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Evaluating the impact of government investment support for crop robots: a multi method approach

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Abstract

Technology plays an important role in the transition towards more sustainable agriculture. The associated costs for farmers may be lowered through government investment support programmes. The German federal state of Bavaria runs such a programme for various technologies, including crop robots that help to reduce chemical plant protection input. Based on official funding application data, an economic model relying on field trial data, and results from an early adopter focus group discussion, the case of the crop robot FD20 (FarmDroid ApS) in sugar beet is evaluated in detail. The funding application data indicates that applicants manage larger farms and work according to organic standards more often than the Bavarian population of farmers. The applicants' counties of residence match areas of sugar beet production, suggesting a use of the robot mainly in sugar beets. The economic evaluation indicates a shift in minimum area of sugar beet production necessary for economical use of the robot caused by the government investment support. The minimum necessary area varies by field size and number and points to the importance of setup times and agricultural structures for robot profitability. The focus group discussion highlights the relevance of the government investment support scheme for farmers' investment into a new type of technology shortly after its market entry. This multi-method approach has provided complementing conclusions from its three components that would not have been possible from each piece of research individually. Overall, the government investment support appears to have been integral to the success of crop robots in Bavaria and may thus serve as an example for other policymakers looking to create similar technology investment support schemes to move forward the digital transition in agriculture.

Keywords

Field robots; early adopters; economic model; focus group; sugar beet production; public funding.

Presenter Profiles

Olivia Spykman works is part of the Digital Farming Group at the Bavarian State Research Center for Agriculture and works on the socio-economic evaluation of crop robots for her PhD. After research crop robot acceptance among farmers and the general society, she currently focuses on questions of labour economics. She has a background in environmental science and agricultural economics.

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Introduction

The European agricultural sector currently faces a lack of manual and skilled labour as well as strict political regulation in response to environmental and societal requirements (cf. European Commission, 2023a), among other challenges. While these issues demand systemic changes rather than technological fixes, shifts in agronomic approaches require longer timescales. Novel (digital) technologies can contribute to the necessary transition both within existing and towards more sustainable systems. Among the digital technologies frequently discussed for this purpose, field robots may contribute to the solution in multiple ways: autonomous operation can reduce the dependency on labour (cf. Lowenberg-DeBoer et al., 2021), and autonomous mechanical weeding can reduce herbicide input and labour cost simultaneously. Furthermore, lower weights than tractors reduce fuel consumption and soil compaction, and electric drives may reduce the dependency of agriculture on fossil fuels. These changes address some of the demands posed in the EU Green Deal to be fulfilled by 2030 (cf. European Commission, 2023a, b). The German federal state of Bavaria has set an even more ambitious goal of halving the use of chemical plant protection by 2028 (StMELF, 2021). Characterized by small-scale agriculture, Bavaria is actively moving forward the transition through an investment support programme (Bayerisches Sonderprogramm Landwirtschaft Digital, "BaySL Digital") for digital technologies that enable the reduction of herbicide use and support organic farming, among others (StMELF, 2023). One such technology eligible for funding through the programme is the seeding and weeding robot FD20 by Danish manufacturer FarmDroid ApS. It is solar-powered and autonomously seeds and weeds sugar beet and other fine seeds, relying on an RTK-enhanced GNSS system as opposed to camera detection. Between October 2019 and December 2022, Bavarian farmers could apply for funding of 40 % for a maximum investment sum of € 100,000 for eligible technologies, including the FD20. After an evaluation break of the technology-specific programme, it was resumed in July 2023. Lowering technology entry costs for farmers while simultaneously moving towards more sustainable agricultural practices is the proclaimed goal of the programme (StMELF, 2023). As such, it addresses financial limitations to technology adoption, which play an important role in farmer decisions for or against new technology.

In the broader context of farm technologization, farmers tend to seek a compromise between costs and realizable benefits of advanced technologies (Kutter et al., 2011). Factors such as farm size, legal framework, operator characteristics, and the relative advantage of farming technologies consistently influence adoption and diffusion (Shang et al, 2021). Against this background, the attitude of farmers in acquiring new technologies is strongly determined by investment cost-related concerns. High investment costs may impede farmers in realizing potential profitability benefits (Eastwood & Renwick, 2020). Other literature indicates that farmers also adopt new farming practices even without an immediate profit (Lehman et al., 1993). However, financial initiatives can support a quicker and broader application of technologies, such as capital grants for technology maintenance, tax breaks, interest rate reductions, and free technical assistance (Tey and Brindal, 2012; Floridi et al., 2013; Shang et al., 2021). One or more of these measures could indirectly change farmers' perceived profitability and improve actual farm productivity or even mitigate technology user risk (Ferrari et al., 2022). A variety of studies shows that the presence of government support services and funding schemes is an important prerequisite for the adoption of digital technologies in agriculture (e.g., Reichardt and Jürgens, 2009; Lambert et al., 2015). However, there are more economic analyses that measure the extent of decoupled farm payments or federally subsidised crop insurance premiums (e. g., Weber et al., 2016). Only few studies document the various country-specific programmes that have a direct impact on the use of digital farming technology. This may also be due to many such programmes having only been implemented in recent years (McFadden et al., 2023). Barnes et al. (2019) postulate that technology-specific subsidies offered by national or regional authorities may be an important driver for adoption of disruptive technologies like crop robots, especially on smaller and low-income farms. In this context, the appropriate type of financial support is also decisive. A very recent study from Switzerland simulated that in the case of site-specific management, coupled payments for reduced nitrogen are more cost-effective than, for example, area-based payments or subsidies for the use of technology (Huber et al., 2023). However, this result is specific to the technology and cannot necessarily be transferred to crop robots, as, for example, savings potentials of herbicides can only be measured in context of the reference (e.g., conventional vs. organic farms).

