other copulae included the total agricultural area and one other relevant crop area (winter wheat, winter rye, legumes mixture, beans, potatoes) or the farm manager's education.

85% of farm agents depicted in the simulation model belong to the farm type "carrot production in crop rotation with arable crops". The farm type "carrots in rotation with other vegetables" comprises 15% of all farm agents. The average agricultural area of the two types at the relevant farm enterprise level is 25 ha and the vegetable area lies at 3.79 ha on average. These parameters are based on own calculations using the data within the scope of this research from the Research Data Centres of the Federal Statistical Office and Statistical Offices of the Federal States (RDC 2016).

Figure 1 depicts an example of the copula between the agricultural area and the vegetable area. The copula approach captures linear as well as non-linear relationships between farm characteristics.

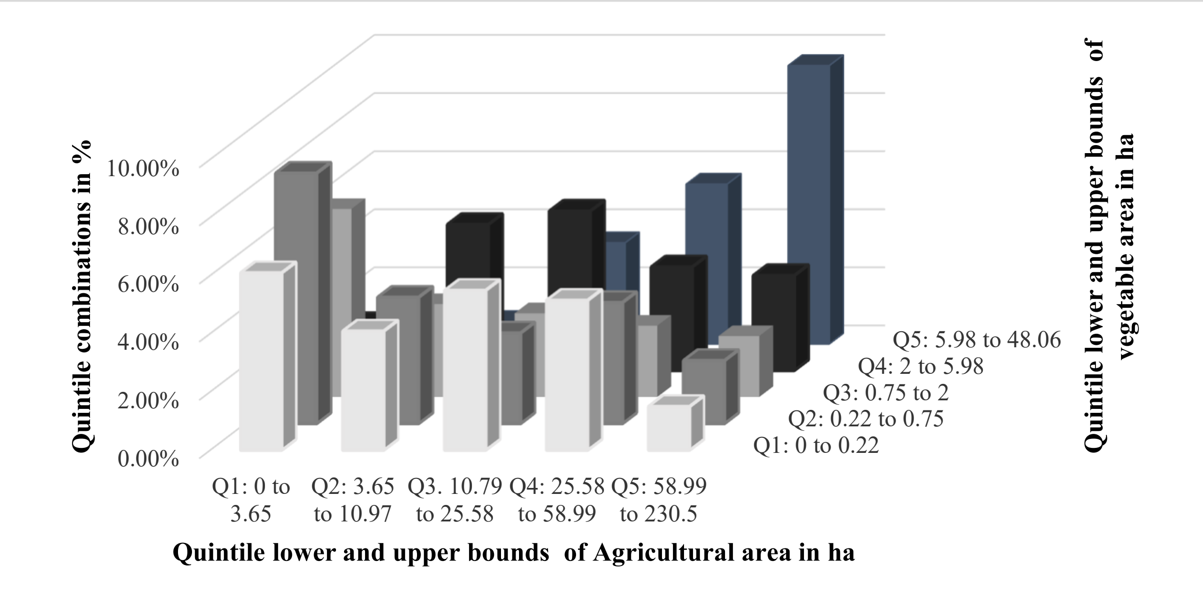

Figure 1: Copula of arable area and vegetable area based on own calculations using the data from the RDC (2016)

To be able to model the diffusion of organic seed and innovations revolving around organic seed and breeding in the farm agent population according to differences in aptness of farmers to adopt organic seed, the model includes a feature that represents the diffusion of an innovation according to the network threshold theory of Rogers (2003) and the procedure proposed by (Troost and Berger 2015b). Following this theory, farm agents were categorised into five segments: Innovators (2.5% of the population), early adopters (13.5%), early majority (34%), late majority (34%), and 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 it and so on. The agents in the model were assigned to the network segments based on statistical estimation of propensity scores. In order to establish the innovativeness scores in the agent population, influential characteristics were regressed on organic seed use with recent survey data on organic farmers (Orsini et al. 2020). More information can be found in Appendix A.3.

Further farm population data were obtained from diverse sources. Whole-sale price data for washed carrots for the fresh market were available as a time series for ten years from the Agrarmarkt Information GmbH (AMI 2020) and detrended to correct for trend-related changes, such as a general increase of prices (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), yield ranges of crops in the crop rotation were calculated and, as with prices, were implemented in the model as triangular distributions for sensitivity analysis (see Subsection 2.4 for further information). Interactions between seed prices and farm gate product prices were captured in a range of scenarios, where higher farm gate prices could for instance compensate for the price gap between organic seed and NCT seed.

The first farm type *"carrot production in crop rotation with arable crops"* was assigned a typical mixed crop rotation including carrots, onion, winter wheat, winter rye, beans, and green manure. Similarly, the second farm type *"carrots in rotation with other vegetables"* was assigned a typical vegetable crop rotation comprising carrot, salad, leek, cabbage, and green manure. Both crop rotations were selected based on the survey among German organic carrot producers and expert verification.

As no complete data set with all necessary parameters was available for our study, technical coefficients and variable 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 database 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.4), we narrowed down relevant farming systems from KTBL out of all available farming systems 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).

2.3 Specification of agent decision-making

2.3.1 Decision making of agents via individual objective functions

At the farming level, the gross margin per farm enterprise agent is maximised. The farm enterprise agent in this model application is defined by the crops in the organic carrot crop rotation. At the seed production level, the gross margin of organic and NCT carrot seed production is optimised for each seed multiplication agent. 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 the breeding level, we implemented a revenue maximisation of the wash/storage carrot section of the breeding agent, including non-organic seed (chemically and non-chemically treated). The breeding revenue is represented by 10 to 30% of the seed sales revenue, depending on the typical actor. A revenue maximisation for the breeding agents was chosen, because the breeding costs were treated as constant over time, and thus the revenue maximisation can be seen as a proxy of profit maximisation. Both of the typical breeding actors we identified do not consider the gross margin at breeding level as key performance indicator, but require a constant breeding budget as part of research and development (Kuin 2018; Syngenta 2015). Simplified decision-making matrices based on optimisation of each value chain level can be found in the Appendix of the ODD-Protocol of the VAL-MAS model.

Interactions between the value chain levels are based on information, financial, and material exchange between the value chain actors regarding seed sales, amounts, prices, including 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 2 shows the simplified interactions in the model, illustrating the decision-making sequence of the agents. The food industry and policy framework are depicted in the square box as they are exogenous factors with no endogenous decision making implemented in the model. Its 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. Under these scenarios, the behaviour of the endogenously modelled actors can change, e.g., more organic seed might be produced and/or used. The figure displays model processes in one year including the feedback loop ("update after sales") at the end of the year.

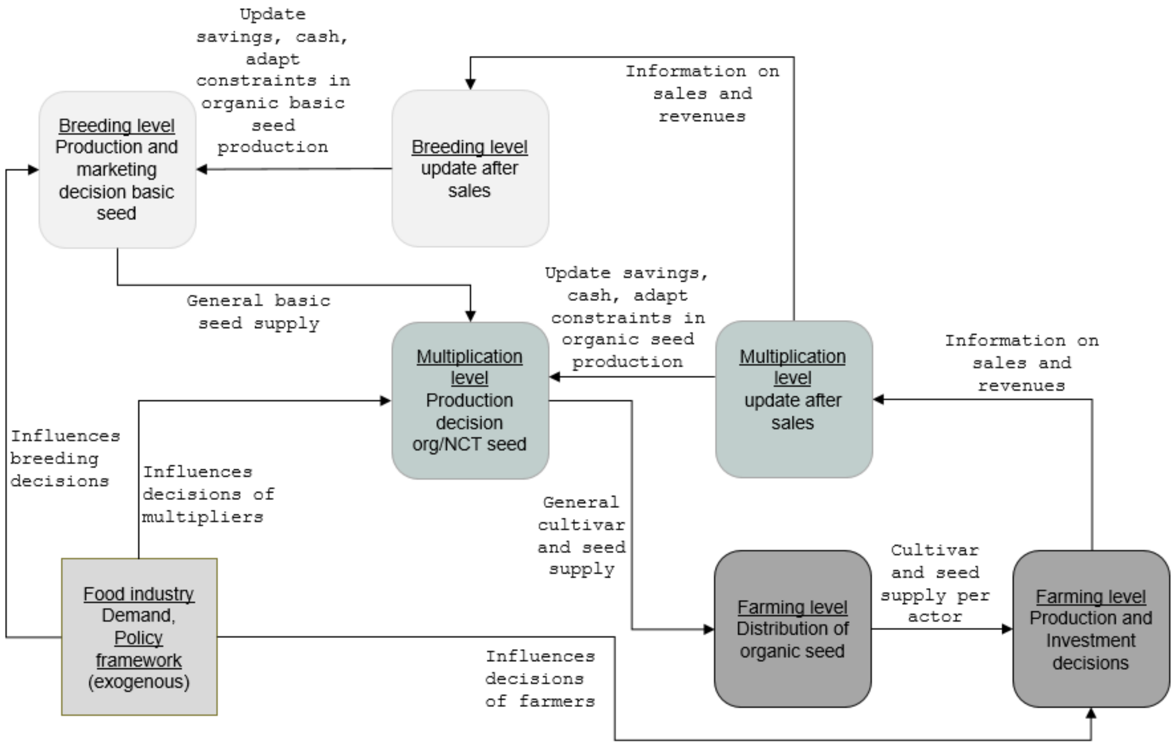

Figure 2: Conceptual framework of the VAL-MAS-*value chain model*

2.3.2 Adaptive expectations of seed producing and breeding agents

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 the multiplication level to smooth increase in the quantity of organic seed supply. The theory of adaptive expectations is based on the assumption that a behaviour, such as organic seed production, is determined by experiences of past sales (Galbács 2015). We defined the upper limit *R* of the amount that can be produced in a year as the average of the sold amount *s* of the last two years multiplied with a growth expectation factor *G*. This factor indicates the trend in demand and is computed as the %-difference 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 *p*. The production reserve factor specifies how much more than the estimated amount is produced for reserve in the case of unexpected higher demand. Lower and upper bounds of *G* were defined as 0.5 and 2. 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 improbable. R_{lo} ensures that a small amount of seed is produced although there is currently no demand, so that re-sowing is possible.

