AUTONOMOUS FIELD ROBOTS IN AGRICULTURE: A QUALITATIVE ANALYSIS OF USER ACCEPTANCE ACCORDING TO DIFFERENT AGRICULTURAL MACHINERY COMPANIES

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Abstract

Great hopes are being placed on the autonomation of agricultural engineering from various perspectives. However, it is unclear whether autonomous field robots (AFR) will make the transition from the development phase to the broader agricultural market. Among various factors, this particularly depends on user acceptance of this new technology. Therefore, this paper provides and discusses the results of an initial explorative qualitative survey of the ex-ante user acceptance of AFR from the perspective of nine different agricultural machinery manufacturers in Germany. The interview guideline developed for this purpose is based on an adapted technology acceptance model (TAM) according to DAVIS (1989). In summary, the results confirm that a large number of factors potentially influence farmers' acceptance from the perspective of agricultural machinery manufacturers, with perceived usefulness being regarded as the greatest motivation for using AFR. Even if all experts assume the need for AFR in the future, the economic advantages of autonomous agricultural technology over conventional technology are not entirely plausible over the medium term from the experts' point of view. The interviewees do not expect AFR to be relevant in arable farming for at least 10 years, although earlier for special crops. AFR's future market share will depend above all on legislation regarding autonomous technologies. If AFR are used on a large scale in arable farming, this will very likely lead to changes in existing business models affecting the end customer. If further development of this innovative technology is desired, political decision-makers should establish a legislative framework for the safe operation of autonomous agricultural machinery and promote the use of AFR through market policy instruments. In addition, the results require quantitative verification among farmers.

Keywords

Acceptance, Autonomous, Farmers, Manufacturers, Robots, TAM

1 Introduction

Autonomous vehicles are becoming increasingly important not only for the automotive industry but also for agricultural engineering in industrialized countries. A higher degree of automation in agricultural processes enables entire systems to be reconsidered. For example, instead of ever larger and heavier conventional agricultural machinery, small autonomous robot units could replace them, performing certain tasks either alone or in swarms with other units. Whereas in the past smallholder farms were labeled uneconomic, autonomous field robots (AFR) could make them economically attractive again and lead to a shift in thinking, saying: "bigger is no longer better" (KING, 2017). In addition to improved scalability, AFR have the potential to be more environmentally friendly and at the same time economically efficient. For example, due to their lower weight, they exert less soil compaction than large agricultural machinery and their advanced sensor technology enables more precise, plant-specific pest detection and elimination, which can save considerable amounts of pesticides (REDHEAD et al., 2015). By replacing the operator, the math is changed, which can be particularly useful in labor-intensive areas of arable farming, such as special crop cultivation. Due to the machines' usual electric drives, less air and noise pollution also occur (GAUS et al., 2017). This is particularly important given that farmers are influenced by their social environment. For example, KUCZERA (2006) found that colleagues, friends and family members have an influence on the farmer's strategic decisions.

Besides the many advantages, there are also potential disadvantages involved with AFR. The shift from manned tractors to unmanned robot systems with no direct visual contact could make some farmers skeptical. According to REDHEAD et al. (2015), farmers fear highly complex AFR for which they do not have qualified staff. DEVITT (2018) adds further cognitive acceptance barriers amongst farmers, such as a lack of trust in AFR or the ongoing loss of agricultural skills associated with further loss of the already diminished public recognition of farming as a profession. In case of high-value crops, KESTER et al. (2013) revealed a conflict between the support for autonomous technologies on the one hand and general skepticism towards new technology on the other.

However, there is widespread agreement that AFR will find a place in future agriculture. But it is not yet clear, when and to what extent this will happen. KING (2017), for example, quotes the assumption of an AFR manufacturer saying that established agricultural machinery companies have little interest in introducing AFR because they represent alternative designs to their existing business models. On the other hand, this new technology also entails a range of new business models for agricultural machinery manufacturers. One option could be AFR offered to farmers as a service by an external supplier or as a cloud-based pay-per-use model (ERL et al., 2019). Moreover, the legal size and weight standards for agricultural machinery have been largely exhausted, so that a rethink in terms of smaller, more specific machines offers the opportunity to further develop agricultural technology (GAUS et al., 2017). FUCHS (2018) even assigns AFR a potential disrupter that could represent a caesura in agricultural engineering. In any case, new possibilities for analyzing data collected by AFR will lead to increased competitive pressure among agricultural machinery manufacturers (PHAM and STACK, 2017). In addition to AgTech start-ups, IT companies such as IBM and Google are entering the agricultural machinery market (GRASSI, 2015; BURWOOD-TAYLOR et al., 2016). The current market leaders should be aware of risk to their present position. It is therefore important to assess whether there is a future market for this new technology. The perspective of various agricultural machinery manufacturers on the factors influencing the ex-ante acceptance of AFR among farmers therefore seems particularly interesting.