The Bavarian government's funding scheme for digital farming technologies represents a case study for the role of technology investment support in the transition currently underway in the farming sector. The particular case of the FD20 robot within this regional funding scheme has been analysed from multiple perspectives. The present contribution forms a synthesis of the analysis of official funding data, a model for calculating economic efficiency of the FD20 (Spykman et al., 2023a; Rossmadl et al., 2023) as well as findings from a focus group discussion (Spykman et al., 2023b) to evaluate a regional investment support programme. The overview provides insights for researchers and policymakers in other regions looking to investigate and support the uptake of digital technologies in agriculture.

Methods

A multi-methods approach was used to understand the impact of funding for crop robots through the government investment support programme BaySL digital in Bavaria. First, applications for crop robot investment support approved by the responsible government agency are evaluated to characterise the funded farms. Then, an economic evaluation shows the monetary impact of subsidy payments on the profitability of the FD20 compared to standard weed control in organic sugar beet. Finally, results of a focus group discussion with early adopters provide perspectives from practical agriculture both on experience with the robot as well as on the role of the funding scheme.

(a) Evaluation of funding application progress

The investment support programme was launched in October 2018, with the robot FarmDroid FD20 only being put on the list of eligible technologies in October 2019. The currently ca. 50 technologies on this list fulfilled the requirements of (1) having a digital component and (2) serving the purpose of reducing the input of chemical plant protection products. Other categories of technologies were also supported under the same funding scheme but will not be discussed here. The funding of digital weeding and spraying technologies, which includes crop robots, was continued until December 2022, when it was paused for evaluation. Funding was resumed in July 2023, but this ongoing period will not be considered in the present analysis.

A list of approved applications for robots over the scheme's duration (October 2019 till December 2022) was provided by the Bavarian State Ministry of Food, Agriculture and Forestry under adherence to data protection regulation. Based on the farm identification numbers, farm size and management type (organic/conventional) could be retrieved from the government database. Further information on the status of the funding process was added: after approval for funding, farmers were given 12 months' time to purchase the crop robot. They were then given another three months to submit the invoice as proof of purchase in order to receive an investment support of 40 % of the purchasing price up to an investment sum of net € 100,000. Therefore, at the time of writing, not all approved applications can be evaluated conclusively. This category will be considered "open" applications, as opposed to "completed" (invoice submitted, funding transferred) and "incomplete" (application retracted or no invoice submitted more than 15 months after approved application).

Given the FD20's suitability of sugar beet production, which relies heavily on manual weeding under organic management, the applicants' postal codes were mapped and combined with data on sugar beet production. For this purpose, the first two positions of the five-digit postal code, which indicate the region, were used to create a color-coded map of approved applications for the FD20 per region in QGIS 3.12.3 (QGIS Development Team, 2023). Additionally, county-level ("Landkreis") data on sugar beet production was provided by the two sugar beet growers' associations (Steinberger, 2023, personal communication, 25 July; Beil, 2023, personal communication, 26 July). Since membership in one of the two associations is mandatory and dual membership is not possible for growers, the provided data can be considered comprehensive. The data were also transferred to QGIS 3.12.3 and color-coded.

(b) Modelling the effect of public funding

Given a lack of long-term empirical data, an economic model of different assumption-based scenarios was evaluated in Microsoft Excel. This model compares organic sugar beet production using the FD20 to the standard method of weed control, relying on a tractor and manual labour (see Spykman et al., 2023a; Rossmadl et al., 2023). Only those measures of the sugar beet production process assumed to differ between robot and tractor operations were included in the model. Table 1 summarises the different measures considered in the model comparing the two variants (FD20 vs. standard variant). The model includes labour and machinery costs for both variants. These costs take into account farm-field distance, error frequency and farmer-response time in the FD20 variant, and time needed for the completion of setup tasks, among others. The time data for the FD20 variant are based on experience as well as dedicated time measurements from various field trials in 2021 (Rossmadl et al., 2023). All other parameters are based on standardized data (KTBL, 2021; Achilles et al., 2020). The model's computations include the difference between the FD20 and the standard variant, so that the produced output was the FD20's profit contribution to sugar beet production relative to the standard variant (Spykman et al., 2023a; Rossmadl et al., 2023).

