Analysing agricultural innovation systems: a multilevel mixed methods approach

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Annotation: Innovations of agricultural suppliers, producers and retailers are directly or indirectly shaping sustainability within the agro food web. If sustainable innovations targeted at the key challenges agriculture is facing worldwide, such as food security, climate change, sustainable use of natural resources etc. should be promoted, knowledge about current innovation processes is needed to reveal mechanisms that allow for promoting sustainable agricultural innovations. In this paper we present the development of an analytical framework to study agricultural innovation systems. We divide the agricultural sector into four levels and expand the innovation system approach (Malerba 2002 and 2004, Koschatzky 2009) to study innovation processes. On the example of the role of farmers and extension services in agricultural innovation processes we demonstrate the adequateness of the approach and give detailed insight into the later stages of the innovation process, where barriers occur most in the German agricultural innovation system.

Key words: innovation system, precision farming, animal monitoring, energy in horticulture

1   Introduction

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Innovations by agricultural suppliers, producers and retailers are directly and indirectly shaping sustainability within the agro food web. In order to promote sustainable innovations targeted at the key challenges agriculture is facing worldwide such as food security, climate change, sustainable use of natural resources – (McIntyre et al 2009) more knowledge about current innovation processes is needed to reveal mechanisms enabling the creation and dissemination of such innovations.

The innovation system approach proposed by Malerba (2002, 2004) facilitates systematic analysis of national and sectoral innovation systems. It does not provide empirical guidance, however, but is rather intended to be adapted for research question-specific research designs. Moreover, innovation systems research has so far been linked only sporadically to knowledge and innovation systems (AKIS) research in agriculture (Dockés 2011).

Understanding of agricultural innovation systems has not primarily been conceived as a research framework in the strict sense, but rather as more of a political concept developed in the 1960s: a mental model for practically guiding actors within an agricultural system. Originating out of the aims of achieving food security and

increasing production ("green revolution"), sectoral agricultural innovation systems involve specific actors compared to other branches, such as administrative structures and institutions of publicly funded agricultural R&D and extension services. These systems have since the 1990's undergone changes in terms of reduction of publicly funded actors and institutions (e.g. Alston 1999) and installment of new intermediate actors, e.g. technology- and knowledge-transfer offices or private consultancies (Klerx and Leuwis 2008). Simultaneously, agriculture has developed into an international agribusiness sector constituted of highly specialized value chains and production branches (e.g. in horticulture, see Bokelmann 2009), involving not only a specialized supplier industry with its own R&D activities, but also very many SMEs besides large corporations as pesticide suppliers and food trade. Hence, innovation processes cannot be assumed to follow a single and linear (research-based) logic; rather, value chains have to be understood as the action arena where innovations are developed in double feedback looped processes.

Research on innovation processes in the field of genetically modified plants has shown in an exemplary manner how societal and consumer expectations and entrepreneurial innovation interests lead to new constellations in comparison to mainly publicly funded innovation systems (Vanloqueren and Baret 2009). However, there are also other innovative technological paths that could potentially contribute towards mastering the challenges agriculture is facing. Examples of potentially globally successful production systems and technologies include innovations developed within the German agricultural system, such as precision farming, animal monitoring systems and low-energy greenhouse systems. Yet each innovation involves different actors and value chains.

From the foregoing we conclude that, for studying agricultural innovation systems and innovation mechanisms, an adapted research framework is required. The development of a consistent conceptual and methodological framework could contribute towards facilitating agricultural economic researchers in advising on ways of improving innovation processes and systems. The aim of this paper is to develop a conceptual synthesis and methodological approach for studying agricultural innovation systems based on the example of Germany. Given the diversity of national agricultural systems in the EU, we only seek here to provide a basis for further discussion and analysis by presenting empirical results from the German case in a way that we hope will demonstrate the validity of our approach.