Nevertheless, only few studies have so far investigated AFR's acceptance process in the agricultural sector. RIAL-LOVERA (2018) interviewed 14 agricultural stakeholders in California about their AFR adoption behavior. The main drivers for adoption were identified as shortages in the workforce and rising labor costs, as well as a missing awareness of the potential benefits of AFR and the lack of compatibility between farm equipment. More broadly, CAFFARO and CAVALLO (2019) interviewed several people about smart-farming-technologies (STF) during an agricultural fair in Northern Italy. They found that farm manager characteristics, such as educational level, moderate STF adoption behavior. In summary, and according to RIAL-LOVERA (2018), there is an enormous research deficit in the study of AFR's technology acceptance process in agriculture. Many studies focus on the effect of individual aspects and neglect the multidimensionality of the acceptance process, resulting in insufficient knowledge of the complexity of the acceptance factors (BUKCHIN and KERRET, 2018; PATHAK et al., 2019).

To address this under-researched issue, the present study examines the factors influencing the farmers' ex-ante acceptance of AFR from an agricultural machinery manufacturer perspective. Therefore, nine agricultural machinery manufacturers were interviewed on this topic using qualitative expert interviews.

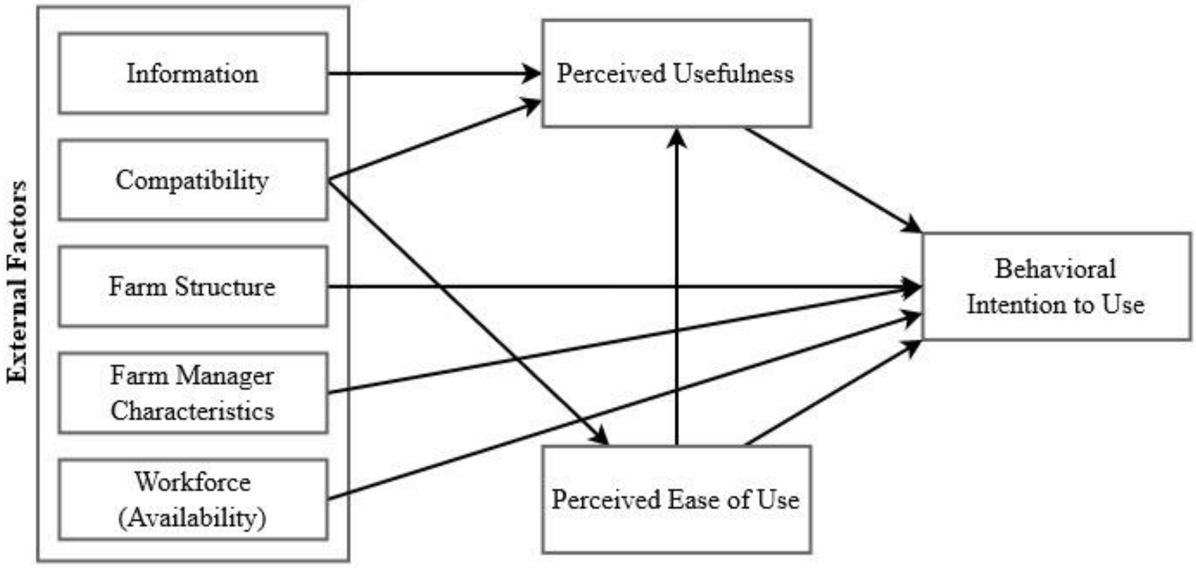
2 Material and Methodology

In order to collect the required data, expert interviews in line with MAYRING (2015) were performed with nine agricultural engineering companies. Among these are seven established agricultural equipment and vehicle manufacturers and two AgTech start-up companies that produce AFR. The questions were formulated in an open and neutral manner then divided into six thematic blocks: drivers and barriers, technology, economics, socio-economic effects, environmental impacts and legal restrictions. After a brief introduction to the topic, the experts were interviewed personally. Finally, the experts had the opportunity to add to or address issues that were not part of the questionnaire. The interview-guide was divided in 25 questions based on factors influencing ex-ante user acceptance of new technologies according to DAVIS' (1989) TAM, including perceived usefulness, perceived ease of use and external factors. The factors attitude toward using and actual system use were excluded from this analysis deliberately. This was due a direct influence of perceived usefulness and perceived ease of use on the behavioral intention being found (CHUTTUR, 2009). In addition, the study's object concerns the future use of a technology, so very little or no experience in handling AFR can be relied on. DAVIS (1989) defines perceived usefulness as: the subjective probability of a potential user employing a particular technology, in this case AFR, will increase his work performance in an organizational context. Perceived ease of use describes the degree to which the future user expects the technology to be free of any effort. Perceived usefulness and ease of use are statistically distinct dimensions and can be affected by various external factors (MILLER, 1977; BENBASAT and DEXTER, 1986). It is assumed that perceived ease of use has a positive influence on perceived usefulness and on behavioral intention, as ease of use makes a technology appear more useful and increases the probability of use (ADRIAN et al., 2005; RIAL-LOVERA, 2018). Based on the available literature on this topic, the external factors of information, compatibility, farm structure, farm manager characteristics and workforce availability were added (AUBERT et al., 2012; KESTER et al., 2013; REDHEAD et al., 2015; PAUSTIAN and THEUVSEN, 2017; DEVITT, 