Table 1: Comparison of FD20 and standard variants in the economic evaluation model (adapted from Spykman et al., 2023a)

FD20 variant	Standard variant
1x blind seeding[1]	
1x seeding	1x seeding
1x blind weeding[2]	
3x inter-row weeding	1x manual weeding
3x intra-row weeding	3x tractor-bound mechanical weeding
0.3x manual weeding (canopy closure)	1x manual weeding (canopy closure

Based on experience from field trials (Kopfinger and Vinzent, 2021), it is assumed that the FD20 variant may fully replace the first passes of manual weeding but still requires some manual weeding at canopy closure due to (1) a safety margin around the individual plants not being weeded and (2) the risk of leaf damage by the FD20 during passes at or after canopy closure. Therefore, the FD20 variant contains a pass of manual weeding at a fraction of the time of a regular pass of manual weeding, as it is assumed that farm labourers will be able to proceed at a faster pace compared to the standard variant due to the FD20's frequent passes throughout the season and thus lower weed coverage compared to the standard variant at canopy closure.

For a sensitivity analysis, different scenarios were calculated in the model (Spykman et al., 2023a). The baseline scenario, using data for the research site in Bavaria, assumed an annual capacity of 18 ha (calculated based on FD20 speed and good field days (Achilles et al., 2020)), which was divided over ten fields of 1.8 ha each, based on the average Bavarian field size of 1.74 ha (LfL, 2014). Further scenarios included a variety of field distributions given a constant total area of 18 ha, ranging from a single 18 ha field to 15 1.2 ha fields. Additionally, a range of maximum possible field capacities (8-20 ha), , calculated from the good field days (Achilles et al., 2020) in German sugar beet producing regions (WVZ, 2022) and own data on the robot's speed during seeding and weeding, was investigated. The upper end of the maximum field capacity spectrum is marked by the manufacturer's specification of 20 ha being the seasonal limit (FarmDroid ApS, 2023), which can also be reached in Bavaria according to the calculations. There are two sugar beet growers' associations in Bavaria, which together represent all sugar beet growers in the state. As specified by these growers' associations, between 26 and 29 % of member farms cultivate sugar beet on areas between 8 and 20 ha (Steinberger, 2023, personal communication, 25 July; Beil, 2023, personal communication, 26 July).

Further parameters include the purchasing price of the FD20 at net € 90,000 (Miller, 2022), and wages at 21 €/h for skilled labour and 16 €/h for manual labour (Die Bundesregierung, 2022; Achilles et al., 2020). Fuel costs were assumed to be 1.40 €/l (Offermann et al., 2022), including both the effect of the Russian invasion of Ukraine and the farm diesel subsidy. The resale value of 20 % after ten years is based on standardized data for agricultural equipment (Achilles et al., 2020) since no empirical data on an FD20 second-hand market exists yet. The baseline scenario was calculated without government investment support (Spykman et al., 2023a); for scenarios with government investment support, the purchasing price of the FD20 was reduced by 40 % to net € 54,000.

(c) Focus group discussion with early adopters

In autumn of 2022, the six farms that had received approval of their funding application prior to the start of the 2020 production season and thus had two seasons of experience with the robot were selected from the list of investment support recipients. A further nine farms that had received FD20 investment support after the start of the 2020 season but before the start of the 2021 season were added to the list. Given the applicants' agreement to future research inquiries during the application process, these 15 early adopters were contacted by telephone and invited to participate in an online focus group discussion to discuss their experience with the robot and challenges in their respective areas of operation in different regions of Bavaria (see Spykman et al., 2023b). Focus group discussions, as opposed to individual interviews, allow for a variety of interpersonal interactions to be provoked, despite a limited time frame, to obtain more details and background information (Mayring, 2016). A rough framework of topics outlined by pre-defined questions is typical for this method of data collection (Roller & Lavrakas, 2015). The focus group participants discuss freely within the prepared topics, which covered before-purchase expectations, funding process, user experience, problems and challenges, suggestions for improvement in the present case. The moderator intervenes as soon as the discussion strays from the topic or content is repeated in the discussion.

Seven of the 15 farm managers contacted took part in the online discussion session (two approved applications before 2020 season, five approved applications before 2021 season), with some variability in the group regarding crops grown, location, cultivation method, soil conditions, and age of operator (see Spykman et al., 2023b). Sample heterogeneity is an advantage for focus groups, as homogeneous groups tend to limit the knowledge gained about the population (Grønkjær et al., 2011). The audio track of the 90-minute discussion session was recorded to transcribe discussion for content analysis. In the transcript, individual statements made by the participants were coded and assigned to the original topic areas investigated.

Results

Descriptive statistics of funding applications

Over the course of three years (November 2019-December 2022), 88 applications for funding of field crop robots (65 by organic farmers) were approved by the Bavarian State Ministry for Food, Agriculture, and Forestry. Based on the available data, it is not possible to state the total number of applications to evaluate whether any applications were *not* approved. Of all these applications, only two were for robots other than the FarmDroid FD20, which will not be considered in the further discussion.

Regarding the 86 applications for the FD20 crop robot, it should be noted that one application was submitted by a machinery group with its proper ID; although this machinery group represents two farms, they applied jointly for one robot. Additionally, four tenancies in common also applied for a robot to be shared by two farms, yet in each of these cases, each farm applied individually. That is, these eight applications represent only four robots. Thus, the total number of robots for which applications were approved amounts to 82 and the total number of individual farms having been approved for funding amounts to 87.