A consistent conceptual and methodological framework has to be developed in order to respond to the current needs of advise on how to improve innovation processes and agricultural innovation systems. Our goal of explaining recent agricultural innovation in Germany based on a case study approach.. in order to answer the "HOW" and "WHY" of agricultural innovation, about which the researcher has little control, since the object of research consists of an ongoing real-world context (Yin 2003)

Nonetheless, according to the literature in innovation systems different levels of innovation analysis can be distinguished (e.g. Geels 2004: niches, trajectories and landcapes),, allowing the development of an adapted multi-level research framework to systematically localize an adequate level for conducting our case study research. Malerba (2002) and Koschatzky et al (2009) also propose that, prior to studying an

innovation system, the level on which innovation occurs has to be identified. In our case, that turns out to be the value chain arena, which is embedded in the sectoral (whole agricultural sector) and subsectors as traditionally divided in the German sectoral nomenclature.

Our approach accordingly divided the agricultural sector into different levels. First, three main subsectors (animal husbandry, plant production and horticultural production) were distinguished from the general sector level (level 1), as the actors at the lower level (level 2) presumably do not have interlinkages in their innovation processes, because their production processes (e.g. pig farming – wheat production – ornamental plant production) are quite different in terms of actors, technologies, marketing channels and the like. Then, on level 3, which we call the "innovation field", we located the value chains organized around a technology, product or a group of products and the corresponding actors and interactions that shape innovation. Only on this concrete level, it is possible to study innovation mechanisms as well as their supporting and hindering factors. Level 3 consists of a variety of single innovations, such as sensors, machinery components labels. By then distinguishing a fourth level (level 4), we were able to look deeper into single innovations, such as efficient light sources in horticultural production or special sensor technologies in animal production.

Malerba (2002 and 2004) and Koschatzky et al (2009) distinguish six elements characterizing innovation systems, analyzed at context-specific levels of abstraction. In order to answer the question HOW innovation occurs, our research team added a seventh element, called "innovation processes", which reveals interlinkages between system elements. The system elements can be described as follows:

1. **Agents and organizations** are actors involved in innovation processes and their characteristics.

2. **Interaction and intermediaries** includes the market and non-market relations and communication between actors with regard to innovation. Intermediaries are organizations or groups within organizations working with the goal of promoting innovation, e.g. at the interface between science and business, and aiming to promote sustainable networks (Dalziel 2010).

3. **Knowledge base and human capital** contains information regarding sector-specific and cross-sectoral knowledge, learning processes, knowledge accessibility as well as tacit and codified knowledge.

4. **Institutions and politics** includes the implicit and explicit rules of actors and organizations, such as norms, laws, rules as well as behavioral patterns and routines.

5. The analysis of existing **technologies**, products and services and the demand for them provides insight into development and future potentials or technological trends and problems that require innovative solutions.

6. The environment of **competition** surrounding the innovation system in question includes national and international aspects.

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7. **Innovation processes** provides insight into the temporal aspects and "making of" of agricultural innovation by linking the other elements together in order to understand their systemic relations better.

2   Methods

In order to describe innovation processes in the German agricultural innovation system, and taking into account that this information can only be obtained on the value chain level (here called level 3 or innovation field), we designed a research framework allowing us to combine knowledge derived on different systemic levels. In this section, we describe our three-level mixed method research concept, which can be seen as a sequential qualitative–quantitative design (Kelle 2007, p. 285).

According to Johnson and Christensen, "[m]ixed methods research […] recognizes the importance of traditional quantitative and qualitative research but also offers a powerful third paradigm choice that often will provide the most informative, complete, balanced, and useful research results." (2007, p. 129)