2018; RIAL-LOVERA, 2018; CAFFARO and CAVALLO, 2019; PATHAK et al., 2019). The factor information follows an approach from precision agriculture (PA) research and is defined as the information collected by AFR regarding availability and quality as a source for strategic decisions on farms. It is assumed that this factor affects perceived usefulness. At the same time, the possible advantage of additional data over conventional production methods is examined. With the factor compatibility, a feature from diffusion theory is included, which has proven to be an essential aspect in the literature review, both in terms of acceptance and technical design (AUBERT et al., 2012). Compatibility is expressed, for example, by the ability to combine AFR with current working practices and existing machinery or equipment. An effect of this factor on perceived usefulness as well as on perceived ease of use is assumed. Furthermore, an effect of the variables explained below is assumed to have a direct effect on behavioral intention. The farm structure is formed by two components. First, the farm size and second, the availability of resources, i.e. the resources needed to implement autonomous technology, are considered (AUBERT et al., 2012). In addition, the characteristics of the farm manager are described separately as an external factor, taking into account socio-economic variables; primarily age and educational level, as well as attitude to risk (PATHAK et al., 2019). The availability of workforce is also defined as an external factor influencing behavioral intention, since labor shortage was identified in previous studies as a factor influencing the acceptance of AFR (GRIEPENTROG, 2010; LOWENBERG-DEBOER et al., 2019). It is important to note that economic benefit as a possible factor for autonomous robotics compared to conventional systems is included in perceived usefulness but receives special attention in the survey. In particular, assumptions of a higher crop yield, cost savings, first of all in labor costs, and an increase in economic efficiency are taken into account. Based on these factors, various potential acceptance influences were assumed (Figure 1).

The data was analyzed using a qualitative content analysis with the help of the software "f4 Analysis" (GLÄSER and LAUDEL, 2010). A qualitative content analysis aims to systematically evaluate the information originating from a specific type of communication in a rule-based approach (MAYRING, 2015). In contrast to quantitative studies, statistical representativeness is not the primary objective. Rather, the idea is to analyze a problem that has, to date, hardly been studied, initially in an exploratory way, using the situations reconstructed from expert interviews to empirically investigate their experiences, opinions and attitudes. In this way, researchers create a base for possible further quantitative research (GLÄSER and LAUDEL, 2010; PATTON, 2015). The qualitative approach has been chosen in the present study, since there is hardly any data available so far for the field of investigation in the agricultural context.

The resulting data was assigned to the TAM factors described above (perceived usefulness, perceived ease of use and external factors) influencing the acceptance of AFR, with the possibility of an ex-post addition in case of newly collected information which had not been considered previously. This was important because, due to the limited literature on this particular topic, there was little evidence or connections between the factors influencing acceptance of AFR that could be determined in advance (GLÄSER and LAUDEL, 2010). The evaluation of the influencing factors provided the information needed to explain the directions of potential influence in the results section below.