At the time of writing, 17 of the 86 approved applications had been retracted or not completed (i.e., invoice submitted within required timeframe) and may thus be considered incomplete. Of the remaining 69 approved applications, six are open as applicants are still within the 15-month timeframe post-approval to submit the invoice for their robot. That is, 80 % of all approved applications so far were or can still be completed. Figure 1 demonstrates the development of cumulative approved applications and submitted invoices in monthly increments over the course of three and a half years, beginning with the first approved applications in February 2020 and leading up to August 2023 (the latest possible date at the time of writing) as submission of invoices remains possible until early 2024 for the last approved applications. It becomes evident that applications were rather slow in the first year but subsequently maintained a steady rate. After the programme was paused (from late December 2022 until resumption in July 2023), submitted invoiced continued increasing for several months.

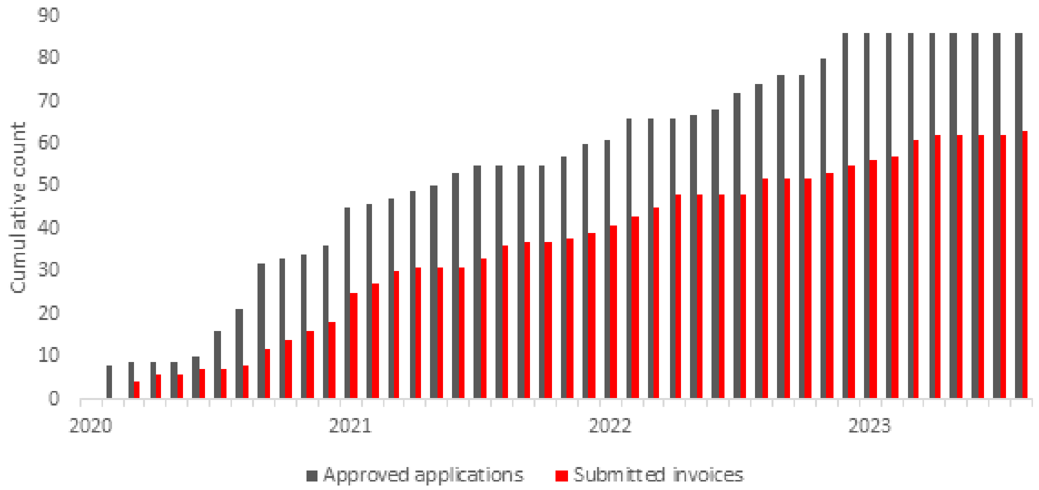

Figure 1: Temporal development of approved applications and submitted invoices for the FD20 (dotted box indicating evaluation pause)

The applicants' farm sizes range from 13 to 458 ha, with a mean of 99.5 ha. The mean farm size is thus markedly larger than the Bavarian average of 36.9 ha (StMELF, 2022). The Bavarian population of sugar beet farmers grows sugar beet on an average of 8.6 ha, although the largest farms reach sugar beet areas of 180-200 ha (Steinberger, 2023, personal communication, 25 July). Additionally, with 87 % of applications coming from organic farmers, the group of applicants quite juxtaposed to the population of Bavarian farmers, of whom only 11 % manage their farm according to organic standards (StMELF, 2022). While the available data did not provide information about the crop(s) in which the robot was planned to be deployed at the time of application, the visualisation of application numbers and sugar beet-producing areas in the federal state of Bavaria in Figure 2 indicates a spatial relationship between FD20 applicators and sugar beet production regions (county/"Landkreis" level). Regions with a higher number of approved applications are concentrated in the major sugar beet growing areas in the north, east and west of the state.

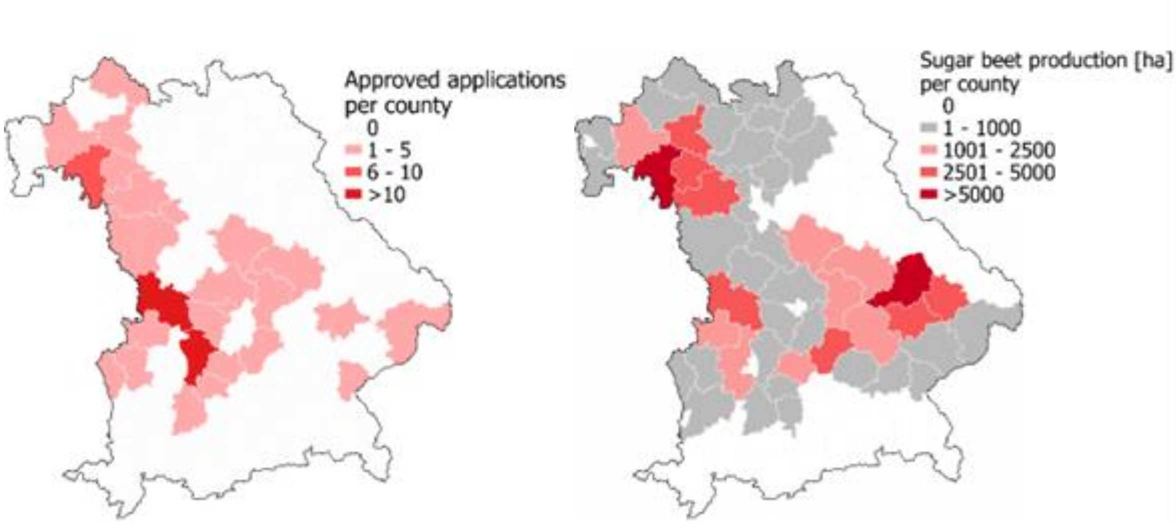

Figure 2: Regional distribution of all 86 approved applications for FD20 (left, own data) and sugar beet producing counties (right, 2022 data from Steinberger, 2023, personal communication, 25 July)

