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Digital Agricultural Policy: Effects Of Digitalization In Agricultural Policy

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ABSTRACT

The agricultural sector is becoming more and more digitalized. At the same time, there are growing calls for agricultural policies that better support sustainability. It is unclear, meanwhile, how digitization can improve agricultural policy's ability to lessen undesirable effects and increase farming's advantages. The extent to which digital technology can lead to new design specifications and a variety of agricultural policy tools that more effectively and potentially more efficiently handle sustainability issues in farming is examined in this article. Using examples from practice and theoretical insights, it creates and implements an analytical framework that focuses on the effects of digitalization in several policy dimensions in a European setting. We demonstrate that traditional agricultural policy's use of analog technologies is not simply replaced by digital agricultural policy. It provides fresh ideas for agriculture policy, such as innovative ways to more successfully handle problems. It specifically presents chances for more efficient spatial targeting and instrument customization, including results-based subsidies. To facilitate policy learning and design adaptation, digital data can be strategically generated utilizing the appropriate instrument designs. Digitalization typically lowers transaction costs while benefiting information-intensive tools and designs the most. Additionally, information-based governance may replace direct action in agricultural policy as a result of digitalization. However, the analysis indicates that research and practice of digitalizing agricultural policy need to pay attention to institutional restrictions and interests as well as the skills of the individuals involved

KEYWORDS: Digitalisation, Information and communication technology Agricultural policy, Policy design, Policy instrument choice

1. INTRODUCTION

Since digitalization helps with precision agriculture production and trade through online platforms and traceability systems, it is anticipated to drastically change the food and farming industries (e.g. Aceto et al., 2019; Kamble et al., 2020; Poppe et al., 2013; Walter et al., 2017). At the same time, digital tools are being added to the agricultural policy toolbox to facilitate data exchange, analysis, and compliance monitoring (OECD, 2019; European Court of Auditors, 2020). However, it is still unclear how the potential of digital technology could cause agricultural policy to change in this direction, even in the face of strong warnings of the urgent need to increase the effectiveness of agricultural policy (e.g. De Schutter et al., 2020; Gawith and Hodge, 2019; Grethe, 2017; Pe'er et al., 2014).

The extent to which digital technologies such as remote sensing or integrated data analytics (1) can lead to a variety of agricultural policy instrument choices, (2) provide a range of instrument design options, and (3) allow for innovative design specifications to more effectively and efficiently address issues is examined in this article. To investigate the impact of digitalization on agricultural policy instrument and design choices, we create an analytical framework that centers on important policy aspects of digitalized instrument designs.

Digital technology adoption for agricultural policy is still sporadic (OECD, 2019). It's unknown what problems result from their use and how much of their potential is being utilized (Klerkx et al., 2019). Digital tools for policy implementation are mentioned occasionally in the literature (e.g. Coble et al., 2018; Finger et al., 2019; Zilberman and Millock, 1997). Increased efficacy and efficiency as a result of.

digital technology's monitoring and targeting capabilities (Weersink et al., 2018) and more economical use of ecologically damaging farming inputs (Finger et al., 2019) are anticipated advantages of employing digital technology for agricultural policy. Additionally, it can lower the transaction costs associated with implementing policies and information asymmetry.

Though choices and design specifications of agricultural policy instruments are limited to what is deemed feasible considering dominant discourses, political constraints, administrative resources, and technology, the implementation technologies currently in use and the policy instruments are largely in line (Erjavec and Erjavec, 2015; Henke et al., 2018; McCann, 2013; Weersink et al., 1998). Therefore, how much might digital technology disrupt this alignment and create new options for agricultural policy tools? With an OECD report on digital agri-environmental policy (OECD, 2019), pertinent material is only beginning to appear.

Additional contributions only highlight the benefits of digitalization for agricultural policy, such as big data analytics and precision farming, rather than concentrating on digital technology for agricultural policy in particular (Finger et al., 2019; Mo¨ckel, 2015; Weersink et al., 2018). By providing better monitoring opportunities, digitalization is anticipated to enable more focused and goal-oriented policies. Digital technology hasn't, however, been directly connected to any particular policy tools or ideas. Research specifically examining digital technology in agricultural policy has not yet been conducted.