Furthermore, to account for uncertainties due to technical difficulties, p under a growth scenario where an increasing organic seed demand is expected is always bounded by 1.2 and 1.5 respectively. 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. The bounds for G and p are based on expert opinions as part of this study's data collection, as empirical data was unavailable. The values thus need be interpreted with caution. The formulae for calculating G and R of are as follows:

$$G = \min(\max(((s_t + s_{t-1})/(s_{t-1} + s_{t-2}))p,\ G_{lo}), G_{up}) \quad (1)$$

$$R = \max(((s_t + s_{t-1})/2)G,\ R_{lo}) \quad (2)$$

At farm agent level, adaptive expectations are not modelled for parsimony's sake. However, each modelling year, farming agents receive a forecast of possible farm gate prices and yields for the current year and the years after by solving the dynamic LP. This forecast is then updated in each modelling period to reflect uncertainty in farming.

2.4 Verification, calibration, and validation

To ensure that the model generates results corresponding to real world observations, verification, calibration, and validation procedures were conducted.

During ***verification***, the generated agent population is examined as to how well it represents the characteristics of the observed data on the actor population. 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. The data can be found in the Appendix A.5.

Calibration of a model is the process of adjusting certain parameters so that the model produces results in the baseline that are as similar as possible to real-world conditions (Howitt 1995; Troost and Berger 2015b). 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 1% seed used of organic cultivars of the overall seed used (Herstatt 2017). First of all, this was achieved by assuming firstly that the organic hybrid seed producer is willing to accept an income reduction for organic seed production amounting to 50 € per 1 Mio marketed seed compared to NCT seed in the current conditions. This number was revealed when comparing gross margins of NCT and organic seed production as part of our data collection. We can assume that this willingness to forego some income for the sake of producing organic seed is a strategic marketing decision to gain an advantage once derogations are phased out. Secondly, an excess willingness to pay (WTP) for organic seed at farming level was assumed, depending on the innovativeness segment of each farm agent. This excess WTP seems plausible, as currently 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). Yet, in reality, we observed a 10%-share of organic seed use among carrot growers. The overall distribution of the excess WTP for organic seed compared to the NCT price was derived from a small survey among organic carrot producers in Germany, as mentioned in Subsection 2.2.2. In Appendix A.6, 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 the farm level, as well as aggregate model results such as overall area, production amounts, and number of agents. As illustrated in Table 2, in most cases, the model baseline result and the observation are closely matched. Only in the case of seed multiplication type II, the difference in gross margins is rather large. However, as all other values seem valid, this deviation is acceptable and the impact estimates are considered valid evidence.

Table 2: Overview of validation indicators, real-world observations and model results

Validation indicator	**Observation**	**Model baseline result (Av. of ten agent populations*)**
Farm level		
Total organic carrot production in tons and hectares	Overall organic carrot production: 2,102.5 ha, 102,418.3 tons (Destatis 2018) Wash/storage carrots: 1,260 ha (On approx. 60% of this area, carrots for the fresh market and storage are produced (own data collection) 51,209 tons (approx. 50% of total production)	Carrots for the fresh market and storage: 1,300 ha, 51,023.3 tons
Organic carrot seed use in Mio seed	10% organic seed use and less than 1% organic seed use from organic cultivars (Herstatt 2017)	9% organic seed use, 0.3% seed use from organic cultivars
Farm enterprise gross margins in €/farm enterprise	Estimated gross margin at farm enterprise level is 7,503.8 € for a crop rotation comprising mostly arable crops and 14,954.8 € for a crop rotation comprising mostly vegetable crops (KTBL 2016; AMI 2020; Destatis 2018)	The average yearly gross margin at farm enterprise level over all farm agents is 6,457.8 € with a crop rotation comprising mostly arable crops and 11,589.5 € with 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: 717,065 € Type II: 1,365 €
Breeding budget for carrots in €	Type I: 5,180,480 € Type II: 300 – 1,500 €, as only less than 5% acquired through re-financing and 30,000 € of yearly carrot breeding budget mostly acquired through donations (own data collection)	Type I: 5,121,817 € Type II: 314 € 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.

Note: *This is part of the sensitivity analysis. See further information in Subsection 2.6.

Furthermore, to validate aspects of the model, where a lack of real-world observations exists for comparison purposes, structural validation can be useful. During a structural validation, stakeholders involved in the investigated problem are consulted to validate these assumptions and model results (Qudrat-Ullah 2005). The assumption that the excess WTP stays constant across scenarios and the occurrence of an organic seed shortage in a derogation scenario without other measures underwent a structural validation and confirmation through seed sector expert interviews.

2.5 Scenario definition

Interventions were co-designed during interviews with project stakeholders and value chain actors in 2018 and 2019 and during an expert workshop in 2019 (Orsini et al. 2019). Interventions of greatest interest to the stakeholders were selected and are listed in the following:

- Step-wise phasing out of derogations at farm level to use organic seed and/or organic cultivars ***[Derog]***
- Condition "Higher germination rate": lygus bug control in organic carrot seed production realised (Weijland 2020)[2] ***[HgermR]***
- Condition "Sufficient seed": Constraint on organic seed production (G_{up}<=2) is relaxed, so that supply can catch up with the organic seed need in a step-wise phasing out of

[2] The lygus bug causes considerable damage in carrot seed production if it is not controlled. Experts confirm that this is currently the main challenge in organic carrot seed production for wash/storage carrots. 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.

derogations, e.g. through close communication between seed producers and organic seed expert groups ***[SuffS]***

- Subsidy for organic seed use related to cultivation area ***[Subs]***
- Organic carrot farm gate price premium per ton of organic seed use ***[Prce]***

Stand-alone or combined interventions are implemented as model scenarios. Scenario development involved a number of specifications. Table 3 provides a detailed overview of all scenarios and corresponding model specifications.

Table 3: 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) 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
(4) Scenario 2 ***[Derog]*** + and 3 ***[HgermR]***	No new specifications
(5) Scenario 4 ***[Derog, HgermR]*** + Condition "Sufficient organic seed" ***[SuffS]***	The adaptive expectations mechanism of seed producers is relaxed to the extent that organic seed supply can meet organic seed demand: Growth expectation factor is calibrated to 3. At this value, there is no organic seed shortage for the two-year step-wise phasing out of derogations as proposed in Scenario 2.
(6) Subsidy for organic seed and organic cultivars use related to cultivation area ***[Subs]***	Same specifications as in Scenario 1 Different levels of subsidies at the 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)
(7) 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 the 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)
(8) Scenarios 3 ***[HgermR]*** + 6 ***[Subs]***	No new specifications
(9) Scenarios 3 ***[HgermR]*** + 7 ***[Prce]***	No new specifications

(10) Scenario 8 ***[HgermR, Subs]*** + Condition "Sufficient organic seed" ***[SuffS]***	No new specifications

2.6 Sensitivity analyses

Sensitivity analyses helped to obtain greater insight into the variations of the outcomes caused by specific model parameters, e.g. input prices or expected yields. We created ten 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 WTP, yields and prices at the farm level are implemented as random triangular distributions, these values changed with each model run if the seed value was adjusted. Furthermore, yields and farm gate prices changed every model period as a proxy for farming uncertainty. Farm gate prices are the same for all farming agents in one modelling year, because the marketing channel and thus the prices are similar for all farmers in our case study. The yields are farm agent specific, as here, a larger variability due to e.g. local weather patterns and soils is to be expected. Seed prices are held constant over the years, because they do not seem to be subject to large variation according to expert opinions. The triangular distributions are listed in Appendix A.7. Sensitivity results are shown in Table 4.

3. Results

The area under organic cropping is held constant over the eight model periods so that effects of interventions can be compared to the baseline without having to account for crop area changes. The results on gross margins and breeding budgets presented in this section are calculated from the last three model periods (years six to eight). Organic seed amounts are also averaged over these three years. Different levels of subsidies and price premiums were tested and the most interesting with regard to organic seed use and production are presented in this section.

Three public policy or private sector interventions were tested under two different conditions, as defined in Table 3. The results of the most relevant intervention scenarios are compared to the baseline results, as shown in the following two subsections and in Table 4.

3.1 Command and control phasing out of derogations with and without improved lygus bug control (Scenarios 2 to 5)

Regarding scenarios with derogations, 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 Scenario 2 ***[Derog]***, representing phasing out of derogations under current conditions, not enough organic seed can be produced according to the model results due to technical limitations in seed multiplication. In all scenarios that involve derogations the farm agents have to bear the burden of insufficient organic seed supply. They incur additional seed costs and have to switch to other, less profitable crops because of seed shortage for carrots. In Scenario 2 ***[Derog]***, this amounts to an average 11% loss in farm enterprise gross margin (see Table 4, Row 3, Column 2).

In Scenario 3 ***[HgermR]***, technical difficulties regarding lygus bug control are overcome. However, as organic seed is still substantially more expensive than NCT seed, there is no demand by the farming agents. Only in Scenario 4 ***[Derog, HgermR]***, where the derogation scheme is applied, farming agents start to use organic seed. Yet, organic seed production can still not match demand, as according to the model implementation, seed producers are conservative with their production increase and form their expectations based on previous experiences (see Subsection 2.1.4). However, due to the higher germination rate, organic seed production becomes more profitable than NCT seed (see Table 4, Row 4, Column 3). Consequently the gross margin of seed multiplication type II (Table 4, Row 4, Column 4) and the overall organic seed production (organic seed and organic seed from organic cultivars) increased substantially (see Table 4, Row 4, Columns 9 and 10). This scenario translates into a slightly lower gross margin reduction at the farm level, in the magnitude of 9%. If seed producer agents increase their production according to expected future demand, accepting a higher risk of losses in case they cannot sell all seed as expected, farm agents incur only a gross margin loss of 3% according to Scenario 5 ***[Derog, HgermR, SuffS]*** in our simulations. The organic seed use and the NCT seed use trajectories in this scenario are illustrated in Figure 3 as the black and the dotted lines respectively. The compensation of income trade-offs incurred in Scenarios 2 and 4 is depicted in Figure 5, which, for various scenarios, displays the distribution of average yearly gross margins per farm enterprise across the farm agent population. When looking at Columns 5 and 6 in Table 4, it can be seen that the change in breeding budgets of both breeding company types is positive. This shows that in Scenarios 2, 4, and 5, the necessary breeding budgets can be sustained or increased.