Effect of government investment support on crop robot economics

In the economic model, the baseline scenario (total area operated by robot of 18 ha, distributed evenly over ten fields) resulted in an FD20 profit contribution of 304 €/ha*a at 0 % investment support and 794 €/ha*a at 40 % investment support, respectively. Given the small-scale structure of Bavarian agriculture, different scenarios of field size and distribution were considered. The profit contribution of the FD20 remained positive over all field distribution scenarios for a total area of 18 ha and irrespective of the 40 % investment support. This suggests that investment support is not necessary for economical operations at the upper end of the robot's annual area capacity, even if operations take place on many small fields and thus require substantial set-up time (see Spykman et al., 2023a). However, given the uncertainty about a potential second-hand market, a worst case of 0 % resale value was also considered. It highlights the importance of the investment support scheme for financial risk reduction. Under the assumptions of the baseline scenario (i.e., total area of 18 ha) a 0 % resale value would lower the profit contribution by 60 % for the no-investment-support scenario, but only by 23 % for the investment-support scenario.

The investment support also impacts the minimum total area (see Figure 3) for economical operations. Considering average field sizes of 2 ha (cf. baseline scenario) and 4 ha, the FD20's profit contribution at each total area (range: 8-20 ha) was evaluated, subject to divisibility constraints. If the 40 % investment support is added to the calculation, both field sizes yield positive profit contributions across the considered range. However, without investment support, larger total areas would be necessary for the robot to break even, i.e., 11.5 ha at an average field size of 4 ha and 13.7 ha at an average field size of 2 ha. Thus, even if farmers have larger-than-average fields in Bavaria, they still require a certain minimum area for the robot to be economically advantageous over the standard method. The required minimum area also exceeds the average sugar beet area per farm of 8.6 ha, which, however, ranges widely between growers (Steinberger, 2023, personal communication, 25 July) This disadvantage of small-scale structures may be attenuated by government investment support.

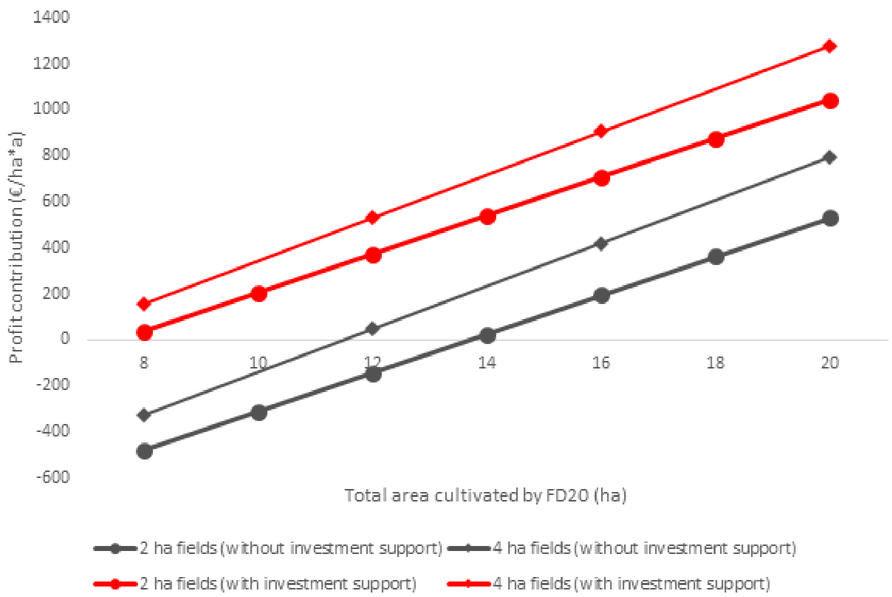

Figure 3: Profit contribution of FD20 under consideration of different field size options with and without investment support

FD20 early adopters' opinion on role of government investment support

Among the early adopters engaged in the focus group discussion, the primary utilisation of the FD20 is in sugar beet production (see Spykman et al., 2023b). In a few instances, it is deployed for sowing rapeseed and subsequently performing hoeing operations between the rows. Notably, one farm manager expressed intentions to employ crop robots in kale cultivation. Regarding the area managed using the FD20, the participants communicated a sizable range from 8 to 25 ha, exceeding the manufacturer's specification of a maximum seasonal usage of 20 ha (FarmDroid ApS, 2022). Most farmers in the focus group found that the robot met their expectations. While the robot successfully reduced manual labour, it did not completely replace it. The FD20's effectiveness in task performance exhibited significant variation depending on the site-specific conditions. Particularly soil structure (i.e., preferably finely textured, minimal presence of stones, and as level as possible) emerged as a pivotal requirement for achieving technical success in utilising the robot.