Figure 1: Modified TAM in the context of AFR



Source: Own illustration according to DAVIS (1989), ADRIAN et al. (2005), AUBERT et al. (2012) and RIAL-LOVERA (2018)

Sample description

Nine experts from agricultural machinery companies were selected for the interviews, including seven established agricultural equipment and vehicle manufacturers and two AgTech start-up companies (see Table 1). The selection criteria for the established companies were direct or indirect involvement in AFR, e.g. by developing their own prototypes or investing in a corresponding Ag-Tech start-up. Also high total revenue, in order to ensure the relevance of the statements. The selection of the experts was left to the companies.

Table 1: Sample description

Company		Headquarter
Established Companies	AGCO Fendt	Marktoberdorf, Bavaria (Germany)
	Amazone	Hasbergen, Lower Saxony (Germany)
	Claas	Harsewinkel, North Rhine-Westphalia (Germany)
	CNH Industrial	Heilbronn, Baden-Württemberg (Germany)
	Horsch	Schwandorf, Bavaria (Germany)
	John Deere	Kaiserslautern, Rhineland-Palatinate (Germany)
	SDF	Lauingen, Bavaria (Germany)

Start-ups	Deepfield Robotics	Ludwigsburg, Baden-Württemberg (Germany)
	Naiture	Friedrichsgabekoog, Schleswig-Holstein (Germany)

Source: Own illustration

3 Results

Perceived usefulness

According to the experts interviewed, AFR profitability has the greatest relevance for acceptance among farmers. However, the majority of experts have doubts about AFR's economic advantages in arable farming at this stage of development: *"There is simply the problem with the practical feasibility, with the economic efficiency, with the functionality of the individual applications and also the proof that it works."* (E8). For example, constant logistic costs with less acreage capacity are mentioned (E1; E7). Two experts agree that crop protection with conventional machinery is much more cost-effective than using AFR and will remain so in the mid-term, unless there is a glyphosate ban (E1; E4). In contrast, possible efficiency gains from the use of AFR in certain work processes were highlighted, provided that such processes required a large amount of time (E1; E3; E6; E7). In particular, the high precision of pest detection and the possibility of 24-hour, 7-day a week operation using AFR are mentioned (E1; E3; E9). Expert 9 added that time saved could be used by farmers to further increase profitability on their farms. However, this requires the farmers to be aware of these effects (E1). The argument that AFR can save input costs such as machine costs, fertilizers, pesticides, seeds and labor cost has been largely confirmed: *"Of course, at one point it is the manpower and all the machinery that I have that I can do without."* (E4). But according to Expert 7, the saved salary would amount to 5-10%. The major potential for savings is seen in the more precise application of pesticides and fertilizers: *"Because, in relative terms, the costs of agricultural engineering are in a ratio to the costs of the inputs, which are very much to the disadvantage of the inputs. This means that a saving of 20% in pesticides is of course an enormous amount of money."* (E1). The price is perceived as a further criterion in deciding whether to use AFR: *"Ultimately, it is relatively easy to break it down to the price. If the thing is too expensive and not worth it, hardly anyone will do it."* (E4). The argument that AFR today are still too expensive is countered by a respondent who argues that total initial savings of 30 to 40% are already possible in certain arable work processes, such as plant protection, fertilization and seeding (E6). In addition, Experts E1, E2 and E6 point out that AFR must operate reliably and safely, so that human intervention is not required constantly: *"(...) if a robot is not reliable and constantly sends out a call for help (...) then the whole thing is over quickly."* (E6).

With regard to the TAM, the assumed potential acceptance influences are reflected by the statements of many experts. The economic benefit, which is included in the factor perceived usefulness, has a direct effect on farmers' behavioral intention according to the experts (see Figure 2). Furthermore, a potential influence of perceived ease of use on perceived usefulness could be found by the expected reliability of AFR, more precisely by the fear of the need for human intervention in the autonomous process. Furthermore, effects of the categories of technology and legal framework on perceived usefulness can be determined.

Perceived ease of use

Perceived ease of use is confirmed by most experts as an important potential influencing factor (E2; E3; E4; E7; E9), although Expert 4 notes that a contractor could also take over the operation of AFR, at which point this influencing factor would be irrelevant to the farmer. Otherwise, the ease of use is to be classified as: *"(...) very, very important."* (E4). It is added that it must not be a solution: *"(...) that can now only be operated by an engineer who has developed it."* (E9). Although two respondents call for training on AFR (E2; E9), Expert 1 states that operating machinery will be easier in the future due to increasing automation. He continues that the advantages of autonomous technology would be lost if it were complicated to operate: *"All I want to say* [as a farmer] *is, Alexa, please go to this field, execute order XL. Then, as I have already stored my farm management software. Done. That's all I want. Give me a report."* (E3). In this context, one expert fears that too much dependence on technology could lead to disappointment amongst farmers, especially if they get the feeling that they are no longer: *"(...) master of things."* (E7). Expert 9 adds that, given AFR's complexity, self-repair is probably no longer an option for the farmers.