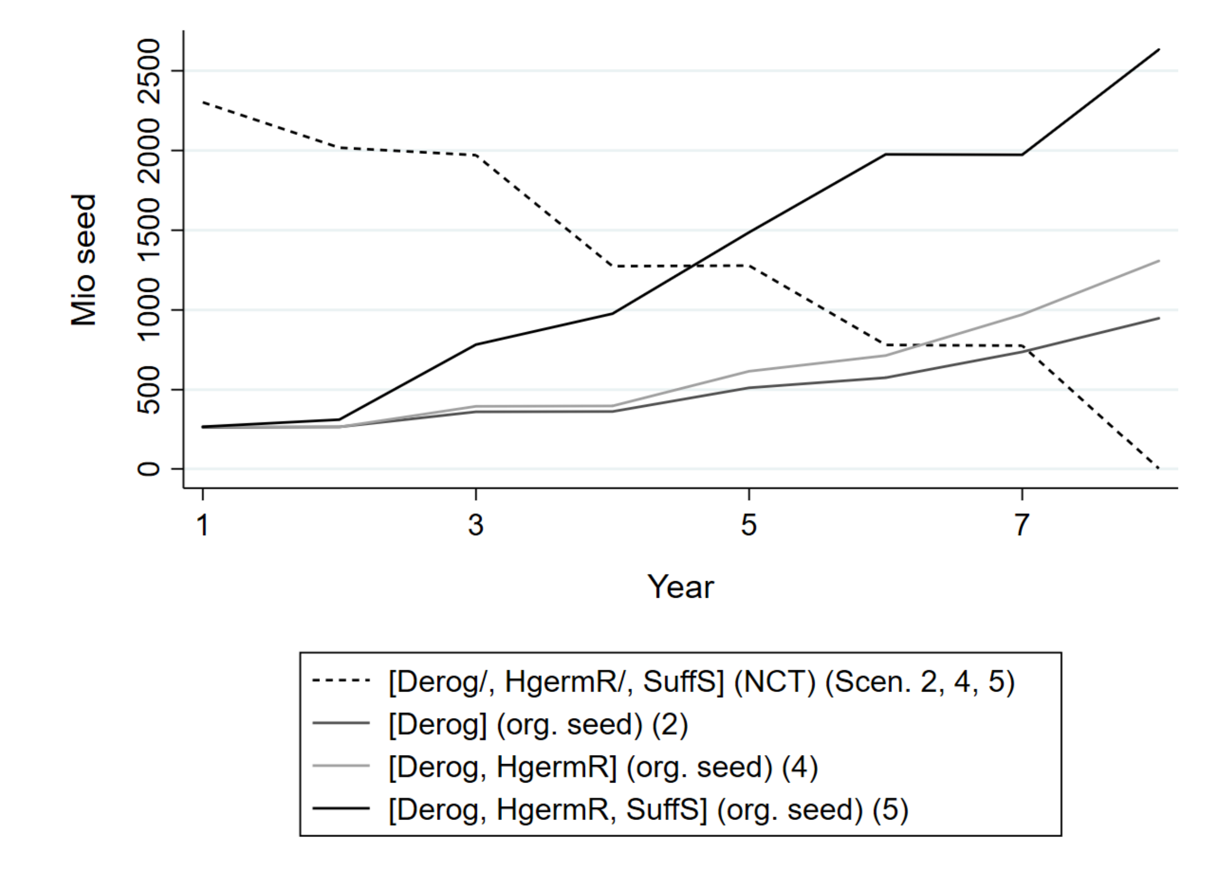

Figure 3: Development of the mean of aggregated organic and NCT seed use over eight years under step-wise phasing out of derogations

3.2 Voluntary measures to incentivise farmers to use organic seed (Scenarios 6 to 10)

A number of measures were identified to support farmers in covering the additional costs of organic seed use, including compensation payments (subsidies) or increased product prices at the production level. In Table 4, Scenario 6 ***[Subs]****,* it can be observed that an area subsidy for using organic carrot seed of 500 € per ha provides an incentive for all farm agents (down to the last adopter group, the "laggards") (see Table 4, Row 6, Column 11) to use organic seed when available. Over the entire modelling phase of eight years and all agents, this amounts to a total subsidy cost of 164,792 € (Table 4, Row 6, Column 7). This goes up to around 690,000 € (see Table 4, Row 6, Column 8) once organic seed production capacities have been increased to match demand ***[HgermR, Subs, SuffS]***. For Scenarios 6, 8, and 10, the modelled subsidy impacts on seed use trajectories can be seen in Figure 4, under current conditions ***[Subs]***, under improved lygus bug control ***[Subs, HgermR]***, and in a combined scenario ***[HgermR, Subs, SuffS]*** (Scenario 10). The gross margin impact of Scenario 10 ***[HgermR, Subs, SuffS]*** is shown in Figure 5. It implies that farm agents are compensated by the 500 €/ha subsidy and that no gross margin losses occur on the whole, while policy costs were estimated at approximately 690,000 €.

The model results in Scenario 7 ***[Prce]*** also demonstrate that, as an alternative to subsidies, a price increase of 10 € per ton of organic carrots provides an incentive to all farm agents (down to the last adopter group, the "laggards") to use organic seed when available. Over the entire modelling phase of eight years, this amounts to a total cost of the price premium of 162,009 € with around 24% organic seed use across the agent population, and around 690,000 € when organic seed production capacities have increased to match demand, so that 100% organic seed is used. Once the price premium is reduced from 10 to 5 € per ton of organic carrots produced with organic seed, organic seed diffuses only to the early majority of the farm agent population, while the intervention would only cost around 22,692 € with overall organic seed use reaching approximately 50% (see Table 4, Row 9, Column 12). As such, this intervention would be more cost-effective, but cannot induce the entire agent population to adopt organic seed.

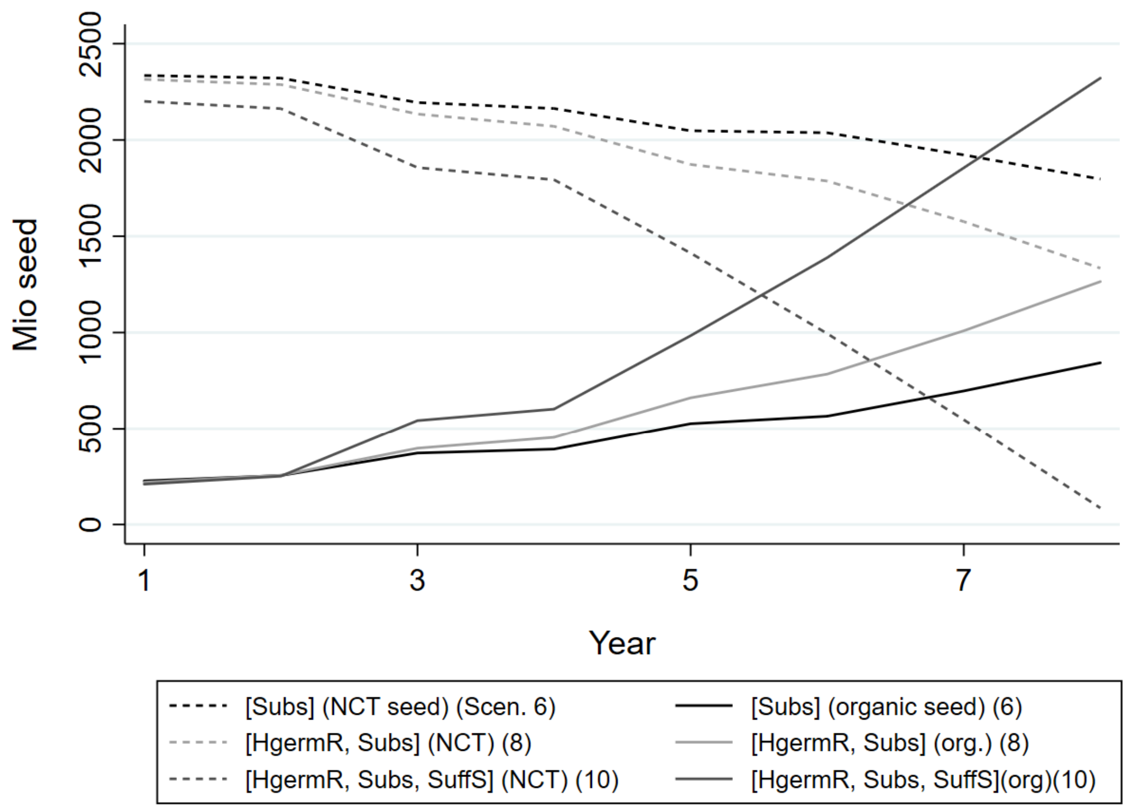

Figure 4: Development of the mean of aggregated organic seed use over eight years under different incentive schemes