Figure 1 shows the above described multi-level approach. Following that, the methods applied on the different levels along the innovation system elements will be described in further detail.
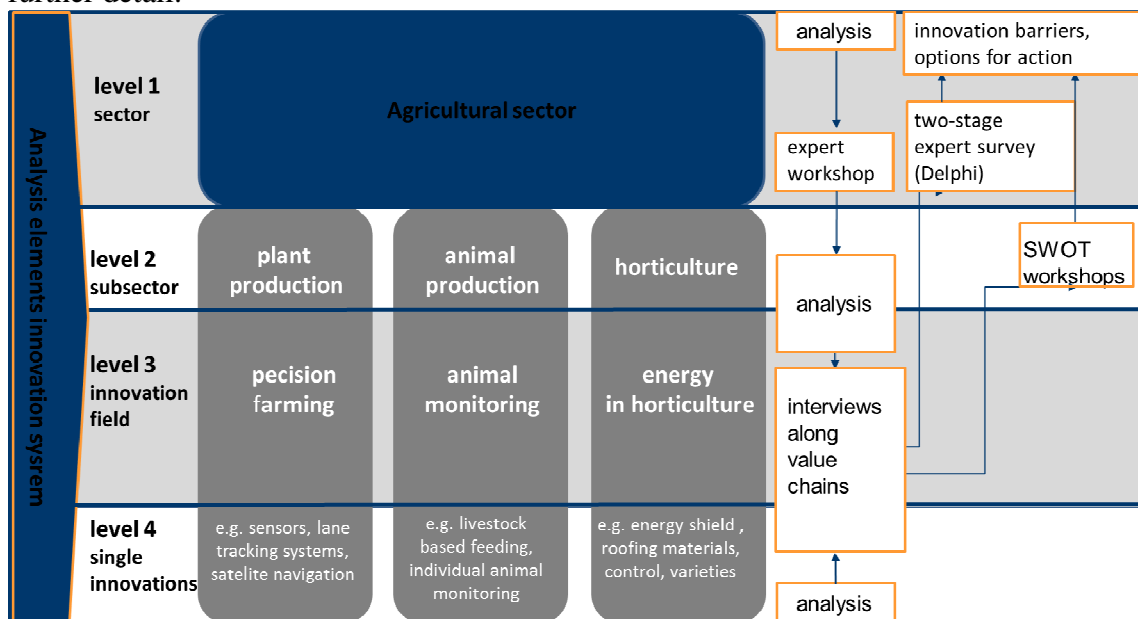

Fig. 1. research design (source: own figure)

Because the data sets usually used to generate innovation indicators either lack relevant data for our purposes or agricultural data cannot be separated from other branches, we designed a multi-level mixed methods approach. Furthermore, data alone provides no

insights into innovation mechanisms. Therefore, as a first step, an expert1 workshop was organized, focused on locating case studies where typical barriers and chances for innovation processes in agriculture could be studied. Then, having selected three exemplary cases, literature and secondary data analyses built the basis for semi-structured expert interviews along their value chains. Based on the data thus collected, already involved and newly identified experts with general knowledge for the subsector discussed the plausibility and transferability of results from the innovation examples to the wider agricultural sub-sectors to which they belong, namely: plant production, animal production and specialized horticultural production.

2.1 Literature and Data analysis

First, on a general sectoral level, a data-based innovation analysis was conducted (patents, publications etc.). The main purpose here was to obtain an overview and see if it were possible to relate innovation information about agriculture to those indicators typically used to analyse innovation systems of other sectors. We feel that this analysis strengthened our argument concerning the chosen multilevel research design with explicit data on the lack of innovation-related indicators for agriculture. At the same time, the analysis of statistics, market reports, publications, documents and websites also served as an entrance point for the case study research itself.

2.2 Semi-structured expert interviews

Experts in the case studies were identified according to their backgrounds and value chain involvement. In order to access their exclusive knowledge on innovation processes in agricultural value chains, interview guidlines were developed, serving as a red thread for our expert interviews. The questionnaire we developed served as a common basis for comparison across the case studies. The openness of the interviews, despite their topically concrete focus, ensured that specific knowledge on innovation processes in each of the case studies could be obtained while also allowing for unexpected aspects to be discovered (Liebold and Trinczek 2002). For each case study, 15 interviews were conducted along the value chain, recorded, transcribed and analysed with qualitative content analysis, supported by the software MAXQDA. The fact that innovation-process knowledge is sensitive in terms of competitiveness was also taken into account.