In order to close this gap, we look at how digital technologies might impact European agricultural policy in particular policy areas, like the extent of cost distribution and spatial targeting, and how this might impact the selection and design requirements of policy tools. The ideas of economic and policy analysis are incorporated into our analytical framework. It conceptualizes a collection of variables that characterize agricultural policy instruments and their designs in a methodical manner in order to assess the impact of digital technology, building on the original work of Richards (2000). Beyond command-and-control vs incentive-based approaches, the policy dimensions idea enables a basic and understandable contrast between policy instruments and their designs (Richards, 2000). Hence, it fulfils the purpose of this study, which is to support policy makers and researchers in identifying the instrument and design alternatives for agricultural policy that arise with digitalisation. Our conceptual analysis is illustrated using practical cases in Europe and insights from literature.

We discover that important digital technologies enhance monitoring and provide georeferenced, integrated analytics across databases. Particularly impacted are specific policy dimensions: Digitalization can (1) increase the measurement of the relationships between farming inputs and outcomes that are significant to policy, (2) improve the location-specificity of instrument designs, and (3) influence the degree to which government regulates farm-level practices when putting policy instruments into effect. Digitalization increases the appeal of policy concepts that demand a lot of information. It does not favor any particular policy tool, such as taxes or subsidies. Both farmers and policymakers can benefit from policy learning opportunities, which can also help guide the selection and design of instruments. Our analysis has a clear message: Digital agricultural policy does not simply replace the analogue technologies used in traditional agricultural policy. It offers new options for agricultural policy, including novel designs to address challenges more effectively.

We begin this study by defining our understanding of digital agricultural policy and outlining the scope of our investigation. Next, we introduce the policy dimensions that are utilized to analyze how digital technologies affect agricultural policy instruments, further developing our analytical approach. Before discussing the main conclusions and their implications for research and policy, we next outline the consequences of employing digital technologies for these policy dimensions.

1. BACKGROUND AND SCOPE OF ANALYSIS

The use of digital technology for data creation, transmission, processing, and analysis in agenda-setting, policy formulation, implementation, and assessment is what we refer to as digital agricultural policy. The first step toward digital agriculture policy was the introduction of computers in the 1950s. Nonetheless, the application of digital technology was centered on data storage and, to a lesser degree, on linear programming-based ex ante effect evaluations (Jones et al., 2017). It is necessary to distinguish between digitalization of current data and more comprehensive digitalization that includes the creation of new data as well as the processing and analysis of vast volumes of data, including automated feedback (Par-viainen et al., 2017).

Existing data digitization is well-established and promises to lower transaction costs without requiring systemic adjustments, but it provides few other advantages. However, traditional agricultural policy's use of analog technologies (such as for recording compliance) is not simply replaced by digital agricultural policy. More comprehensive digitalization promises bigger benefits due to deeper systemic changes and transaction cost savings, especially in the long run, even though initial costs and risks may be higher. In order to handle agricultural policy difficulties in relation to environmental and food policy goals, new and more effective options become accessible.

To better define our contribution, we employ the idea of the policy cycle (**Fig. 1)** (Jann and Wegrich, 2007). The many phases of the agricultural policy cycle, including agenda-setting, problem-framing, policy creation and execution, and policy evaluation, can make use of a variety of digital technologies (see OECD, 2019). Potential uses of digital technologies, including sensors, remote sensing, data storage, and sharing, are depicted in Fig. 1 at various phases of the agricultural policy cycle. By concentrating on how digitalization influences the selection of specific policy instruments and their design specifications, we are able to identify the development and implementation stage of the agricultural policy cycle. Based on the several policy issues listed in section 3, policymaking and implementation in this case select policy tools and specify their designs. However, intersections with the evaluation stage must also be considered. Digital tools such as big data and remote sensing are essential when results are monitored to evaluate the efficacy of implementation (e.g. Be´gu´e et al., 2018; Sitokonstantinou et al., 2018; Weersink et al., 2018). This monitoring immediately helps the implementation stage, particularly with regard to compliance, the effect on the desired outcomes, and the expenses incurred by the public and private sectors.

This brings an end to our focus on analysis. However, short-term evaluations can eventually impact problem-framing and agenda-setting, which will then trickle down into the stage of creation and implementation (Giest, 2017; Ho¨chtl et al., 2016; OECD, 2019). Furthermore, social media and other digital innovations have an impact on how agri-food policy is framed (Stevens et al., 2016, 2018). Our analysis focuses on the choice and design of policy instruments at the formation, implementation, and evaluation stages of the policy cycle, even though these developments are significant from a wider policy design perspective (Howlett, 2009; Schneider and Ingram, 1997; Schneider and Sidney, 2009).