It is demonstrated that the influence of the TAM factor ease of use on AFRs acceptance is reflected in statements from the respondents. Although different levels of importance were identified, a high level predominates. The assumed potential influence on perceived usefulness could be found, for example, by the suggestion of training programs for farmers. Possible operating methods for AFR reveals a wide range of approaches, from the transfer to a contractor up to complex operations, although the majority was in favor of a simple and intuitive operation. In addition, an influence of the sales structure on the factor ease of use became apparent through the service transfer mentioned.

Information

With regard to data protection and data security, several respondents made a distinction between pure machine data and farm-based agronomic data, which does not only apply to AFR: *"For us, this is not a specific AFR problem, because it is already an issue today with the introduction of telemetry systems and field mapping and all the information that vehicles nowadays are collecting and possibly reporting back to the manufacturers."* (E5). Many respondents agree with this statement, highlighting that farmers are already willing to share their data if there is a visible benefit for them (E2; E3; E4; E9). Potential conflicts are seen in the lack of data sovereignty in a data cloud and the danger of unauthorized access to the machines (E3; E7). Expert 6 adds that: *"Data collection alone is not that bad. (...) The problem is if you can evaluate the data with AI. And depending on who then gets hold of the whole thing and pushes the interests, you can of course mess around with it quite a bit."* One interviewee believes that many farmers are not yet aware of this data issue (E8).

It appears that any assumed influence of the factor information on user acceptance is very limited from the perspective of the interviewees, since agricultural machinery manufacturers already collect and use large amounts of data and no relevant relationship to user acceptance could be drawn so far. However, a danger is seen in the misuse of the information, especially in the sense of external control of autonomous agricultural machines. This applies more to large-scale autonomous technology than to small-scale autonomous technology. Nevertheless, information is important for the further development of AFR and questions of data protection and user authority should be clarified from the experts' point of view.

Compatibility

The effect of the factor compatibility is linked to technical design (E4) and the associated process dependency (E1; E3) of AFR. The range of possibilities for AFR technical design was still very wide (E4; E7; E9). Furthermore, according to Expert 2, it depends on whether only individual machines or a complete system should be autonomous. Two experts add: *"Will it be more like a cable-less tractor as a dumb pulling device with appropriate equipment? Or will it be a completely different system? We think it probably only makes sense if it will be a completely different system."* (E7). *"But there is also simply the question: Is it really the right step to base a new technology on it, (...) our avowed three-point is the thing that everyone has to do. Or is there no other solution? Just because we've solved it this way with tractors, do we have to do it this way?"* (E3). Expert 1 adds that any AFR with a specific field of application must achieve higher savings than universal AFR because of its fewer operations. The universal applicability of AFRs is regarded as an important factor for user acceptance (E8). Several experts also underline the importance of a transition period towards autonomous techniques to promote acceptance of AFR among farmers (E3; E4; E9).

Thus, the assumed potential influence of the external TAM factor compatibility on perceived usefulness could be confirmed by the required transition period for farmers. During this transition period, AFR and conventional agricultural machinery must be compatible. A potential influence of compatibility on perceived ease of use could be seen in the required technical design and process dependency of AFR.

Farm structure

One expert identifies farm structure as having a direct influence on AFR acceptance, in addition to professionality on farms, since the trend towards increasing farm concentration also puts productivity pressure on farm managers (E8). Apart from farm size, field structure is also considered relevant: *“The larger the fields I have and the fewer fields I have, the faster I can use robots, because the less I have to move them from field to field, the more effective it becomes. (...) This could also be the 100 hectare farm now, which simply has 100 hectares arranged around its house. This is the perfect robot farm. Not so the 500-hectare farm in Bavaria that has spread out over 250 fields.”* (E3). Expert 1 assumes that larger farms are more likely to replace machinery and purchase robots than smaller farms because of a better resource allocation. In contrast, Expert 4 considers the size of the farm to be irrelevant if a: *“(...) weeding service is offered.”* (E4). Larger farms would also be more able to cover expected investment costs of AFR (E1; E7). Two experts explicitly do not consider farm size to be crucial, as smaller farms can also be highly modern (E2; E8).