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[1] experts where defined in our study as actors with a special knowledge about agricultural innovation processes in terms of social processes, professional and practical action context (Gläser/ Laudel 2004)

2.3 Expert workshops

Workshops with selected experts were conducted at two stages of the research process as a means for deriving the "collective orientation" and tacit knowledge (Liebig and Nentwig-Gesemann 2002) of actors involved in agricultural innovation. The first workshop included experts from different fields (regional entrepreneurship, bioenergy, banking, farmmachinery, new fruit varieties, terra preta etc.) who were invited to discuss opportunities and hindering factors in agricultural innovation processes. According to criteria previously developed by the researchers and the funding organization of BMELV (see box), three topics for case studies were identified during the workshop.

Box 1: Criteria for case study selection formulated for the first workshop:

1. Best practise example in terms of mastering current challenges (environment and resources, market development, social trends and ethics, food security and safety, climate change…);
2. Supporting competitiveness of the sector (efficiency, cost reduction, new markets, niches…);
3. Relevance for employment and value creation (labor conditions, jobs in agriculture and supplier industries…);
4. Important actors in the innovation process are located in Germany; and
5. Systemic relevance (sustainability dimensions).

After the case studies had been conducted, their results were tested in three expert workshops. These workshops were to answer the following questions: Are the results from the case studies generalizable for the given subsector (animal monitoring -> animal production, precision farming -> plant production, energy in horticulture -> horticulture)? Are the critical factors identified by the analysis of system elements from other innovation fields in the subsectors (e.g. plant breeding, ergonomics, extension, farmer organizations, innovative entrepreneurs, experimental station representative). Actual workshops had six to eight participants each.

The research team developed a process concept for the workshop that first introduced the case study results to the participants and then discussed the relevance of the major results for the subsector. The most relevant critical factors for the subsector were selected by the experts and then SWOT and risk analyses were conducted for them. Resulting options for action were also discussed.

All workshops were moderated and visualized by a professional facilitator (Kühl 2002). According to participant feedback, the workshops fulfilled their functions of (1) providing the researchers with relevant information while also (2) spurring a learning process for the participants (Dreher and Dreher 1995).

2.4 Delphi survey

After the research topic had been opened up (expert workshop), and knowledge had been obtained in the three case studies, testing of generalizability of the results to the subsectoral level was conducted in SWOT workshops, while generalizability to the general sectoral level was tested with a Delphi survey, which also served to detect general technological trends. Generally, Delphi studies are used in innovation research as foresight instruments to collect different opinions and facilitate expert dialogue by presenting results of the first questionnaire in a second round (Cuhls 2009:207, Häder 2002, Meier et al 2005:65). In our case, the second round repeated the questions from round one, with the addition of a question that resulted from the SWOT Workshops on the presumed different roles of farmers within innovation processes. Again, the focus was laid on experts involved in innovation processes. In both rounds, 150 experts were contacted. In the first round 65 experts answered and 63 in the second round. The questions for the Delphi survey were developed according to the results of the case studies in the innovation system elements scheme and were refined through the results of the above-reported literature and general data analysis.

3 Results and Discussion

In this section, based on the example of the role of farmers and the role of extension, we demonstrate the advantages for generating knowledge with the chosen multi-level approach. We have chosen these two aspects because barriers in agricultural innovation processes have been reported as mainly occurring in later stages of the innovation process in the interviews as well the Delphi survey (see figure 2).
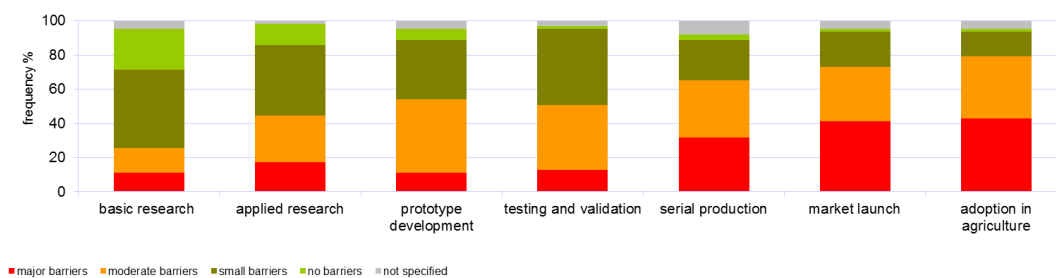