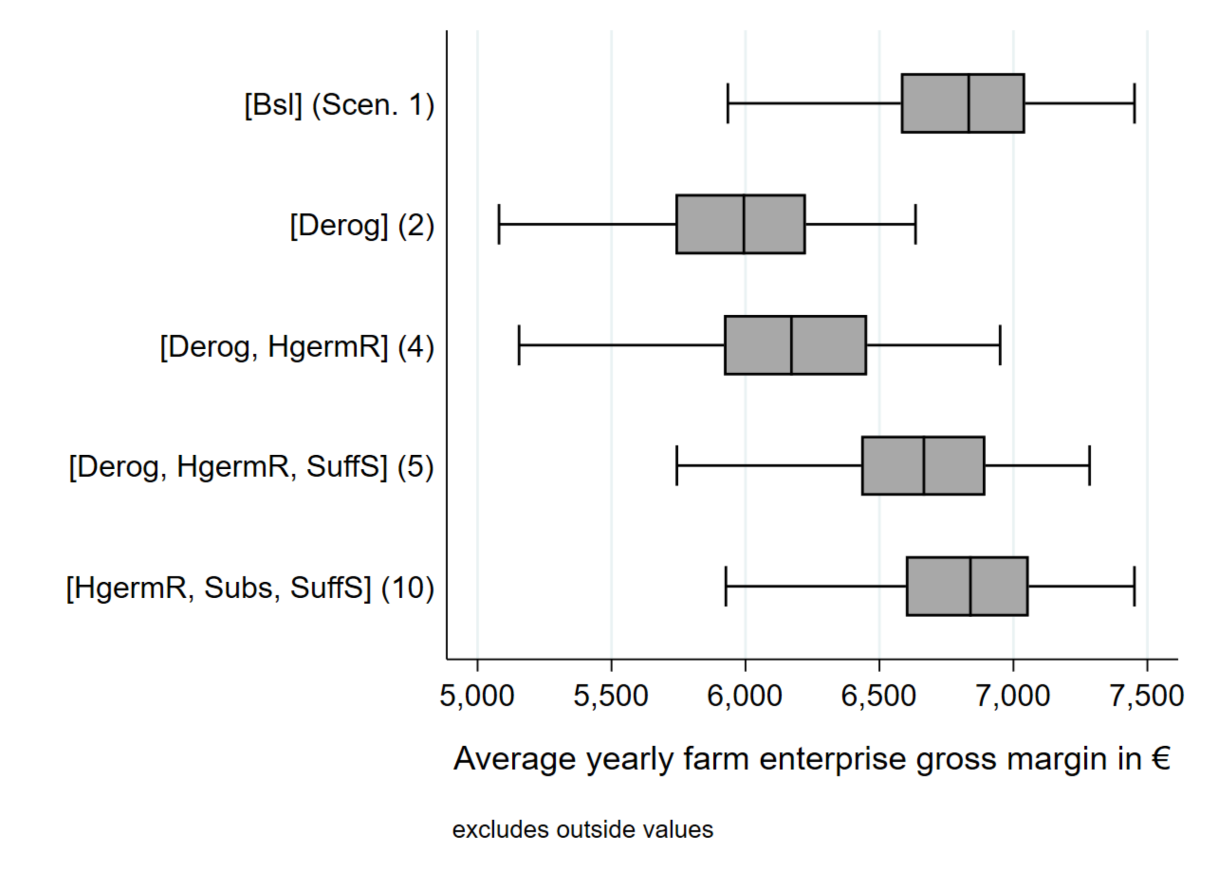

Figure 5: Distribution of yearly gross margins per hectare at farm enterprise level under selected scenarios (excluding values that do not lie within 1.5 times the interquartile range (outside values))

Table 4[3]: Summary of results using key outcome variables

(1) Scenarios	(2) % Δ GM/ Farm Enterp.	(3) % Δ GM/seed multipl. org. + NCT seed	(4) % Δ GM/seed multipl. org. cultivars	(5) % Δ breeding budget (org., NCT, CT seed)	(6) % Δ breeding budget org. cultivars	(7) Costs of intervention in model period in €	(8) Predicted total costs of intervention in €	(9) % marketed organic seed of total market	(10) % marketed seed of org. cultivars of total market	(11) Diffusion of organic seed to adopter group	(12) Cost effectiveness (Ha planted with organic seed per €)
(2) [Derog] (Scen. 2)	-11%	-3.6%	515%	0.6%	401%	n/a	n/a	23.7%	1.9%	n/a	n/a
(3) [HgermR] (Scen. 3)	0%	0%	0%	0%	0%	n/a	n/a	0%	0%	n/a	n/a
(4) [Derog, HgermR] (Scen. 4)	-9%	8%	582%	0.6%	501%	n/a	n/a	37.9%	2.4%	n/a	n/a
(5) [Derog, HgermR, SuffS] (Scen. 5)	-3%	36%	373%	4.3%	937%	n/a	n/a	81.3%	1.5%	n/a	n/a
(6) [Subs] (500 €/ha) (Scen. 6)	0.08%	-0.4%	1246%	0.4%	1293%	164,792	690,000	20.6%	3.1%	Laggards	0.002
(7) [Subs] (150 €/ha) (Scen. 6)	0%	-0.3%	950%	0.4%	1095%	23,015	103,500	19.6%	2.5%	Early Majority	0.007
(8) [Prce] (10 €/ton org. carrots) (Scen. 7)	0.03%	-0.1%	1078%	0.6%	1160%	162,009	690,000	20.4%	3%	Laggards	0.002
(9) [Prce] (5 €/ton org. carrots) (Scen. 7)	0%	0%	941%	0.4%	1098%	22,692	103,500	19.2%	2.6%	Early Majority	0.007
(10) [HgermR, Subs (500 €/ha)] (Scen. 8)	0.1%	8%	1538%	0.5%	1795%	273,980	690,000	34.4%	6.4%	Laggards	0.002
(11) [HgermR, Prce (10 €/ton org. carrots),] (Scen. 9)	0.02%	8%	1507%	0.6%	1794%	270,537	690,000	34.1%	5.1%	Laggards	n/a
(12) [HgermR, Subs (500 €/ha), SuffS] (Scen. 10)	0.1%	36%	1338%	4.3%	2093%	700,000	690,000	73.1%	6%	Laggards	0.002

[3] Gross Margin (GM), Not Chemically Treated (NCT), Organic (org.), Chemically Treated (CT), for abbreviations of scenarios, see Table 3

4. Discussion

4.1 Policy implications

Organic carrot producers in Germany seem to have a rather high excess WTP for organic seed and cultivars, estimated at 45% on average if compared to NCT seed. Other studies confirm that the higher price of organic seed is not always the main obstacle for farmers to use organic seed (Hubbard and Zystro 2016; Levert 2014). However, organic carrot seed use from hybrids or OP cultivars in carrots of the market segment wash/storage is very pricy (around 60% more expensive than NCT seed). The excess WTP across the farm population is thus not high enough to induce the whole farm agent population to use organic seed. In order to encourage farmers and stimulate investments in organic seed and breeding in this segment, a subsidy at the country level or a premium price at, e.g. the processor level, could be a potential first step. In Estonia, Slovenia, and the Czech Republic, a payment for organic seed use is already integrated into the Common Agricultural Policy (CAP) area payments. For example, in Latvia the CAP area payment is 20% increased if organic seeds are used as a second pillar measure (Fuss et al. 2020). However, as this payment has only been integrated recently, there is no evidence available about its effectiveness. Based on simulation runs, we estimated 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 organic carrot producer agent population to adopt organic seed. However, a subsidy of 500 €/ha seems to be rather high, on top of 390 to 590 €/ha already received by organic vegetable producers in Germany as part of the second pillar rural development payments for organic production (BLE 2021). Conversely, a 10 € increase of the farm gate price per ton of organic carrots would result only in an increase of around 1% of the current average end consumer price (AMI 2020). This higher price does not seem prohibitive and could thus be a way forward towards more organic seed use. Approximately half of the modelled organic carrot producer population gain access to organic seed 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, further uptake would be accelerated (Orsini et al. 2020).

High uncertainty in seed production occurs with respect to organic carrots in the market segment wash/storage, as there are several technical problems in organic seed production. This is true also for other crops to varying extents and especially for other biennial seed crops, for example cauliflower. Furthermore, the results of this study imply that under current conditions organic seed production is not yet profitable. If technical problems are not addressed first, there may be a seed shortage under scenarios like phasing out derogations for the use of 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 NCT seed for all crops 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. 2020). Thus, it seems advisable to prioritise investment into research on the stability of organic carrot seed production for the investigated segment. 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. This investment could be financed through public means, or the currently needed WTP of the seed producer to produce organic seed could be paid as a subsidy to seed producers in order to incentivise them to produce organic seed. However, an investment in pest control seems a more long-term solution and is thus maybe preferable. This may be true for other biennial seed crops, such as cauliflower. According to our modelling results, the investigated organic and NCT carrot seed multiplier can increase their gross margin by 36% if they produced organic seed as opposed to NCT seed if the germination rate is higher. 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 essential changing this. For example, lygus bug management in carrot seed production is frequently mentioned as main challenge (Wohleb 2019; High Mowing Seeds 2021).

It seems advisable to conduct similar studies for important organic crops throughout Europe, to establish sound scientific knowledge about the necessary steps to increase organic seed use and production. This is of particular importance in the light of the farm-to-fork strategy recently put into action by the EU. With this strategy, the EU commits to increasing the organic farm land share by 25% until 2030 (European Commission 2020). The realisation of this goal will need to be accompanied by a substantial increase in organic seed production and breeding for the organic sector.

4.2 Limitations and novelties of this study and outlook

Some limitations of this study need to be mentioned. We used a case study approach by selecting one country-crop combination, but also by selecting specific companies and initiatives for data collection. Thus, conclusions are not necessarily representative of the organic sector as a whole and they also need to be interpreted with caution at the value chain level. Furthermore, some parameters that influence the simulation outcome are based on expert assumptions, such as the growth expectation factor (see 2.3.2). Uncertainties in these parameters were addressed through sensitivity analyses, wherever possible.

While there are some limitations inherent to the VAL-MAS modelling approach, this is the first study, to our knowledge, that models the behaviour of an entire value chain using a mathematical programming and agent-based approach. This goes beyond previous approaches in value chain analysis which mainly focused on qualitative analyses of seed systems (Bellù 2013; Mulugeta et al. 2010; Kumara et al. 2012). Taking heterogeneity of value chain agents across the seed and breeding value chain into account, the agent-based approach is more refined than a sector model. In the latter, important aspects such as the diffusion of an innovation or individual behaviour of seed multipliers cannot be addressed. (Möhring et al. 2016; Crooks and Heppenstall 2012). In VAL-MAS on the contrary, dynamic in the seed and breeding value chain as well as in the entire farm population could be represented over time. Another novelty is the simulation of future policy scenarios for the organic seed and breeding sector, while taking the economic situation of the entire chain into account and investigating an important country-crop case in Europe. For future research, this model could be adapted to other crop-country cases in order to move forward the discussion on a road map to 100% organic seed use in Europe. Potential extensions of the model could be the incorporation of risk or external effects, as innovations that reduce risk or provide positive externalities(e.g. pesticide reduction or diversification of crop rotations) gain in importance to achieve more sustainable food systems, in line with the farm-to-fork strategy of the European Commission (European Commission 2020).