To summarize, most experts see a positive correlation between AFR's use and increasing farm size, due to greater resource allocation. With regard to the TAM, the effect of farm structure on behavioral intention is reflected. In addition, there seems to be a potential influence on perceived usefulness in terms of investment costs and on ease of use in terms of logistic costs, whose intensity remains to be investigated.

Farm manager characteristics

The characteristics of the farm manager were assessed differently by the interviewees, although a certain degree of openness towards new developments is generally seen as encouraging (E1; E9). However, this openness varies among farmers: *“Well, I am in contact with many farmers who are very open to new technologies and who promote this and also ask for it. Or even come up with suggestions themselves. And I also know farmers who say that they have been doing this for 100 years and will continue to do so.”* (E9). The majority of experts see a positive correlation between openness towards AFR and the level of education of farmers (E1; E2; E4; E7; E8). In addition, two of the respondents see a negative correlation between lower educational levels and increasing age (E7; E8). The majority of experts believe that younger farmers have a greater affinity for digital technologies, such as AFR, because they have grown up with them (E2; E4; E5; E6; E7; E8). While Expert 3, in contrast, assumes that farm managers aged 45 to 60 will adopt AFR the fastest, Experts 1 and 9 share a different opinion: *“Well, I think that age is not really important, but rather the horizon of experience or the willingness to innovate. For us it is not always so clear that innovative farmers always have to be 25 or 35 years old, there are also innovative 50-60-year olds.”* (E1).

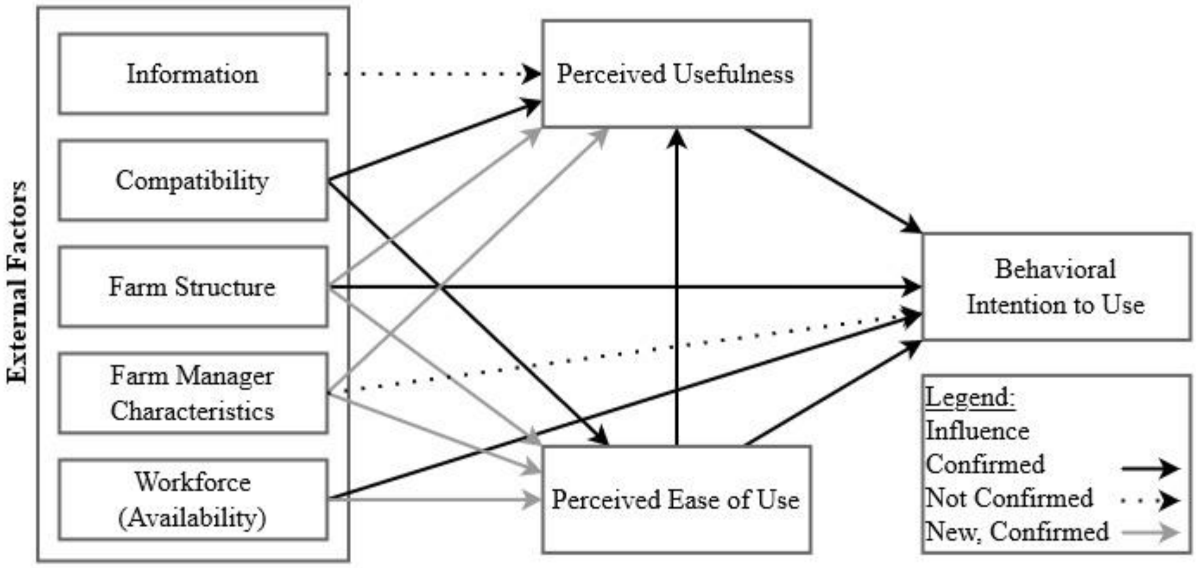
Although these results indicate the relevance of the effect of the farm manager's characteristics as an expression of age and educational level, this expression is not entirely clear. Regarding age, a higher acceptance is increasingly assumed among younger farmers. With regard to the level of education, a slightly lower relevance was found among the respondents. In summary, it is noticeable that the experts do not usually attribute the influence of the farm manager's characteristics directly to the behavioral intention assumed but rather an effect in the form of the farm manager's openness towards new technology on perceived usefulness and perceived ease of use (see Figure 2).