Fig. 2. In which stage of the innovation process do barriers occur most frequently? (Delphi 2, n=63)

Role of farmers in innovation processes. Besides industry and science, agricultural producers are an integral part of the triangle where innovation impulses occur most often in agriculture. The case study interviews revealed that the role of farmers in innovation processes is not restricted to ("passive") adoption. Rather, some farmers act as lead users, such as in research and development in precision farming. They provide qualified detailed feedback to suppliers and formulate needs that lead to new innovation processes. In the SWOT workshops, the role of farmers was discussed as a prominent critical factor that was revealed by the case studies. Although this is especially relevant

for the plant production subsector, possible strategies of better integration of farmers in innovations processes were also addressed in animal husbandry and horticulture.

The experts in the plant production workshop estimated the number of farmers generally open to innovation, who are seen to be a strength for the subsector, to be up to 10%. A weakness with a moderatelikelihood and strongeffect is the phenomenon that farmers' own technological developments often remain singular solutions for their own farms. Three opportunities were identified. First, well-targeted funding would allow farmers to generate additional income from innovations. Second, changes in the organizational structures of farms would support the adoption of innovations (e.g. because they are only feasible from a certain farm size on). Similarly, third, a personnel and operational structural change will favour certain innovations. A weakness in the innovation system with a high likelihood and a strong effect is the possibility that funding schemes favor windfall gains.
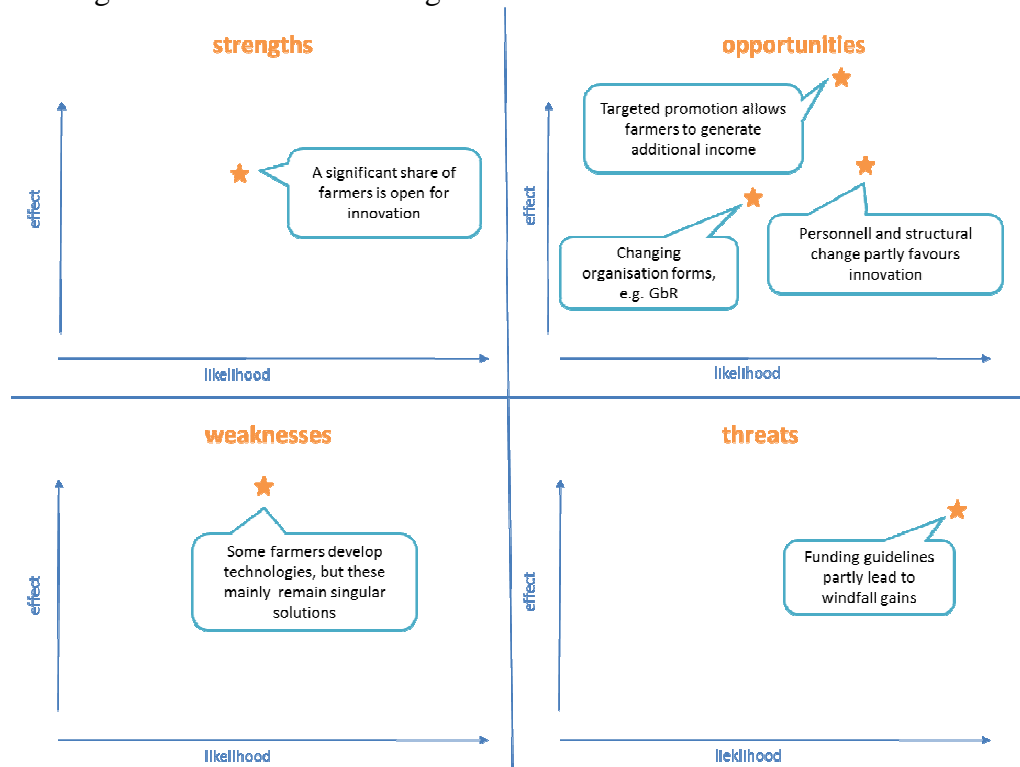