At the moment, European agricultural policy employs tools that span the entire spectrum of policy alternatives, from economic incentives to regulation and information dissemination. But when put into practice, they frequently fall short of providing adequate support for social, economic, and environmental sustainability (Navarro and Lopez-Bao, 2018; Pe'er et al., 2019). According to Pe'er et al. (2020), the EU's Common Agricultural Policy (CAP) is also criticized for lacking the procedures and indicators necessary for efficient monitoring and enforcement. By assisting instruments in achieving precise geographical and time-bound objectives and enabling instrument designs adapted to particular qualities of locales and farms, digital technology can improve the efficacy and efficiency of agricultural policy (van Tongeren, 2008). It improves the transparency of trade-offs and jointness of production, reduces asymmetric information, makes monitoring easier, makes it easier to find technologies and practices, allows for spatial targeting, and helps develop alternative policy tools and designs (Jacobsen and Hansen, 2016; OECD, 2019). Therefore, it is necessary to break down digital agriculture policy into its component tools and their unique design requirements. The operation of digital technology in combination with various instruments can then be clearly demonstrated.

The employment of digital technology in agri-food businesses and on farms can also be the focus of policy. To improve food safety and environmental footprints, examples include food quality tracking and precision agricultural technology (e.g. Finger et al., 2019). Both the implementation and assessment phases of the policy cycle can benefit from the data and policy-relevant results generated by these technologies. However, rather than using digital technology on farms and in the agri-food industry as a policy aim in and of itself, we concentrate on using them for the design, implementation, and assessment of policy instruments. Additionally, we limit the analysis to agricultural production governance.

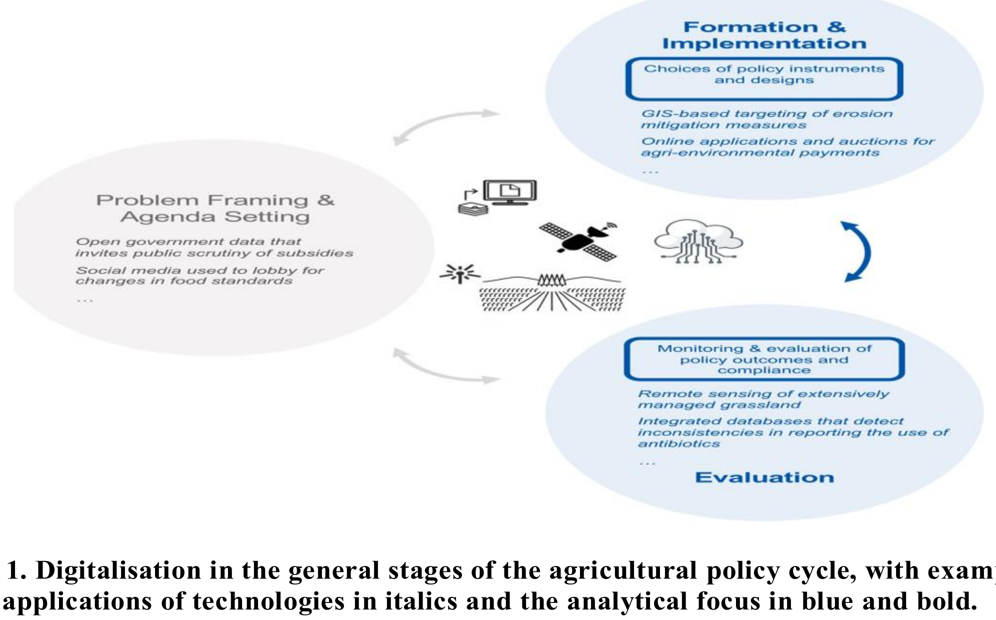

Fig. 1. Digitalisation in the general stages of the agricultural policy cycle, with example applications of technologies in italics and the analytical focus in blue and bold.

2. ANALYTICAL FRAMEWORK

Using policy dimensions that provide analytical descriptions of agricultural policy instruments and design specifications, we examine how digital technologies are used to support agricultural policy instruments and designs (see Richards, 2000; Weersink & Wossink, 2005). Certain governmental and digital technology functions are defined by the interconnected policy aspects. Determining the amounts or costs of environmental consequences, as well as their locations, is a pertinent job of government. In turn, digital technology can be used to detect the locations of environmental problems and estimate their costs or amounts.