5. Conclusions

The VAL-MAS model application confirms that the end of the derogation system poses a challenge for the organic carrot seed value chain. Addressing this issue is of particular EU-wide importance to meet EU policy goals such as the farm-to-fork strategy. Countervailing measures are needed to smooth the transition from the current system to the end of derogations. Our scenarios suggest that investment in agricultural innovation at seed multiplication together with economic incentives for farmers represent viable mitigating measures .Improved germination for pest control during seed production, accompanied by a step-wise phasing out of derogations for the use of non-organic seed is a potential way forward. Furthermore, in order to avoid income trade-offs at farm level, our model results imply that either a subsidy or a price premium for organic seed use would be required. Simulation results show that a subsidy of 500 €/ha organic carrot production or a price premium of 10 €/t organic carrots for the use of organic carrot seed at farm level would be necessary to counter trade-offs. We calculated that a subsidy of 500 €/ha organic carrot production or a price premium of 10 €/t organic carrots for the use of organic carrot seed at farm level would be necessary.

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3. Discussion of results

3.1 The need for and use of organic seed and breeding

There is a debate whether organic seed and especially organic cultivars are necessary. On the one hand, organic seed is described as mandatory in the EU organic regulation. Furthermore, adapted cultivars are recommended (Organic Regulation 848/2018). Organic breeders and a part of the overall organic movement argue that cultivars bred completely under organic conditions are the most suitable for organic agriculture (Lammerts van Bueren et al. 2011). They further argue that organic breeding is crucial to maintain the integrity of organic agricultural production and in order to avoid a food scandal around this. Consumer trust in organic products is currently high (Murphy et al. 2021). Demand has been growing at a fast rate since the introduction of a harmonised EU organic regulation (Willer et al. 2020, 2021; Willer and Lernoud 2016, 2019, 2017, 2018). However, scandals can have a detrimental and immediate effect on sales (Bánáti 2011). An example in the vicinity of organic agriculture and breeding is the scandal around brassica bred with cell fusion technology (Organic Market 2013). Consumers are currently not aware of the challenges in organic agriculture with regard to the non-availability of organic seed and cultivars. In general, there is limited communication by e.g. retailers on the subject (Richter 2012; Bioverita 2020). This could cause an organic food scandal in the future.

On the other hand, the derogation system is established and the majority of organic farmers are in reality used to non-organic bred cultivars and seed produced under non-organic conditions (Orsini et al. 2020; Solfanelli et al. 2020). Breeders and seed multipliers supplying the organic sector with these inputs argue that the status quo of the organisation of these value chains is already well-functioning and that the government should not interfere (Orsini et al. 2019).

Organic seed does not bear tangible advantages for organic farmers and is in most cases more expensive than NCT seed, as was shown in Studies 3 and 4 of this thesis. However, this thesis has shown that, in combination with a suitable cultivar for organic production, this price difference can become irrelevant, as shown in Study 1. In the case studies illustrated in Studies 3 and 4, organic seed uptake had to either be made mandatory or incentivised to account for the additional costs. Nevertheless, it was used by organic farmers in all three cases in the phasing out of derogations scenarios and thus the organic focus crop production was still deemed profitable.

The debate around the use and need of organic breeding is more controversial. In this thesis, this debate has been brought forward in several ways. In Study 1, a successful example of the use of organic breeding for society could be shown. While much evidence on the usefulness of breeding has been created for conventional breeding, evidence on the economic effects of research and development in breeding for organic crops is still missing. In Study 1, the adoption, economic impact, and rates of return to the organic crop improvement research programme of a Winter wheat cultivar wide spread in Switzerland and Southern Germany were therefore assessed. Substantial economic returns of 18.6% for the period from 1988 to 2019 could be calculated. The standard economic surplus model was extended with indicators measuring crop nutrient and processing quality as well as resilience gains. This shows that organic breeding can have an overall societal welfare gain. Especially as regards climate change mitigation, the resilience gain measured with a reduction of downside risk is of particular importance in organic agriculture, where preventative measures are central. Thus, the first research focus of this thesis has shown that further investment in organic breeding is a promising strategy for resilient and sustainable food systems.

However, in Studies 3 and 4, some of the tested organic cultivars did not show an increased positive economic effect in comparison with other available, non-organic cultivars. An example is the open pollinated organic bred carrot cultivar that is only taken up by around 1% of all organic carrot farmers in the baseline. Although some excess willingness to pay for organic integrity and economic incentives such as a subsidy or price premium than the current non-organic cultivars are assumed, the organic cultivar is only adopted to a very limited amount. Here, it seems that organic seed from non-organic cultivars are more attractive to organic farmers. The organic carrot cultivar is open pollinated and can therefore be reproduced by the farmer. This is one of the main principles of organic breeding. This is not possible with hybrid varieties, as they are only homogeneous in the first generation. Furthermore, although the yield of the OP organic bred cultivars is effectively lower than hybrid yield, there is some evidence that dry matter and nutrient contents are the same (Ebner 2018). Nevertheless, the main obstacle for farmers to use organically bred carrot cultivars is the around 20% lower yield, as they are generally not compensated with a higher farm gate price or similar (Ebner 2018).

Another example is the OHM in organic durum wheat production, where the adoption in our modelling analysis in Study 3 only takes place when heavily incentivised. It is sometimes argued in the organic sector that this could be a promising attempt at moving towards organically bred cultivars well suited for organic agriculture. This is the case because OHM is very stable in its yield and has a low external input need, which can be a notable advantage in low input systems (Bickler 2018; Messmer et al. 2018). Here, the chosen method is likely to not fully show the uptake of this cultivar, because it may be more interesting for more extensively managed farms than the identified typical farms. Additionally, the approach did not allow for the assumption of an excess WTP. However, as it is assumed in this study that the majority of farms is similar to these typical farms, the analysed OHM is still likely to stay a niche. This is the case because the yield of this specific OHM is substantially lower than the other cultivars on the market. The reduction in external inputs in the OHM case cannot compensate for this.

This shows that in some cases, there is a discrepancy of beliefs in benefits of organic cultivars and their real performance in the current organic breeding value chain. Some cultivars are still not up to the current standards to meet market demands. Another explanation is in some cases that organic breeding goals prioritised by organic breeders are not in line with these standards. Furthermore, when pre-defining breeding goals that resolve a certain issue, such as low nitrogen uptake in organic perennial ryegrass seed production as was tested in Study 3, breeding for the organic sector can have explicit positive effects. This scenario assumes sufficient funds to achieve these breeding goals.

In Study 2, a screening of existing organic breeding initiatives has revealed that insecure und insufficient funding seems to be one of the main barriers for organic cultivars to meet current market standards. In the course of the same research, a pathway for financing organic breeding in the future was defined in a participatory process, i.e., a stakeholder dialogue comprising several key informant interviews and workshops. Results from the stakeholder dialogue show that this pathway could be a value chain partnership where organic breeding is financed by down-stream value chain actors and breeding goals are defined as a collective effort. Furthermore, in Study 2, the survey results of organic farmers in Europe shows the necessity to better integrate long organic value chains such as processors, traders, and retailers and seed supply, as farmers currently marketing through long value chains use significantly less organic seed.

Moreover, all farmers having participated in the above mentioned survey highlighted the development of organic breeding a crucial step to achieving higher organic seed use. This indicates that overcoming organic seed shortage is more likely to be achieved when also including breeding activities.

Committed actors may not want to join in for a long-term, substantial financial commitment assuming that other firms would not join and be free riders on the cultivars being produced though the pool-funding (Ostrom 1998). Although the organic value chain can significantly benefit from investments in organic breeding, while there are no binding agreements between the actors to invest, game theory predicts them to maximise their short-term interests. This will be further discussed in the following section.

All in all, there is no conclusive answer to the question of the current use of and need for organic cultivars. One organic cultivar was taken up by farmers for its useful qualities and societal welfare was improved through the uptake. In other cases, organic breeding seems to not yet be advanced enough. Finding financing strategies to build up the organic breeding industry appears to be a major issue.

3.2 The effects of measures to increase organic seed and cultivar use and production

There are different perspectives about the need for measures to promote organic seed and cultivar production and use or if the market can provide 100% organic seed. A recent study concludes that measures, more specifically policy measures, are needed to make the transition, as the market has continuously failed to provide sufficient organic seed in the last 25 years. They further caution that a full enforcement of the organic regulation (immediate phasing out of derogations) could lead to seed shortages. Thus, they recommend a coordinated public strategy including information disclosure across the value chain on potential organic seed demand and supply, investment in organic seed production and breeding to close bottlenecks, and a step-wise phasing out of derogations. However, they caution to choose measures with care and based on a case per case procedure (Padel et al. 2021).

This thesis is the first study to present concrete figures on the effects of organic breeding and of policy and voluntary measures to encourage organic seed use and production. A number of measures were evaluated. Study 1 shows that organic breeding can be successful on the basis of voluntary financing strategies and that farmers adopt an organic cultivar if it has substantial benefits over the preceding cultivars. It needs to be taken into account that societal gains do not assure profitability of the breeding activities themselves. They only show the larger benefits of such research and development investments, while the small organic breeding initiatives often cover their costs only with difficulty. The initiative that bred Wiwa is financing its activities mostly through donations and sponsorships. It cannot yet re-finance its breeding activities through seed sales. The positive findings on the wider economic benefits welfare of organic breeding, however, provide a rationale for developing creative funding solutions and boosting public and private Research and Development (R&D) spending in the sector.