Fig. 3. The role of farmers in innovation processes in plant production: strengths, weaknesses, chances and risks – their likelihood and effect (SWOT workshop plant production)
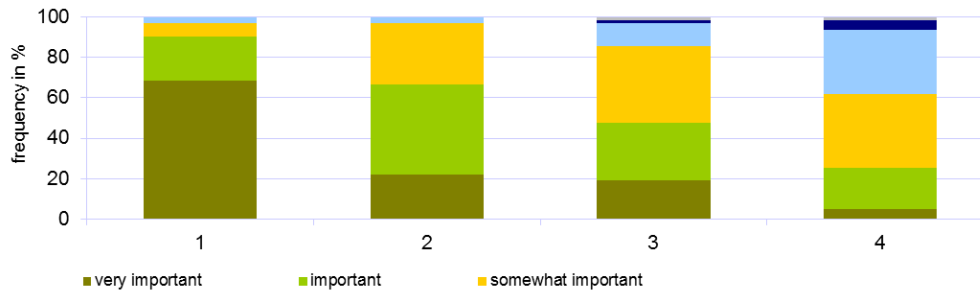
Fig. 4. The role of agricultural producers in innovation processes (1) User/ adopter, (2) initiator, giving impulses, (3) inventor, (4) entrepreneur (Delphi 2, n= 63)

Role of extension services in innovation processes. Extension services are ranked number five behind suppliers, agriculture, science/ research amd international competition as actors that give impulses to agricultural innovation. In the case studies on precision farming and energy in horticulture, a lack of neutral information about the benefits of innovations and information on their implementation was mentioned as a relevant gap, an issue of particular importance in the highly specialized horticultural subsector. Extension in horticulture is not only provided by extensionists, but also by experimental stations and their publications as well as internet platforms. Extensionists embedded in the work of experimental stations, were seen by experts as ideal knowledge brokers between science and the horticultural business.

Being heterogeneously distributed among the Federal states, and a with primarily regional range of extension, horticultural production faces uneven innovation preconditions in Germany, due to the federal organization of the extension system. Yet, in some cases, such as highly specialized and competitive market segments (e.g. asparagus production), extension is organized by geographical distance of the producers from each other. A current strength of horticultural extension with regard to innovation is its function as contact partner for producers. Due to its neutral function, extension allows networking and provides neutrally assessed knowledge on horticultural innovations for producers. Both factors will have a high likelihood and a high effect on the innovation system, according to the experts. A weakness is the limitation that extensionists do not always have knowledge of the whole pool of innovations potentially applicable for producers. Moreover, to provide neutrally assessed knowledge, expert knowledge is needed, but specialized extension is not sufficiently available in horticulture, which was also a finding from the interviews in the field of precision farming. Again, both factors were assessed with a high likelihood and a high effect on innovation in horticulture. Hence, an opportunity could be the continued funding of the currently basically well-functioning parts of the transfer system, but only