Policymakers selected tools and their designs based on these policy dimensions during the formulation and execution of policies. Policy dimensions are either directly or indirectly impacted by digitalization (Fig. 2). Our study thoroughly examines the ways in which digital technologies are involved in these interconnected policy dimensions, which are outlined in the paragraphs that follow and examined in-depth in Section 4 and Table 1 with reference to European instances.

Three policy elements are directly impacted by digitalization. First, an instrument can target outputs like nitrate emission quotas or inputs like fertilizer tariffs, buffer strips, or technologies and behaviors. Furthermore, in order to accomplish a corresponding end, such nitrate content in drinking water as a policy aim, instruments can target agricultural sub-units (like fields) or higher levels (like entire farms or catchments and landscapes). Digital technology can create additional data and create higher correlations between inputs, results, and targets. This is characterized by the input-outcome correlation dimension. Second, the policy dimension of location specificity—which is made possible by digital georeferencing—is directly impacted by digitalization. Third, digital monitoring and databases directly affect the *intertemporal flexibility* dimension, which involves intertemporal adjustments of regulated quantities and price levels of taxes or subsidies.

The other policy elements are more indirectly impacted by digital technology. These include the locus of discretion dimension, which measures how much or little control farms have over how to comply with regulations or accomplish goals in relation to the loss or gain of control over authorities, like governments or food companies, who have varying degrees of power to impose quantities, technologies, and practices on farms. The price versus quantity dimension indicates whether a policy tool aims to control prices (for example, by taxing agricultural inputs) or quantities (for example, by directly regulating the amounts of agricultural inputs). An additional component is the allocation of costs among the government, farms, and other stakeholders.

Whether tools and designs have an impact on farms globally is described by the degree of involvement dimension. Exemptions may be included, and farms may be encouraged to participate or discouraged from doing so. Specific domains, ranging from private (such as farms, technology providers, or food processors) to public, are where data is stored and transported. The data domain dimension is used to define this. Last but not least, the information governance dimension identifies whether policy tools are employed to provide information on farming and its effects rather than to actively interfere with production and manage effects. Our investigation shows the individual effects of digital technology on these interconnected variables. Through a focus on interlocking policy dimensions, the analysis helps to derive implications for future choices and designs of agricultural policy instruments giving consideration to legal and political feasibility.