Workforce availability

Due to experts' frequent differentiation between arable farming and special crops, the factor workforce was examined in a differentiated manner as well. The availability of workforce in agriculture is perceived as a general problem: *"But it will still be difficult to find workers at all, (...) so that the considerations can go as far as to say that a robot can also do such work, for example."* (E8). Expert 7 sees the monotony of work, especially on large-scale farms (>1,000 hectares), as an obstacle for young people working in agriculture. Two experts assume that salary costs will rise in the future (E8; E9), whereas Expert 1 argues that in the case of Germany, first, machine operators will continue to be affordable and, second, as mentioned above, the skill level will decrease due to the higher degree of automation in agricultural machinery (E1). It would rather result in: *"(...) different or additional skills being required from employees."* (E5). Extending the analysis to special crop cultivation reveals a more uniform picture: *"I think that at the moment it can save mainly handwork. And that costs. And it's only used in organic or special crops. At least for now."* (E4). It is noted that the workforce: *"(...) are coming from further and further away and the effort is increasing."* (E1). Expert 1 continues, if, as a result of political constraints, workers are not allowed in any region where AFR operates, this may also have a positive effect on the adoption of AFR.

The experts see only a limited influence of the factor workforce on the acceptance of AFR in relation to arable farming in Germany. However, in the field of special crops this relationship is considered to be of high importance, since the effort increases with the number of workers required. This indicates a potential influence of perceived ease of use on behavioral intention, as assumed. Furthermore, there might be a potential influence on behavioral intention due to the fact that AFR are perceived as a response to workforce shortage in agriculture.

Figure 2: Examined TAM in the context of autonomous field robotics



Source: Own illustration according to DAVIS (1989), ADRIAN et al. (2005), AUBERT et al. (2012) and RIAL-LOVERA (2018)

4 Discussion and conclusion

The opportunities for data collection and evaluation through smart farming technologies such as AFR are gradually increasing competition in the agricultural machinery market from not only new AgTech start-ups but also from established IT giants such as IBM or Google. In order to remain dominant in the market, existing agricultural engineering companies should be careful not to fall victim to such disrupters. Therefore, the aim of this exploratory study was to provide a qualitative understanding of the factors influencing the ex-ante user acceptance of AFR from the perspective of the agricultural machinery companies. For this purpose, guideline-based interviews were conducted with nine experts from the German agricultural machinery sector. The interviews were based on the TAM according to DAVIS (1989), supported by external factors derived from the available scientific literature on this topic. In summary, it was found that the topic’s wide scope means that a large number of factors influence farmers' acceptance from the point of view of agricultural machinery manufacturers, with perceived usefulness being regarded as the greatest motivation for using AFR. Even if future need for AFR is assumed by all experts, the economic advantages of autonomous agricultural technology over conventional technology are not plausible in the medium term from the experts' point of view. The interviewees do not expect AFR to be relevant in arable farming for at least 10 years, although earlier in special crops. AFR's future market share will depend above all on legislation regarding autonomous technologies. If AFR are used on a large scale in arable farming, this will very likely lead to changes in the existing business models affecting the end customer. Most of the assumed potential interactions of the factors surveyed in the TAM on user acceptance of AFR have been confirmed by the experts (Figure 2). This again demonstrated the transferability of the TAM to agricultural research as a model for explaining technology acceptance (e.g. ALAMBAIGI and AHANGARI, 2015). However, there were also differences and newly revealed potential influences.