Main drivers for investing in the robot FD20 were similar across participants. One of the key motivations were Covid-19-driven concerns about not being able to host seasonal workers due to travel restrictions or stricter housing regulation. The market-availability of FD20 in Germany at the start of the pandemic and the possibility to reduce economic risks through the investment support programme presented farmers with the opportunity to increase resilience and decrease cost of organic sugar beet production. They confirm the application process of the funding scheme to be well organized and easy to manoeuvre, so that no suggestions for improvement of the procedure were discussed in the focus group.

Towards the end of the group discussion, farmers were asked whether they would repeat the investment in the FD20, given the knowledge they had gained during the two years since purchase. The farmers' responses to this question were more differentiated. Some were generally happy with the robot's performance but were deterred by the increase in its catalogue price since they had purchased it so that, without investment support, they would not purchase the robot a second time. This sentiment was echoed by another fraction, who highlighted the value of improved resilience in production due to a reduced dependence on seasonal labour. This subgroup agreed also that they would still make the investment under similar conditions, i.e., price and investment support. A third subgroup appreciated the work relief presented by the FD20 but based on their experience would now prefer waiting for further technological developments to improve the relative advantage before investing in a crop robot.

Discussion

The multi-perspective evaluation of government investment support for farmers' participation in the technological transition towards autonomy in agriculture highlighted the importance of farmer characteristics as early adopters and the relevance of targeted support programmes for small-scale regions. The investment support programme in Bavaria has resulted in more than 55 robots being used predominantly in sugar beet production within three years of funding. This represents more than a quarter of all FD20s operating in Germany, according to the manufacturer (Georgsen, 2023, personal communication, 26 July).

While investment support generally lowers the risk for farmers, the ones who invested in the robot directly after its market entrance in Germany in 2020 may still be described as venturesome. The government investment support programme in Bavaria supported this incentive, as opposed to the general CAP subsidy mechanism, which does not grant additional funds to promote innovations for sustainable agriculture (Reinhardt, 2022). In the specific case of the FD20, the high rate of organic farmers among applicants (87 %) suggests that this technology may facilitate organic sugar beet production, which could influence farmers' decision to adopt organic farming practices, thus contributing to a socio-political objective in Bavaria. Further, FD20 early adopters had to find technological solutions on their own to put the robot to its most effective use, adding to the general learning costs that come with the change from tractor to robot. The focus group participants also underscored the importance of direct exchange with the manufacturer (cf. Rial-Lovera, 2018; Rose et al., 2021) and the importance of ongoing technological development of crop robots for their retrospective opinion. Research into the applications of the specific technology in question and possibly subsidies for their early adoption (Sparrow & Howard, 2020) may thus contribute to broader dissemination and lower risk for small-scale farms (Fleming et al., 2018).

Sectoral diffusion at large is linked to incentivising infrastructural conditions and policies. Ferrari et al. (2022) gathered expert opinions and conclude initiatives for public awareness, taxes and subsidies, training and education, cohesion funds, and general policies reducing the risk of use to be important drivers of digital transformation. However, government investment support programmes should be designed with caution. Transparency and care are needed because many farmers feel strongly monitored by the state (due to regulations on subsidies). This leads to fear of data misuse or exposure of grievances among farmers (Linsner et al. 2021). However, the focus group participants did not express any such concerns. The processing of applications for the BaySL Digital funding scheme occurred through the same platform as applications for direct payments, so that necessary operational data was recorded by the funding body anyway.

The economic model assessing the profitability of the use of the FD20 underscores the importance of government investment support in the context of small-scale farming, as is typical in Bavaria. Investment support reduces the total area required to reach break-even by 45 % under the declared assumptions. Given the lack of long-term empirical data on the technology, the resulting profit contributions should be considered only in relative terms, though, being highly dependent on the assumed input values. Nonetheless, the resulting patterns indicate that some farms, depending on their field distribution, may not have been able to use the robot economically without co-funding. This observation indicates that crop robots, too, are subject to economies of scale, which may be attributed to costs of labour for setup tasks (e.g., transport between fields). Thus, despite autonomous vehicles reducing active labour time on the field, they do require increased labour at other stages of the field work process, somewhat analogous to the shift, yet not reduction in labour due to milking robots (cf. Martin et al., 2022). The described difference in economy due to farm size may cause a digital divide, which can be softened by government policy (van Woensel et al., 2016).

Conclusion

The multi-method approach to evaluating technology-specific government investment support by means of the FD20 robot case allowed drawing a combined conclusion from three individual investigations. The economic assessment allows for evaluation of potentials for specific farm types and sizes. The identified range of profitability matches the production areas of almost a third of sugar beet growers in Bavaria, although more detailed analyses will be needed to differentiate between organic and conventional producers. The economic model further suggests government funding to represent a decisive financial incentive, which was confirmed by the focus group. The three perspectives provide an overview of the alignment of funding scheme, farm structures, and target user group in Bavaria, which would not be possible on a stand-alone basis.