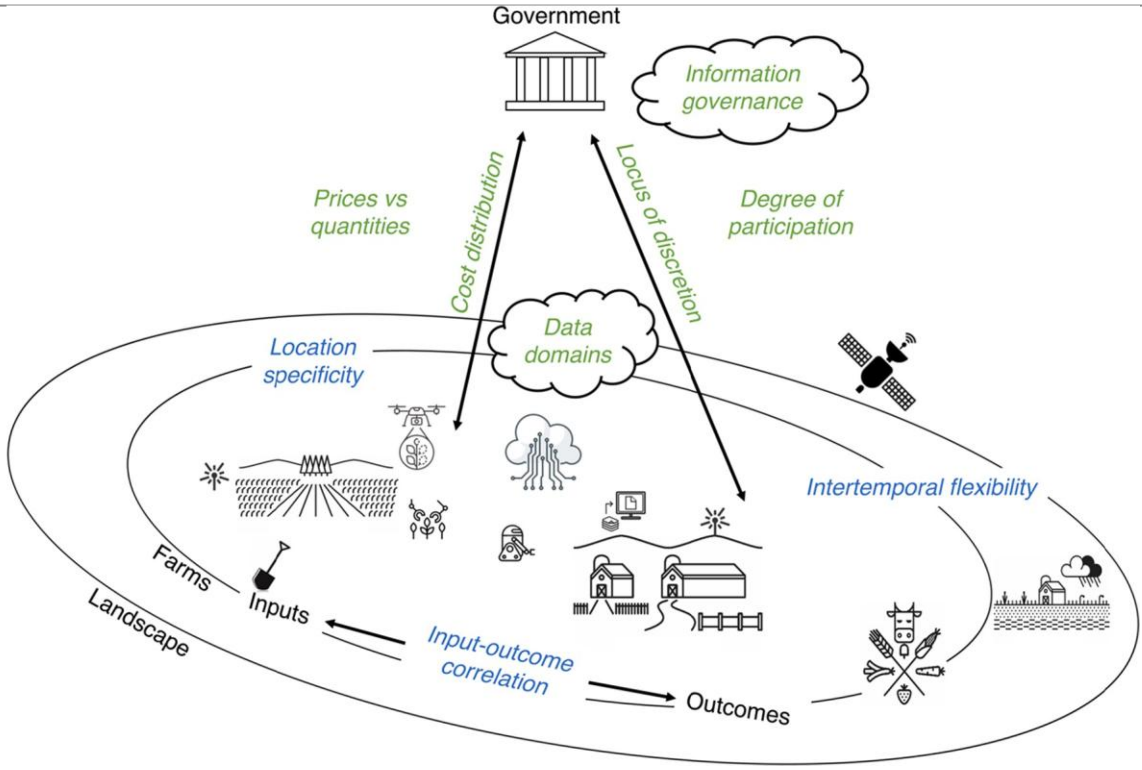

Fig. 2. Dimensions (in italics) of digitalised agricultural policy instruments and designs. Blue: dimensions directly affected by digital technology. Green: dimensions indirectly affected by digital technology.

3. EFFECTS OF DIGITALISATION IN AGRICULTURAL POLICY DIMENSIONS

During the development, implementation, and assessment phases of the agricultural policy cycle, the policy dimensions function as analytical categories that conceptually outline possible impacts of digitalization (Fig. 1). We ascertain the potential theoretical effects of digital technology on each of these dimensions and, when feasible, support our conclusions with information from study literature and documented real-world examples. Table 1 summarizes the impact of digitalization on specific policy aspects and the main implications for instrument selection and design. This section provides a more thorough analysis of them, exposing trade-offs across the dimensions that are further examined in later sections.

3.1. *Input and outcome correlation – Targeting policy outcomes*

For agricultural policy, it can be difficult to precisely target policy objectives (see Erjavec and Erjavec, 2015). As stand-ins for the desired policy results at the farm level, policy instruments typically target the inputs, practices, technologies, or outputs of farms or their sub-units (such as fields). Even if they enhance ecosystem services, inputs or outputs at larger spatial levels—like catchments or landscapes—are rarely addressed (Gawith and Hodge, 2019). Appropriate strategies include communal landscape management initiatives (Prager 2015) or agglomeration payments (Banerjee et al. 2017). Closer input-result correlations between various levels can be established in these situations by the digital integration of related data sources, including direct outcome monitoring.

First, as stand-ins for ecosystem services, digital technology makes it easier to monitor practices that policy tools are meant to encourage. In order to better identify input-outcome connections, it offers the chance to monitor ecosystem service outcomes more closely, potentially in real-time (OECD, 2019). This may result in new proxies that would not otherwise be found. According to Sitokonstantinou et al. (2018), several farming practices that are necessary for receiving direct payments under cross-compliance in the CAP can already be detected remotely or recorded in databases (Bertoni et al., 2018). There is enormous hope in the remote sensing of biodiversity (Turner, 2014).

The most sophisticated use of remote sensing that appears to be highly correlated with result goals is digital monitoring of cutting dates, soil cultivation, or buffer strips (Be´gu´e et al., 2018; Kolecka et al., 2018). Because observed results at the landscape level strongly correlate with location and time-specific conversion practices, standard satellite and geographical information system (GIS) technology can already help monitor and control the conversion of grassland into arable land (D'Andrimont et al., 2018). Nevertheless, effective monitoring of ecosystem service proxies does not, in and of itself, improve input-outcome correlations. Only when farms adopt optimal management techniques by causally connecting actions to results at certain levels will they get stronger (Stupak et al., 2019; Uthes and Matzdorf, 2013). Digitalized solutions include site-specific comparison of various environmental elements utilizing sensors, remote sensing, or big data analytic techniques, as well as chronological trial-and-error (Weersink et al., 2018; Wolfert et al., 2017).