Perceived usefulness was identified as the most mentioned potential influencing factor, which is expressed primarily as economic benefit in terms of investment costs and input savings of and through AFR. This confirms the results of PIERPAOLI et al. (2013), who used a TAM to investigate the factors influencing the ex-ante acceptance of PA technologies. The price of AFR assumed by the experts differed widely. One reason for this could be that AFR is still at an early stage of development for certain workflows (RÜBCKE VON VELTHEIM et al., 2019). Nevertheless, a strong dependence on future user acceptance on price was revealed, which is in line with the results of RIAL-LOVERA (2018), who identified investment costs as a barrier to the adoption of AFR. Despite the cost and efficiency advantages of AFR assumed by the experts and various studies (GAUS et al., 2107; LOWENBERG-DEBOER et al., 2019; SHOCKLEY and DILLON, 2019), an advantage of autonomous agricultural technology over existing conventional agricultural technology in arable farming is not perceived at present, nor in the mid-term. Therefore, and in addition to DÖRR et al. (2019) who argue that farmers would not perceive the user benefits of autonomous agricultural technology, it can be concluded that better communication of economic advantages could promote greater acceptance among farmers. The experts also assigned ease of use as highly relevant for user acceptance, which is in line with other agricultural studies using the TAM (e.g. ADRIAN et al., 2005; AUBERT et al., 2012). At the same time, the majority of the experts forecast a decreasing level of operator qualification, which also depends on the business model (e.g. outsourcing of certain processes to service providers). However, this confirms the findings of DEVITT (2018) and DÖRR et al. (2019), according to whom the relationship between operator and machine will be weakened by the introduction of AFR and a change from machine operator to a less skilled system operator will take place. Nevertheless, the experts demand to retain the possibility of human intervention in the work process. There is greater consensus among the experts on the compatibility factor, since they assume that, particularly in the predicted transition period from semi-autonomous systems to fully autonomous ones, compatibility with conventional technology will be essential for AFR acceptance among farmers. This is confirmed by RIAL-LOVERA (2018), who cites a lack of compatibility and AFR standardization as a possible barrier to acceptance among farmers. The respondents underlined the dependence of compatibility on the intended area of application, with a distinction being made between special AFR with less required compatibility and universal AFR with more required compatibility. DÖRR et al. (2019) additionally anticipate a future increase in universal AFR approaches. The farm structure showed a diverse picture, with the larger share of experts associating higher acceptance with increasing farm size. This is in line with previous studies on PA (CAFFARO and CAVALLO, 2019). Larger farms are considered to have better resource allocation, which allows them to invest more in new technologies. DÖRR et al. (2019) also take differences in farm structures as an acceptance factor, which will lead to different introductions of AFR regionally. In contrast, SHOCKLEY and DILLON (2019) provide evidence for higher profitability from operating AFR on smaller farms, as smaller farms are still able to achieve economies of size with autonomous machinery. Regarding farm manager's characteristics, age and level of education were considered to be of some relevance to AFR's acceptance process, even though there was disagreement among experts. DEVITT (2018) findings showing that younger, better educated and more technologically advanced farmers are more likely to use new technologies can only be partially confirmed. The effects of the farmers' level of education, as recorded in PA studies, could not be clearly confirmed (CAFFARO and CAVALLO, 2019). However, a certain open-mindedness towards new technologies amongst farmers was mentioned by the experts as promoting acceptance and traditional attitudes as inhibiting acceptance. DEVITT (2018) unanimously confirmed the lack of ability to generate trust in AFR as an important cognitive barrier to acceptance. Demonstrations of the new technology could be used to overcome possible acceptance barriers due to the farm manager’s personal characteristics. Among the external factors, availability of workforce was identified as an important driver in the user acceptance process, although the respondents believe that this factor will be more important in special crops than in arable farming. Regional differences are confirmed by GRIEPENTROG (2010), who found that regions with high labor availability and low wages will be less attractive for the introduction of AFR. The influence of workforce availability on ease of use was found to be caused by the high coordination effort of a large number of seasonal workers in special crop cultivation. Confirming this, RIAL-LOVERA (2018) identified workforce availability and rising wages in agriculture as key drivers for the adoption of AFR. Only for the factor information no recognizable influence could be found. This may be due to the fact that agricultural machinery manufacturers have found from experience that a lot of production-related and general data is already collected from farmers as potential AFR users on a daily basis, either by the manufacturers themselves or through the various applications on farmers' smartphones.

However, despite the interesting results regarding the ex-ante user acceptance of AFR, as with most data collected empirically, a number of limitations must be taken into account when interpreting the findings. For instance, the majority of the agricultural machinery manufacturers interviewed are established companies which, unlike the two AgTech start-ups, may have a conservative perspective on this new technology and may have little experience with farmers using AFR. It can also be questioned to what extent agricultural machinery manufacturers are suitable as experts to predict the behavioral intention of farmers. However, since the experience of technical innovations has been shown to influence its acceptance, the results could differ if the sample composition were to change (e.g. more AgTech start-ups and less established agricultural machinery companies) (MELENHORST and BOUWHUIS, 2004). The concept of the study also offers a target for misinterpretation. Thus, despite all efforts to assign the experts' statements as objectively as possible to the factors formed, a certain subjectivity can never be excluded. Nevertheless, as mentioned above, the present qualitative study is only an exploratory study designed to identify and assess the ex-ante acceptance of AFR and its influencing factors. No claim is made to representativeness.

Nevertheless, the results can be used to help AFR manufacturers and political decision-makers to promote the diffusion of AFR. It also offers starting points for further research in the area of acceptance of autonomous machinery in agriculture. Thus, it could not be clearly identified whether a high level of ease of use could outweigh a lack of perceived usefulness or whether there would be an acceptance of this technology given less ease of use. From a methodological point of view, it would be valuable to carry out further quantitative research.

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