Government investment support like the BaySL Digital programme can play an important role in facilitating the adoption of novel technologies such as the FD20 robot. Hardware technology may only become economical when used at a certain intensity, meaning that the investment case may not be clear or given at all for farms below a certain acreage. Investment support programmes may decrease the required acreage by lowering the effective sum of investment, thus enabling otherwise disadvantaged small farms to participate in technological progress.

Technological progress in agriculture is not an end in itself. Rather, current developments aim to make farming more ecologically compatible while guaranteeing economic competitiveness and social support. Government investment support should be coupled to the achievement of milestones in the agricultural transition. In the BaySL Digital programme, this was achieved by restricting funding to technologies that could meet pre-defined objectives (e.g., the reduction of synthetic plant protection inputs). Other options may be devised, but this general aspect should not be omitted by policymakers wishing to implement a funding scheme for agricultural technologies.

References

ACHILLES, W., ECKEL, H., EURICH-MENDEN, B., FRISCH, J., FRITZSCHE, S., FUNK, M., … & WULF, S. 2020. Betriebsplanung Landwirtschaft 2020/21. KTBL e.V., Darmstadt.

AIVAZIDOU, E. & TSOLAKIS, N. 2022. Transitioning towards human–robot synergy in agriculture: A systems thinking perspective. Systems Research and Behavioral Science, 40(3), 536-551.

BARNES, A. P., SOTO, I., EORY, V., BECK, B., BALAFOUTIS, A., SÁNCHEZ, B., … & GÓMEZ-BARBERO, M. 2019. Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. Land Use Policy, 80, 163-174.

DIE BUNDESREGIERUNG. 2022. Anpassung des gesetzlichen Mindestlohns. Available at https://www.bundesregierung.de/breg-de/aktuelles/mindestlohn-gestiegen-1804568 (Accessed: 28 September 2022).

EASTWOOD, C. R. & RENWICK, A. (2020). Innovation uncertainty impacts the adoption of smarter farming approaches. Frontiers in Sustainable Food Systems, 4, 24.

EUROPEAN COMMISSION. 2023a. Agriculture and the Green Deal. Available at https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/agriculture-and-green-deal_en (Accessed 19 July 2023).

EUROPEAN COMMISSION.2023b. Cleaning Our Energy System. Available at https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#cleaning-our-energy-system (Accessed 19 July 2023).

FARMDROID ApS. 2022. Welcome (landing page). https://farmdroid.dk/en/welcome/ (Accessed: 20 July 2022).

FERRARI, A., BACCO, M., GABER, K., JEDLITSCHKA, A., HESS, S., KAIPAINEN, J., ... & BRUNORI, G. 2022. Drivers, barriers and impacts of digitalisation in rural areas from the viewpoint of experts. Information and Software Technology, 145, 106816.

FLEMING, A., JAKKU, E., LIM-CAMACHO, L., TAYLOR, B., & THORBURN, P. 2018. Is big data for big farming or for everyone? Perceptions in the Australian grains industry. Agronomy for sustainable development, 38, 1-10.

FLORIDI, M., BARTOLINI, F., PEERLINGS, J., POLMAN, N., & VIAGGI, D. 2013. Modelling the adoption of automatic milking systems in Noord-Holland. Bio-based and Applied Economics Journal, 2, 73-90.

GRØNKJÆR, M., CURTIS, T., DE CRESPIGNY, C., & DELMAR, C. 2011. Analysing group interaction in focus group research: Impact on content and the role of the moderator. Qualitative Studies, 2(1), 16–30.

HUBER, R., SPÄTI, K., & FINGER, R. 2023. A behavioural agent-based modelling approach for the ex-ante assessment of policies supporting precision agriculture. Ecological Economics, 212, 107936.

KOPFINGER, S. & VINZENT, B. 2021. Erprobung und Bewertung eines autonomen Feldroboters. MEYER-AURICH et al.: Referate der 41. GIL-Jahrestagung, Potsdam, 8-9 March, 175-180.

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft). KTBL-Feldarbeitsrechner. Available at https://daten.ktbl.de/feldarbeit/home.html (Accessed 02.12.2021).

KUTTER, T., TIEMANN, S., SIEBERT, R. & FOUNTAS, S. 2011. The role of communication and co-operation in the adoption of precision farming. Precision Agriculture, 12, 2-17.

LAMBERT, D. M., PAUDEL, K. P. & LARSON, J. A. 2015. Bundled adoption of precision agriculture technologies by cotton producers. Journal of Agricultural and Resource Economics, 325-345.

LEHMAN, H., CLARK, E. A. & WEISE, S. F. 1993. Clarifying the definition of sustainable agriculture. Journal of Agricultural and Environmental Ethics, 6(2), 127–143.

LFL (Bayerische Landesanstalt für Landwirtschaft. 2022. Agrarstrukturentwicklung in Bayern – IBA-Agrarstrukturbericht 2014. Available at https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/agrarsturkturentwicklung-bayern_lfl-information.pdf (Accessed 04 October 2022).

LINSNER, S., KUNTKE, F., STEINBRINK, E., FRANKEN, J., & REUTER, C. 2021. The Role of Privacy in Digitalization-Analyzing Perspectives of German Farmers. Proceedings on Privacy Enhancing Technology, 2021(3), 334-350.