As regards the results in Study 2, there is a variety of governance models and financing strategies. Organic breeding seems still under-financed and this impairs results (see Studies 3 and 4). Results from Studies 1, 3, and 4 build the rationale for finding a secure and well-functioning financing strategy for organic breeding. In Study 2, a voluntary measure as a result of a stakeholder dialogue is proposed. As mentioned in Section 3.1. already, there may be the problem of free riding of actors on positive outcomes of investments in organic breeding from other actors. In order to overcome this dilemma, binding contracts and clear communication strategies need to be developed. There are some crucial points mentioned in the pool-funding framework like conditions to mitigate this risk. Food industry actors and organic breeders would enter into a longer-term commitment to define breeding goals and budgets together. This type of standardised funding would allow a collective investment and long-term commitment of the food industry. This could ensure a constant supply of cultivars and animal breeds. The awareness-raising and communication element of the pool funding strategy is another important part. Only participants in the pool-funding could communicate their commitment to organic breeding. However, it is likely that voluntary measures alone or a reliance on market mechanisms are insufficient.

In Studies 3 and 4, a variety of different interventions to increase organic seed and cultivar use and production is modelled in three different case studies. These are two of the first studies taking the gross margin changes of seed production and farming with regard to organic seed and cultivars under different conditions into account.

Looking at a step-wise phasing out of derogations scenario across case studies, this seems to work in some cases, in others the steps may have to be adapted and closely aligned with what is possible in production. In this kind of command and control scenario, the financial burden would be with the farmer. However, it is possible that there would be a re-allocation towards another level of the value chain, e.g. a farm-gate price increase.

In order to compensate farmers for their decrease in gross margin and to incentivise them on a voluntary basis, a subsidy could be a first step to encourage farmers to use organic seed. At a certain subsidy level in the modelling exercise, farmers start using organic seed. It is uncertain if this would be the case in reality. A combination of a subsidy with a clear plan of a phasing out of derogations may be a better way forward, as then farmers can get used to the available cultivars with a compensation of the higher costs and organic seed production is being incentivised indirectly.

However, in the case of wash/storage carrots in Germany, organic seed production is not yet as attractive as NCT. Here, a subsidy may be necessary to incentivise seed producers to take up organic seed production. Nevertheless, anecdotal evidence shows that political security with regard to planned measures such as the phasing out of derogations is a primary factor for seed producers to enter into the decision whether or not to increase organic seed production.

A further measure in the case of organic carrots would be an investment in pest control. This could either be financed publicly, or seed producers might be incentivised through market security to conduct the research themselves. This market security could be given through e.g. a binding governmental plan regarding the phasing out of derogations to use NCT seed that would allow for sufficient time for research.

A publicly organised organic breeding programme can be found in Switzerland. There, a public-private partnership is set up, where costs and tasks are shared by a public institution and a medium-sized seed company (Wilhem 2016). It could be a promising approach to fund organic breeding for perennial ryegrass and other components in forage seed mixtures.

In general, as organic seed production and organic breeding can be described as infant industries (Shafaeddin 2005), because there is a potential market and justification for the products, but the established technologies still have an advantage. For example, organic seed production still faces some difficulties e.g. in pest management, because investments lacked in the past. Based on these aspects, public support seems to be justifiable.

However, the feasibility of the individual subsidy amounts per case needs to be taken into consideration. In the case of organic wash/storage carrots in Germany, it was estimated 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. However, a subsidy of 500 €/ha seems to be rather high, on top of 390 to 590 €/ha already received by organic vegetable producers in Germany as part of the second pillar rural development payments for organic production (BLE 2021). In the case of durum wheat in Italy, a subsidy of 1 €/ha durum wheat to incentivise own organic seed production would be needed. In both Southern and Northern Italian farm types, the current level of subsidies for durum wheat ranges from a minimum of 220 €/ha to a maximum of 258 €/ha (Regione Basilicata 2021; Regione Marche 2021). Here, adding 1 €/ha seems to be a reasonable measure.

Lastly, there could be incentives from food industry actors, i.e. processors or wholesale actors offering a higher farm gate price for organic seed or cultivar use. For example, in the case of wash/storage carrots in Germany, a 10 € increase of the farm gate price per ton of organic carrots would result only in an increase of around 1% of the current average end consumer price (AMI 2020). Such a price premium can help farmers bear the additional costs of organic seed. However, price premiums are subject to a willingness to pay by the downstream actors and can therefore only be recommended in association with the voluntary use of organic cultivars and private labels.

4. Discussion of methods

In this Section, the suitability of the chosen methods, their draw-backs, and the knowledge gain through their application and further developments is discussed. In Study 1, the economic surplus model was used to estimate the adoption, impact, and returns of an organic cultivar. The approach is widely used and thus established. There are, however, some draw-backs (Morris and Heisey 2003) that our application resolves in some ways, while others still remain to be tackled. The traditional approach does not capture advantages not reflected by yields and prices. Attributes not covered are for example shelf-life, taste, micronutrient contents, or regional infrastructural developments through a strengthened local seed industry (Schreinemachers et al. 2017). In this study, the economic surplus model was enhanced by taking quality aspects and reduction of down-side risk in yield losses into account. It was, however, not possible to include other potentially relevant external effects, such as the resulting strengthened local organic seed industry and spill over effects to conventional agriculture and e.g. resulting climate resistance. These aspects could not be taken into account, because measuring and pricing them was beyond the scope of the study.

In Study 2, two main methods were used: Firstly, a multi-step stakeholder dialogue and secondly, a survey among organic farmers across Europe. A multi-step stakeholder dialogue was conducted (Dodds and Benson 2012) with the goal to identify existing financing strategies for organic breeding and to develop a long-term, large-scale financing concept for organic breeding that represents the views of all relevant stakeholders. Steps of the dialogue were (1) explorative interviews with breeders and seed producers in Europe and (2) two formal participatory workshops with all relevant stakeholders and (3) bilateral meetings of scientists with selected stakeholders. A framework for a promising financing strategy for organic breeding could be developed. Renn (2015) point out that one of the major disadvantages of such procedures is that actors that have not been involved might resent the results and not take part. Indeed, it was a particular challenge to engage the food industry players who would need to make commitments to financing organic breeding. However, as some players already participate, others were induced to get involved. Thus, through this participatory approach, a common ground for discussion and more willingness of food industry actors to participate could be created.

Another challenge in the further implementation of the strategy might be that some points in its framework seem hardly consolable. For example, some organic breeders are against property rights for cultivars, meaning that all cultivars produced by them should be publicly available.

In a game-theoretical setting, exclusive property rights is one of the main levers to overcome the problem of free riding (Ostrom 1998). Solving this issue remains a challenge for the successful implementation of the framework. From this perspective, a top-down approach primarily coordinated with food industry partners might have been advantageous. After the setup of a suitable framework, all organic breeders willing to accept the necessary constraints, could join. However, this might exclude many of the established organic breeders. Overall, as a conclusion, a dialogue with all important actors of the value chain seems to be the most appropriate approach.

As regards the second part of the analysis, several constraints need to be mentioned. Firstly, the implementation of a more robust sampling design such as a randomized sampling or purposive sampling would have been desirable to generate more robust results. This was, however, not possible due to privacy restrictions. The comparative analysis of marketing channels required data pre-processing to overcome the unbalanced composition of the two groups (responses grouped as short *vs* long value chains) arising from the opportunity sampling strategy used. The sampling strategy may have caused a bias towards a higher response rate from farmers who are motivated to use organic seed. Various weighting methods were applied to address the bias that will be explained in the following. Through the application of these weighting methods, the dataset can still yield relevant results, e.g. explaining differences in quantity of used organic seed between different farmer groups.

Different data pre-processing methods were evaluated before inverse probability weights with regression adjustment was chosen. For example, the method of propensity score matching for comparison was applied. However, probability weights and standard errors allowing for intragroup correlation with the country indicator as the cluster variable are not implemented in the treatment effects routine in STATA 15; thus, the results are not as accurate as inverse probability weighting combined with regression adjustment (ipwra). Moreover, if the propensity score model is miss-specified, there is no control mechanism as in ipwra (Liu et al. 2019). This is why it was refrained from using either only inverse probability weights or regression adjustment. A more up-to-date method considered in this study was entropy weighting, however, the data for corrections was not available.

In Study 3, two seed and breeding value chain case studies in organic agriculture were analysed. For this, an ex-ante value chain approach was used. A simulation model based on an agent based model across the seed and breeding value chain was parameterised and interventions aiming at organic seed and cultivar use and production increase were tested in the model. Due to data constraints, only typical actors could be represented. This is a draw-back, as one of the main advantages of agent based modelling is the representation of heterogeneity across an agent population (Möhring et al. 2016). However, the typical farm approach also has several advantages. As available samples of farm populations are often small and not collected in a representative way, biases often occur. These can be avoided with the typical farm approach (Chibanda et al. 2020). Another aspect is that an aggregation bias occurring when using average data for model parameterisation can be mitigated (Feuz and Skold 1992). Generally, the approach strives to combine sufficient data depth, consistency and accuracy with reasonable time and resource input for data collection (Chibanda et al. 2020). In Study 4, one additional case was analysed where more data were available and a more comprehensive farm agent population could be modelled.

The cases should cover the three main organic crop sectors forage, cereals, and vegetables. The chosen crops and countries were organic durum wheat in Italy, organic wash/storage carrot in Germany and organic perennial ryegrass intercropped with white clover in England. These case combinations were selected for their importance in the respective organic crop sectors. Data availability and the willingness of seed companies to share economic data were the main constraints. Due to this, e.g. the United Kingdom (UK) had to be included as a case study, although the UK is no longer part of the EU. However, our project partners were situated there and could provide economic data at seed supplier level. Although the strategy regarding derogations has not yet been decided upon in the new agricultural regulations in the UK, the results of this study can still serve as guidance to other countries with a large forage sector and similar climatic conditions.