a small likelihood with a high effect was estimated for this. On the contrary, pioneering horticultural entrepreneurs could serve as role models for others, with a high likelihood and a high effect. Yet, the manifestation of different extension services within the federal structure of Germany bears the risk of lack of equal competition conditions within the horticultural innovation subsystem, having a high effect with a high likelihood.
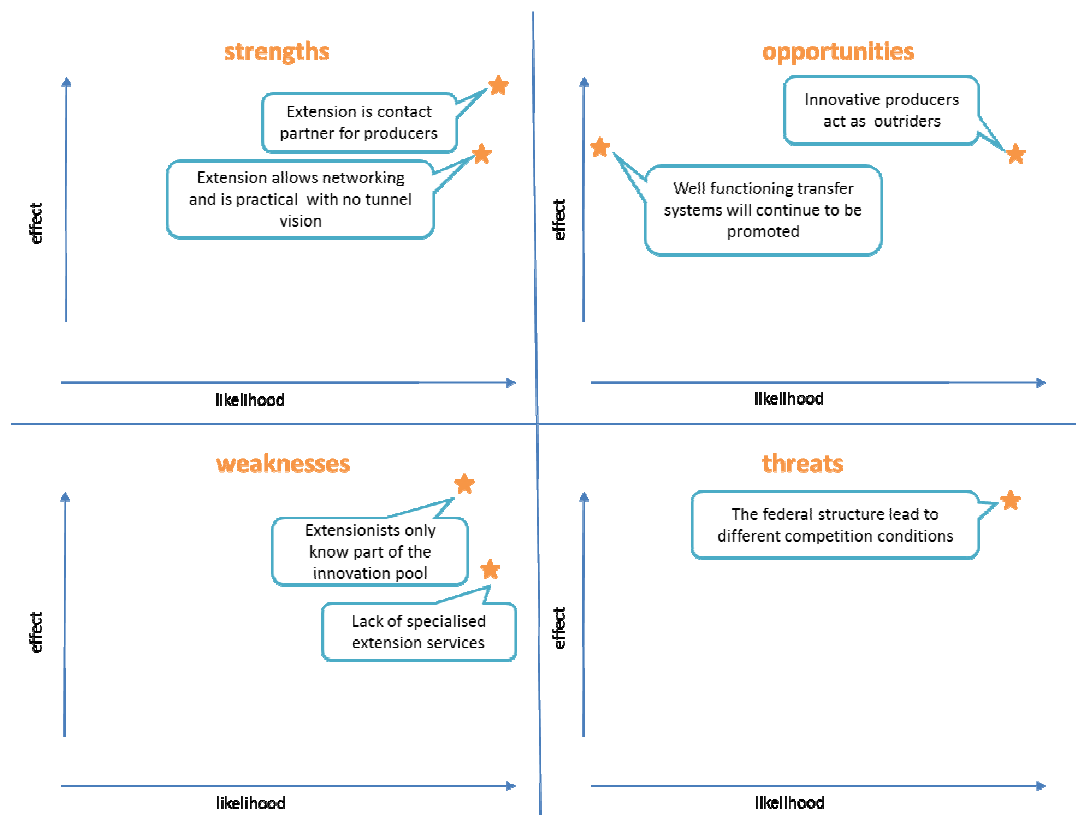
Fig. 5. The role of extension services in innovation processes in horticulture: strengths, weaknesses, chances and risks – their likelihood and effect (SWOT workshop horticulture)

The Delphi analysis rounded out the study's insights into the role of farmers and extension services in the current agricultural innovation system in Germany. Agricultural production and extension are the two fields of employment in agriculture which the experts consider to be most lacking in personnel specially trained to foster innovation processes. As extension was described as one of the important actors after the top four (supplier industry, producers, science/ research, international competition), a lack of innovation (absorptive) capacity might be expected in the German agricultural innovation system due to inadequacies in this domain. Moreover, science is thought to lack personnel with sufficient understanding of and connection to practical concerns. This illustrates the need to further study and develop mechanisms of innovation production and diffusion, and the role of extension therein, and investigate whether new actors or applied research should take over some of the intermediating and knowledge- and technology-diffusing functions in a new mode.
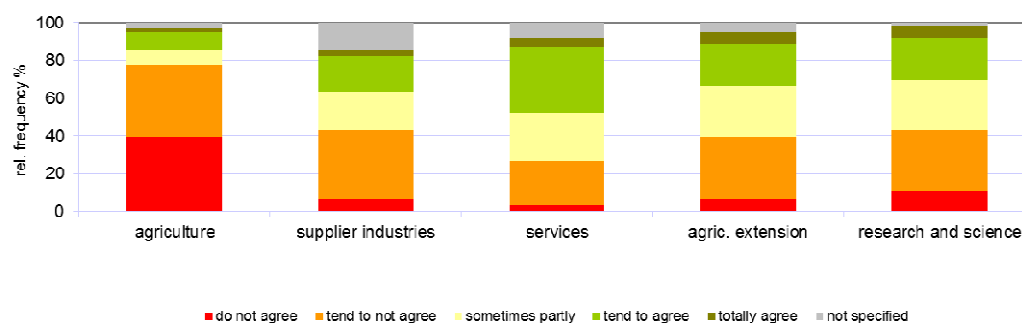
Fig. 6. Assessment of personnel: "The number of qualified personnel will be sufficient within the next 5-10 years" (Delphi round 2, n=63)
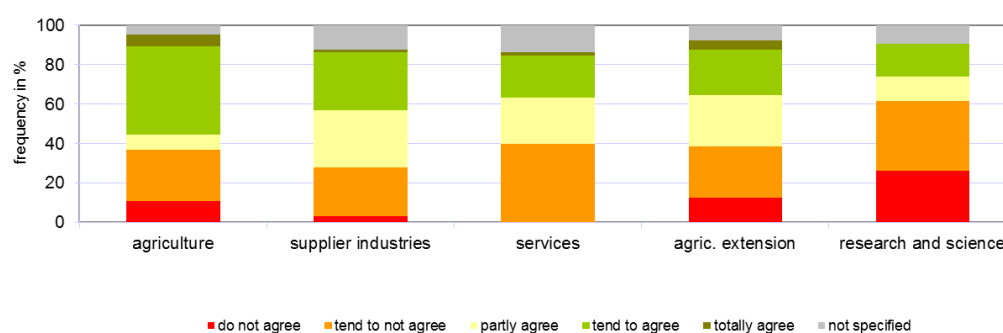