LOWENBERG-DEBOER, J., FRANKLIN, K., BEHRENDT, K., GODWIN, R. 2021. Economics of autonomous equipment for arable farms. Precision Agriculture, 22, 1992-2006.

MARTIN, T., GASSELIN, P., HOSTIUOU, N., FERON, G., LAURENS, L., PURSEIGLE, F. & OLLIVIER, G. 2022. Robots and transformations of work in farm: a systematic review of the literature and a research agenda. Agronomy for Sustainable Development, 42, 66.

MAYRING, P. 2016. Einführung in die qualitative Sozialforschung. Beltz, Weinheim, Basel.

MCFADDEN, J., NJUKI, E., & GRIFFIN, T. 2023. Precision Agriculture in the Digital Era: Recent Adoption on US Farms. Economic Information Bulletin 248, USDA.

OFFERMANN, F., DEBLITZ, C., ELLSSEL, R. & NIEBERG, H. 2022. Umsetzung der EU Krisenmaßnahme nach Art. 219 GMO – Auswirkung des Preisanstiegs in Folge des Ukrainekriegs auf die verschiedene Agrarsektoren – Stellungnahme für das BMEL. Thünen-Institut, Braunschweig.

QGIS DEVELOPMENT TEAM (2023). QGIS Geographic Information System Version 3.12.3. Open Source Geospatial Foundation Project. http://qgis.osgeo.org"

REICHARDT, M. & JÜRGENS, C. 2009. Adoption and future perspective of precision farming in Germany: results of several surveys among different agricultural target groups. Precision Agriculture, 10, 73-94.

REINHARDT, T. 2022. The farm to fork strategy and the digital transformation of the agrifood sector—An assessment from the perspective of innovation systems. Applied Economic Perspectives and Policy, 45(2), 819-838

ROLLER, M. R., & LAVRAKAS, P. J. 2015. Applied qualitative research design: A total quality framework approach. Guilford Publications.

ROSE, D.C., LYON, J., DE BOON, A. HANHEIDE, M. & PEARSON, S. 2021. Responsible development of autonomous robotics in agriculture. Nature Food, 2, 306-309.

ROSSMADL, A., KOPFINGER, S., BUSBOOM, A. (2023, accepted). Autonomous robotics in agriculture – a preliminary techno-economic evaluation of a mechanical weeding system. To be presented at 56th International Symposium on Robotics (ISR Europe), September 26-27.

SHANG, L., HECKELEI, T., GERULLIS, M. K., BÖRNER, J. & RASCH, S. 2021. Adoption and diffusion of digital farming technologies-integrating farm-level evidence and system interaction. Agricultural Systems, 190, 103074.

SPARROW, R., & HOWARD, M. 2021. Robots in agriculture: prospects, impacts, ethics, and policy. Precision Agriculture, 22, 818-833.

SPYKMAN, O. ROSSMADL, A., PFEIFFER, J., KOPFINGER, S., BUSBOOM, A. 2023 a. Wirtschaftlichkeitsbewertung eines Feldroboters auf Basis erster Erfahrungen im Praxiseinsatz. In (Hoffmann, C. et al.) Referate der 43. GIL-Jahrestagung, Osnabrück, 13-14 February, 255-266.

SPYKMAN, O., KOPFINGER, S., GABRIEL, A., & GANDORFER, M. 2023 b. Erste Praxiserfahrung mit einem Feldroboter–Ergebnisse einer Fokusgruppendiskussion mit early adopters. In (Hoffmann, C. et al.) Referate der 43. GIL-Jahrestagung, Osnabrück, 13-14 February, 243-254.

STMELF [Bavarian State Ministry for Food, Agriculture and Forestry]. 2021. Regierungserklärung 2021. Available at https://www.stmelf.bayern.de/mam/cms01/agrarpolitik/dateien/regierungserklaerung2021_kurzfassung.pdf (Accessed: 20 July 2023)

STMELF [Bavarian State Ministry for Food, Agriculture and Forestry]. 2022. Bayerischer Agrarbericht 2022. Available at https://www.agrarbericht.bayern.de/landwirtschaft/ (Accessed: 28 June 2023).

STMELF [Bavarian State Ministry for Food, Agriculture and Forestry]. 2023. Bayerisches Sonderprogramm Landwirtschaft Digital. Available at https://www.stmelf.bayern.de/foerderung/bayerisches-sonderprogramm-landwirtschaft-digital-baysl/index.html (Accessed 25 July 2023).

TEY, Y. S., & BRINDAL, M. 2012. Factors influencing the adoption of precision agricultural technologies: a review for policy implications. Precision Agriculture, 13, 713-730.

WEBER, J.G., N. KEY, AND E.J. O'DONOGHUE. 2016. Does Federal Crop Insurance Make Environmental Externalities from Agriculture Worse?, Journal of the Association of Environmental and Resource Economics, 3(3), 707–742.

WVZ (Wirtschaftliche Vereinigung Zucker e. V). 2022. Jahresbericht 2021/2022. Available at: https://www.zuckerverbaende.de/wp-content/uploads/2022/06/WVZ_VdZ_Jahresbericht_2021-2022.pdf (Accessed 25 July 2023).