In Study 3, only economic considerations are taken into account. This is justifiable, as so far no studies exist that analyse this crucial aspect in the necessary degree of detail. An extension towards the inclusion of aspects in behavioural economics was made in Study 4 to do justice to the well-founded assumption that actors do not necessarily only decide upon economic grounds (Shefrin 2002). This is an important inclusion and brings the implementation of realistic decision making in agent-based modelling forward. A recent comprehensive review of the state-of-the-art of decision making in European agent-based models comes to the conclusion that only few attempts to model farmers' emotions, values, learnings, risks, and uncertainty or social interactions are currently undertaken, although these aspects are crucial to realistically model decision making (Huber et al. 2018).

5. Topics for future research

Both the methodological and the research area of this thesis are likely to be of growing importance in the future. As regards the research area, it would be of interest to further investigate policy interactions such as a phasing out of derogations and the achievement of the Farm-to-Fork strategy. Furthermore, it would be valuable to conduct some more selected case studies, e.g. in the East of Europe, to gain a more comprehensive understanding of potential road maps to achieve a substantially higher share of organic seed and cultivars.

The VAL-MAS simulation model has much potential to give insights into effects of interventions along the upstream value chain. It is a case study model that does not have the goal to depict entire economies or sectors. It rather focuses on heterogeneous behaviour in a value chain of interest. In order to more accurately depict agro-ecological consequences of interventions, it would be advisable to include information on environmental effects of activities in the model.

Moreover, currently, prices throughout the value chain are exogenous. The inclusion of a market module where prices could react to changes in the system would be another compelling extension of the model. In this case, price reactions to e.g. a higher supply of organic seed at seed multiplication and farm level could be quantified endogenously. An example of an agent based model with a market module is SWISSland, where a farm agent population takes production decisions and prices are calculated through a coupled partial equilibrium model (Möhring et al. 2016).

6. Conclusions

As a conclusion, the results of this thesis show that there is ambiguity about the current usefulness of organic cultivars. Organic seed is compulsory under the EU organic regulation and it is recommended to use adapted cultivars. Organic breeders and part of the whole organic movement argue that cultivars bred entirely under organic conditions are the most suitable, also to maintain the integrity of organic agricultural production. They further argue that the current high level of consumer confidence and the resulting increase in demand could be damaged by a scandal exposing the lack of use of organic seeds and breeding. Others argue that the derogation system is established and that farmers are in fact used to non-organically bred cultivars and seeds produced under non-organic conditions.

This is contradicted by the results of Study 1, where a significant social welfare gain from an organically bred winter wheat cultivar could be calculated, showing that organic cultivars can be the first choice for organic farmers. This could not be proven in Studies 3 and 4, where the tested organic cultivars did not show an increased positive economic effect compared to other available non-organic cultivars. When setting breeding targets that solve a specific problem, such as low nitrogen uptake in organic perennial ryegrass seed production, breeding for the organic sector can have explicitly positive effects. In this scenario, it is assumed that sufficient resources are available to achieve these breeding objectives. In Study 2, a screening of existing organic breeding initiatives revealed that uncertain and insufficient funding seems to be one of the main obstacles for organic breeding to meet current market standards.

Various interventions proposed in workshops with stakeholders and interviews with key informants were tested. This thesis is the first study to present concrete figures on the impact of organic breeding and policy and voluntary measures to promote organic seed use and production. Study 1 shows that organic breeding based on voluntary funding strategies can be successful and that farmers will adopt the cultivar if it has significant advantages over its predecessors. It should be noted that social benefits do not ensure the profitability of the breeding activities themselves.

Study 2 proposes a voluntary measure as a result of a stakeholder dialogue. The problem of free-riding by stakeholders on positive outcomes of investments in organic breeding by other stakeholders is seen as a threat. To overcome this dilemma, binding contracts and clear communication strategies need to be developed, as proposed in a pool funding framework where food industry actors and organic breeders would make a longer-term commitment to jointly define breeding targets and budgets.

However, there is still a risk that voluntary measures alone or recourse to market mechanisms will not be sufficient. Additionally, while the use of organic cultivars is not mandatory in organic agriculture, the use of organic seed is and the phasing out the use of NCT seed is a policy goal. Thus, policy measures to achieve this seem justified. Looking at the scenario of phasing out the derogations in the case studies, in some cases this is possible, in others the steps need to be adapted and closely aligned with seed production capabilities, or complemented with investments in e.g. pest management at organic seed production level. In this type of command and control scenario, the financial burden would be on the farmer. However, it is possible that there could be a redistribution to another level of the value chain, e.g. by increasing the farm-gate price. To compensate farmers for the decrease in their gross margin and to provide them with an incentive on a voluntary basis, a subsidy could be a first step to encourage farmers to use organic seed. At a certain level of subsidy, farmers start using organic seed.

In general, organic seed production and organic breeding can be described as infant industries, as there is a potential market and justification for the products, but the established technologies still have an advantage. However, the feasibility of individual subsidy amounts should be considered on a case-by-case basis.

All in all, this thesis shows that it is important to find feasible solutions on a case-by-case basis to increase the use of organic seed and cultivars in order to achieve the policy objectives set and to maintain the integrity of the sector. This thesis provides an initial overview of the aspects that need to be addressed and a toolbox on how this can be realised. Consequently, an in-depth knowledge has been created to advise policy makers, organic farmers, organic seed producers and breeders, and other actors in the organic sector. In addition, actors interested in entering the organic sector can also be advised. Lastly, future research can build upon the generated results and methods.

7. Summaries

7.2 Zusammenfassung

Die vorliegende Doktorarbeit befasst sich mit der Wertschöpfungskette für Saatgut und Sorten im europäischen Ökolandbau. Laut der EU-Öko-Verordnung muss Vermehrungsmaterial im ökologischen Landbau aus ökologischer Erzeugung stammen. Seit Inkrafttreten der EU-Öko-Verordnung gibt es jedoch ein Ausnahmesystem für diese Vorschrift: Biolandwirte und Biolandwirtinnen können eine Ausnahmeregelung für die Verwendung von nicht chemisch behandeltem Saatgut (NCB) beantragen, das unter nichtökologischen Bedingungen erzeugt wurde. Außerdem empfiehlt die Öko-Verordnung zwar die Verwendung von Sorten, die für den ökologischen Landbau besonders geeignet sind, doch gibt es dafür keine Kontrollmechanismen. Infolgedessen wird die ökologische Landwirtschaft häufig von nichtökologischen Saatgutproduzenten und -züchtern mit NCB-Saatgut aus nichtökologisch gezüchteten Sorten beliefert.

In dieser Doktorarbeit wurde ein schrittweiser und komplementärer Ansatz entwickelt und angewendet, um das Saatgut- und Züchtungssystem für den ökologischen Landbau aus verschiedenen Blickwinkeln zu beleuchten. Bei den ersten beiden Forschungsschwerpunkten (Studien 1 und 2) handelt es sich um Ex-post-Bewertungen des Status quo des gesellschaftlichen Werts ökologischer Züchtung, der Finanzierung der ökologischen Züchtung und der Beziehung zwischen den Vermarktungskanälen und der Saatgutwahl der Landwirte und Landwirtinnen, sowie ihrer Einstellung zu ökologischem Saatgut und ökologischen Sorten. In der ersten Veröffentlichung wurde der gesellschaftliche Wert der ökologischen Züchtung und

des ökologischen Saatguts bewertet. Dazu wurde der soziale Wohlfahrtsgewinn berechnet, um die Verbesserung der Kulturpflanzen durch Züchtung sowie einige externe Effekte zu quantifizieren.
In der zweiten Studie wurden der Status quo der Finanzierungsstrategien der ökologischen Züchtung und die Bedeutung der Vermarktungskanäle für die Verwendung von ökologischem Saatgut auf Betriebsebene analysiert. Es konnten einige Empfehlungen im Hinblick auf die weitere Finanzierung der ökologischen Züchtung gegeben werden. Diese Empfehlungen wurden in einem explorativen Prozess auf der Grundlage eines Dialogs mit den wichtigsten Interessensgruppen und qualitativer Interviews erarbeitet. Die Analyse der Beziehung zwischen der Saatgutwahl der Biolandwirte und Biolandwirtinnen und den jeweiligen Vermarktungskanälen beleuchtete die Rolle der nachgelagerten Akteure der Wertschöpfungskette. Bei der Analyse der Vermarktungskanäle wurde eine doppelt robuste Standardmethode zur Analyse von Beobachtungserhebungsdaten verwendet, eine Kombination aus inverser Wahrscheinlichkeitsgewichtung und Regressionsanpassung.
Der dritte und vierte Forschungsschwerpunkt waren Ex-ante-Bewertungen. Die Ex-ante-Bewertung politischer Maßnahmen mit Hilfe von Simulationsmodellen ist nützlich, um politische Instrumente zu testen, die den Übergang zu einer verstärkten Verwendung und Erzeugung von ökologischem Saatgut und ökologischen Züchtungen erleichtern könnten. In dieser Doktorarbeit wurde ein Simulationsansatz zur Bewertung der Reaktionen entlang der Wertschöpfungskette unter verschiedenen Bedingungen entwickelt und angewandt, um die vielversprechendsten Szenarien für die Steigerung der ökologischen Saatguterzeugung und Saatgutverwendung zu ermitteln.
Aufgrund von Datenbeschränkungen wurden für den dritten Forschungsschwerpunkt typische Akteure anstelle von individuellen Akteuren als Agenten im agentenbasierten Modell verwendet. Das bedeutet, dass die Anzahl der Agenten von der realen Anzahl der Akteure (z.B. die reale Anzahl der Biobetriebe in einer bestimmten Region) auf zwei Akteure reduziert wurde, die nach dem Ansatz der typischen Betriebe als solche angesehen werden. Für den vierten Forschungsschwerpunkt konnten einzelne Akteure als Agenten auf Betriebsebene eingesetzt werden. Dies bedeutet, dass eine Agentenpopulation modelliert werden konnte, die in Bezug auf die Anzahl der Agenten und die Heterogenität der Agenten näher an der realen Betriebspopulation liegt. Dadurch war es möglich, eine Simulation der Verbreitung von Innovationen und der Kalibrierung der Verwendung von ökologischem Saatgut auf Betriebsebene einzubeziehen.
Die Ergebnisse dieser Arbeit zeigen, dass es Unklarheit über den derzeitigen Nutzen von

ökologischen Sorten gibt. Ökologisches Saatgut ist gemäß der EU-Öko-Verordnung obligatorisch und es wird empfohlen, angepasste Sorten zu verwenden. Ökologische Züchter und ein Teil der gesamten Biobewegung argumentieren, dass Sorten, die vollständig unter ökologischen Bedingungen gezüchtet wurden, am besten geeignet sind, auch um die Integrität der ökologischen landwirtschaftlichen Produktion zu erhalten. Sie argumentieren weiter, dass das derzeitige große Vertrauen der Verbraucher und die daraus resultierende steigende Nachfrage durch einen Skandal, der die mangelnde Verwendung von ökologischem Saatgut und ökologischer Züchtung aufdeckt, beschädigt werden könnte.