Fig. 7. Assessment of availability of personnel with practical knowledge and skills (Delphi round 1, n=65)
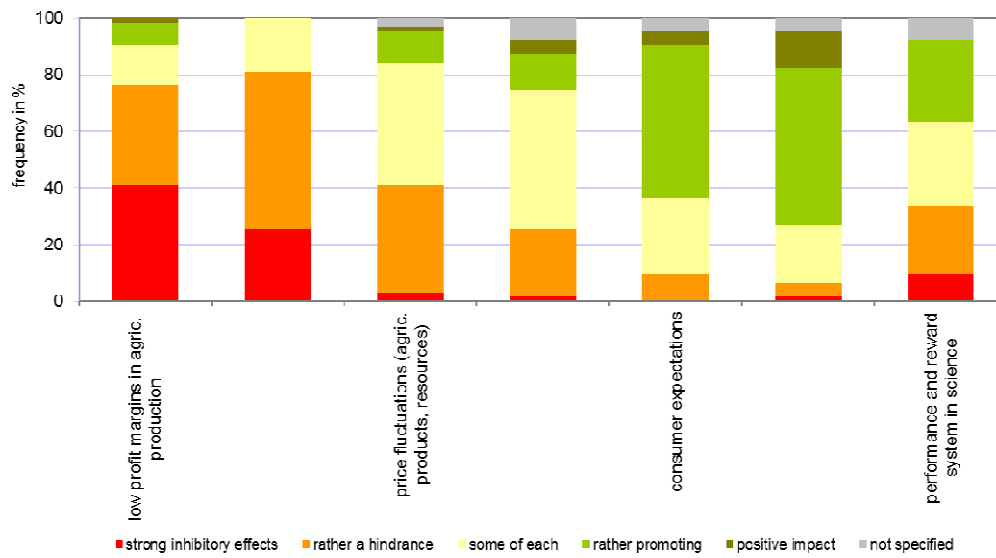
Fig. 8. Hindering and promoting factors for the innovative capacities of the German agricultural sector (Delphi round 2, n= 63)

4   Discussion and Conclusion

The aim of our paper has been to demonstrate the benefits in knowledge gained from using a multilevel mixed method approach, here used specifically for the analysis of the German agricultural innovation system through presenting results for two selected aspects. We have sought to demonstrate that different methods applied at different levels of an innovation system can enable more detailed insight into key barriers occurring in the later stages of the innovation process, which we feel is more than can be achieved with only indicator-based analyses. We have also sought to bring attention to the role of farmers and the ability of the system to enable farmers to participate more actively in innovation processes and to reasonably support adoption decisions, as this situation requires further attention from researchers, policy makers, administrators and by the actors themselves.

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