Second, in situations where digitalized outcome monitoring is difficult, particularly when measurement costs are high, modeling results may be more practical (Bartkowski et al., 2019). For instance, Denmark utilizes models that incorporate a variety of digital data to estimate outcomes at the catchment level and correlations to inputs at the farm level in order to carry out its current nitrate policy. These include databases that are heavily georeferenced, such as the EU's Integrated Administration and Control System (IACS), animal stock and movement, fertilizer sales, manure trade, and climate (DEPA, 2017; 2012;; Gault et al., 2015). To track the results of pesticide policy, Denmark still manually enters spraying information (Kudsk et al., 2018). As an alternative, data to assess correlations with outcomes at highly granular but higher spatial levels, such as catchments, comprising diverse inputs, such manure, could be obtained via automated data that feeds directly from field application equipment or from field management software. Farm management software, in turn, can assist farms in managing adherence to laws and pursuing more general policy objectives like sustainability (Knuth et al., 2018; Lindblom et al., 2017; Rose et al., 2016). Strong input-outcome correlations are necessary to support decision-making with actionable rules, even though it may frequently import the relevant data (Kuhlmann and Brodersen, 2001; Sørensen et al., 2011).

3.2. *Location specificity – Spatial targeting*

Spatial targeting through the selection and design of location-specific policy instruments is made easier by geo-referenced tracking of agricultural input use, technologies, practices, outputs, or outcomes. The use of digital monitoring or database integration to identify pollution levels and ecosystem services at specific locations is becoming more and more popular. It facilitates the use of both new and old tools. To digitally ascertain location and farm-specific nitrate-fertilizer accounts and compliance, for instance, Denmark combines several databases that are georeferenced or connected to specific farms. This allows them to target on-the-spot controls and customize complementary measures (DEPA, 2017; Gault et al., 2015). Likewise, spraying records of farms and multiple georeferenced databases support the calculation of location specific levels of pesticide loads and correlating outcomes down to parish level (Jørgensen et al., 2019). When linked to local ecosystem data, hot spots of pesticide exposure and leaching can be determined to inform early warning systems and monitoring of compliance with further pesticide regulations, such as distances to water bodies and buffer strips (Ministry of Environment and Food of Denmark, 2017). In methods beyond the straightforward digitization now in use, georeferenced data produced by application equipment or field management software can guide location-specific risk assessment and the application of agricultural inputs. Such technology can serve as the foundation for new instrument designs, such as new spatially focused subsidies. For instance, digitalized auctions can represent ecosystem services by allocating subsidies and quotas based on spatial targets (e.g. Hanley et al., 2012; Reeson et al., 2011). Completionary quota ceilings or tariffs in pollution hotspots can then be informed by digital monitoring of the effects of quota allocation and trade on the spatial distribution of farming impacts.

In order to identify hot and cold spots, compare and trace a variety of environmental consequences site-specifically, and influence the implementation and assessment of location-specific designs and farm responses, georeferencing typically makes compliance easier. Additionally, it enhances targeting at geographical levels ranging from low to high granularity. For instance, as part of the IACS for current CAP payments, the EU's Land Parcel Information System assists in detecting location-specific compliance and rectifying areas (Devos et al., 2018b; To´th and Kúcas, 2016). It could be used to create and advance new spatially focused agri-environmental metrics when paired with additional data and authority-farm interfaces. Then, farmers can find appropriate agri-environmental measures with the aid of online data and GIS-based planning tools. Additionally, web interfaces and database integration allow payment providers to obtain farm and local ecosystem data. Then, they can only recommend policies that are appropriate for a given area or that offer the most advantages there. By comparing environmental and farming aspects site-specifically, farms and their advisors can also learn location-specific policy responses by causally connecting actions to outcomes. Finally, location-specific payments based on findings can be made easier by monitoring results, for instance by remote sensing.

3.3. *Intertemporal flexibility – TTime-bound targeting*

Digital technologies monitor policy results and their drivers in order to enable intertemporally flexible responses, which falls under the intertemporal flexibility dimension. In Denmark, for instance, time-specific nitrate requirements are already supported by digitalized analysis and modeling based on integrated databases. These are modified annually based on the effects (DEPA, 2017; Gault et al., 2015). From intertemporally variable tax and subsidy levels and quota ceilings to intertemporal banking of quotas or compliance operations, real-time monitoring and database analytics present new opportunities (see, for example, Cullenward et al., 2019; Maron et al., 2012). These may represent intended, time-varying results, such as ecosystem services that are dependent on time. For instance, intertemporally flexible strategies to lower pesticide loads, manage pesticide resistance, and improve pesticidigilance can be informed by digitalized monitoring of pesticide use throughout time (Kudsk et al., 2018; Milner and Boyd, 2017). Furthermore, real-time monitoring of the fluctuating nutrient input from farms into aquatic bodies could be done (Yeshno et al., 2019). Last but not least, digital monitoring and analysis can help with outcome comparison and chronological trial-and-error exercises to promote learning and, as a result, instrument design modifications over time.