Andere argumentieren, dass das Ausnahmesystem etabliert sei und die Landwirte an nichtökologisch gezüchtete Sorten und unter nichtökologischen Bedingungen erzeugtes Saatgut gewöhnt seien. Dem widersprechen die Ergebnisse von Studie 1, in der ein signifikanter sozialer Wohlfahrtsgewinn durch eine ökologisch gezüchtete Winterweizensorte berechnet werden konnte, was zeigt, dass ökologische Sorten für Biolandwirte die erste Wahl sein können und dass sie aus gesellschaftlicher Sicht von Vorteil sein können. Dies konnte in den Studien 3 und 4 nicht bestätigt werden, in denen die getesteten ökologischen Sorten im Vergleich zu anderen verfügbaren nichtökologischen Sorten keinen erhöhten positiven wirtschaftlichen Effekt zeigten.

In Studie 2 zeigte eine Bestandsaufnahme bestehender ökologischer Züchtungsinitiativen, dass die unsichere und unzureichende Finanzierung eines der Haupthindernisse für die ökologische Züchtung zu sein scheint, um die aktuellen Marktstandards zu erfüllen. Um dieses Problem zu lösen, wird in Studie 2 eine freiwillige Maßnahme als Ergebnis eines Dialogs mit den Interessengruppen vorgeschlagen. Das Problem des Trittbrettfahrens von Akteuren, die nicht selbst in ökologische Züchtung investieren möchten, wird als Bedrohung angesehen. Um dieses Dilemma zu überwinden, werden u. a. verbindliche Verträge und klare Kommunikationsstrategien im Rahmen einer gemeinschaftlichen Finanzierung vorgeschlagen. Es besteht jedoch nach wie vor die Gefahr, dass freiwillige Maßnahmen allein oder der Rückgriff auf Marktmechanismen nicht ausreichen werden. Da die Abschaffung der Ausnahmeregelung für NCB-Saatgut geplant ist, erscheint es außerdem gerechtfertigt, politische Maßnahmen zur verstärkten Verwendung von ökologischem Saatgut in Betracht zu ziehen. Dies ist unter anderem der Schwerpunkt der dritten und vierten Veröffentlichung. Betrachtet man das Szenario des Auslaufens der Ausnahmeregelungen in den Fallstudien, so ist dies in einigen Fällen möglich, in anderen müssen die Schritte angepasst und eng mit den Möglichkeiten der ökologischen Saatgutproduktion abgestimmt werden. Bei dieser Art von ordnungspolitischen Maßnahmen würde die finanzielle Belastung von den Biolandwirten und

Biolandwirtinnen getragen werden. Es könnte jedoch eine Umverteilung auf eine andere Ebene der Wertschöpfungskette erfolgen, zum Beispiel durch eine Erhöhung des Ab-Hof-Preises. Um die Landwirte und Landwirtinnen für den Rückgang ihrer Deckungsbeiträge zu entschädigen und ihnen auf freiwilliger Basis einen Anreiz zu bieten, könnte eine Subvention ein erster Schritt sein, um die Landwirte zur Verwendung von ökologischem Saatgut zu bewegen.

Abschließend zeigt diese Arbeit, dass es wichtig ist, von Fall zu Fall praktikable Lösungen zu finden, um die Verwendung von ökologischem Saatgut und ökologischen Sorten zu erhöhen, damit die gesetzten politischen Ziele erreicht und die Integrität des Sektors erhalten werden kann. Diese Arbeit gibt einen ersten Überblick über die Aspekte, die angegangen werden müssen, und stellt ein Instrumentarium zur Verfügung, mit dem dies erreicht werden kann. Damit wurde ein fundiertes Wissen geschaffen, das politischen Entscheidungsträgern, Biolandwirten, Herstellern und Züchtern von ökologischem Saatgut und anderen Akteuren im Biosektor und darüber hinaus als Orientierung dienen kann.

7.1 Summary

This thesis focuses on the value chains for seed and cultivars in European organic agriculture. According to the EU organic regulation, propagating material in organic agriculture should be organically produced. However, a derogation system to this rule has been in place since the EU organic regulation was put into effect: Farmers can apply for a derogation to use not chemically treated (NCT) seed that is produced under non-organic conditions. Furthermore, although the organic regulation advises to use cultivars particularly suited for organic agriculture, this is not mandatory. Consequently, organic agriculture is often supplied by non-organic seed producers and breeders with NCT seed from non-organically bred cultivars.

In this thesis, a step-wise and complementary approach was developed and applied to shed light on the seed and breeding system for organic agriculture from different angles. The first two research foci (Studies 1 and 2) are *ex post* evaluations of the status quo of the societal value of organic breeding, financing of organic breeding, and the relationship of marketing channels and farmers' seed choices and attitudes towards organic seed and cultivars. In the first publication, the societal value of organic breeding and seed was assessed. For this, the economic surplus method was applied and enhanced to quantify crop improvement as well as some external effects.

In the second study, the status quo of financing strategies of organic breeding and the importance of marketing channels for organic seed use at farm level were analysed. Some recommendations with regard to further financing of organic breeding could be given. These

recommendations were established through an explorative process based on a stakeholder dialogue and qualitative interviews. The analysis of the relationship between the seed choices of organic farmers and the farmers' marketing channels shed light on the role of downstream value chain actors. In the analysis of marketing channels, a doubly robust standard method for analysis observational survey data was used: A combination of inverse probability weighting and regression adjustment.

The third and the fourth research foci were *ex ante* assessments. *Ex ante* policy assessment via simulation models is a useful means of testing policy instruments that could smooth the transition period to more organic seed and cultivar use and production. In this thesis, a simulation approach assessing reactions along the value chain under different conditions was developed and applied in order to identify the most promising scenarios for the increase of organic seed production and use.

Due to data constraints, for the third research focus, typical actors instead of individual actors were used as agents in the agent-based model. This means that the number of agents was reduced from the real number of actors (e.g. the real number of organic farms in a defined region) to two actors that are considered typical according to the typical farm approach. For the fourth research focus, individual actors could be used as agents at farm level. This means that a farm agent population closer to the real farm population in terms of the number of agents and in terms of the heterogeneity of the agents could be modelled. This made it possible to include a simulation of the diffusion of innovations and calibration of organic seed use at farm level.

The results of this thesis show that there is ambiguity about the current usefulness of organic cultivars. Organic seed is compulsory under the EU organic regulation and it is recommended to use adapted cultivars. Organic breeders and part of the whole organic movement argue that cultivars bred entirely under organic conditions are the most suitable, also to maintain the integrity of organic agricultural production. They further argue that the current high level of consumer confidence and the resulting increase in demand could be damaged by a scandal exposing the lack of use of organic seeds and breeding.

Others argue that the derogation system is established and that farmers are in fact used to non-organically bred cultivars and seeds produced under non-organic conditions. This is contradicted by the results of Study 1, where a significant social welfare gain from an organically bred winter wheat cultivar could be calculated, showing that organic cultivars can be the first choice for organic farmers and that they can be beneficial from a societal point of view. This could not be confirmed in studies 3 and 4, where the tested organic cultivars did not show an increased positive economic effect compared to other available non-organic cultivars.

In Study 2, a screening of existing organic breeding initiatives revealed that uncertain and insufficient funding seems to be one of the main obstacles for organic breeding to meet current market standards. To tackle this, Study 2 proposes a voluntary measure as a result of a stakeholder dialogue. The problem of free-riding by stakeholders on positive outcomes of investments in organic breeding by other stakeholders is seen as a threat. Binding contracts and clear communication strategies are proposed, among others, in a pool funding framework aiming at overcoming this dilemma.

However, there is still a risk that voluntary measures alone or a recourse to market mechanisms will not be sufficient. Furthermore, as the end of the derogation system for NCT seed is planned, the consideration of policy measures to increase the use of organic seed seems justified. This is the focus of the third and fourth publication. Looking at the scenario of phasing out the derogations in the case studies, in some cases this is possible, in others the steps need to be adapted and closely aligned with organic seed production capabilities. In this type of command and control scenario, the financial burden would be carried by the farmer. However, there could be a redistribution to another level of the value chain, e.g. by increasing the farm-gate price. To compensate farmers for the decrease in their gross margin and to provide them with an incentive on a voluntary basis, a subsidy could be a first step to encourage farmers to use organic seed.

To conclude, this thesis shows that it is important to find feasible solutions on a case-by-case basis to increase the use of organic seed and cultivars in order to achieve the policy objectives set and to maintain the integrity of the sector. This thesis provides an initial overview of the aspects that need to be addressed and a toolbox on how this can be realised. Consequently, an in-depth knowledge has been created to advise policy makers, organic farmers, organic seed producers and breeders, and other actors in the organic sector and beyond.

Contribution of PhD Candidate to the included publications

For research articles with several authors, a short paragraph specifying the PhD Candidate’s contributions is provided. In Study 1, the PhD candidate was involved in the funding acquisition, conceptualisation, methodology, and reviewing and editing the draft manuscript. In Studies 2- 4, the PhD candidate was involved in the conceptualisation, methodology, validation, formal analysis, data curation, and writing of the original draft preparation.

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Eidesstattliche Erklärung

Ich erkläre: Ich habe die vorgelegte Dissertation selbständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der „Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis“ niedergelegt sind, eingehalten.

Ort, Datum, Unterschrift

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