3.4. *Locus of discretion – Levels of prescription*

Two main choices result from digitally enhanced input-outcome correlations: An authority (such as the government or food company) that depends on the improved correlations to approach outcomes with instruments targeting correlating inputs, technologies, or practices has the locus of discretion. Alternatively, farms can use the improved correlations to comply more confidently with instruments targeting outcomes.

Farms' discretion is diminished while authorities' is increased when policy instruments are implemented that involve information flows from farms to authorities for compliance and policy monitoring. The new Sentinel satellites, for instance, enhance data for tracking existing CAP payments, giving a government and its analysts more discretion (Devos et al., 2019). Insofar as the IACS verifies eligibility, proposals to issue payments automatically involve a type of algorithmic governance that lessens farms' discretion (Deutscher Bauernverband, 2018).

As digitalization makes monitoring more accurate and reinforces input-outcome correlations, they have less freedom to participate in moral hazard to break the law, avoid paying taxes, or claim more subsidies or quotas than are permitted by the law. Since digital technology makes farms more transparent, novel behavioral nudges (e.g. Just, 2017; Kuhfuss et al., 2016) may likewise lessen farms' discretion in relation to authorities and technology providers. Additionally, automatic data flows from field management software or equipment to technology providers can be included into farm management software intended to direct farms. This increases the discretion of software and algorithm suppliers to the detriment of farmers.

Lastly, modeling results gives modeling contractors more freedom to use data and models in various ways, such as loosening or tightening nitrate regulations, as is the case in Denmark at the moment (Veihe et al., 2006). As a result, instrument designs may become increasingly standardized, reducing farmers' ability to innovate and save money. However, switching to instrument designs that directly target outcomes might also give farmers greater discretion because they have more options on how to get there.

In general, when technology suppliers install and maintain the artificial intelligence and algorithms involved, authorities that depend on outside software provision, data analytics, and information release to achieve policy goals forfeit their discretion. When authorities are forced to utilize a particular decision-support system, their discretion is reduced, even though more precise data processing can make implementation easier (Lemmen et al., 2015). The ability of an authority to impose individual agreements with farms is also diminished by the use of digital technology to coordinate auction bidding processes and to verify restrictions, such as those pertaining to innovative agri-environmental initiatives. In this regard, more dispersed loci of discretion are implied by the rising decentralization of agricultural knowledge and advisory systems brought about by digitalization (see Carolan, 2020; Fielke et al., 2020).

3.5. *Prices versus quantities – Financial incentives or regulation*

Stronger identification of input-outcome correlations produced using digital technology is advantageous for both quantity-based instruments, such as tradable quotas and regulatory standards, and price-based instruments, such as taxes and subsidies. According to Devos et al. (2019) and the European Court of Auditors (2020), current CAP payments contain quantity-based limits such as greening measures, which are supported by the IACS and related digital technologies for identifying areas and locations as well as for monitoring, including remote sensing. Quantity-based quotas and permits can be supported by comparable technology, additional databases, and digital trading platforms. Through initial allocation through trade and auctions, these disclose prices. They assist in reaching a comprehensive quantity standard at the most affordable price. Similar impacts are seen when digital technology enhances the connections between target outcomes and tax and subsidy levels.

In agricultural policy, quota systems were once common, but many have since been abandoned, such as milk and sugar quotas. Tariff-rate quotas continued to be significant for agricultural imports and exports, although they hardly ever involved trade. Environmental quantity standards are governed by more contemporary agricultural quota regimes. As demonstrated by the expensive Dutch manure quota accounting system MINAS (Oenema, 2004; van Grinsven et al., 2016; Backus, 2017), which fully integrated nutrients and financial audits (Breembroek et al., 1996), incentives for fraud in initial allocation and trading can occur despite high data management demands. Similarly, because transaction costs are thought to be high, there has been no progress in integrating agriculture into carbon trading (e.g. Ancev, 2011; Grosjean et al., 2018).

Since trading results in ownership changes and the total of quotas should represent the general standard, proper enforcement and monitoring are especially important for tradable quotas. In order to facilitate grandfathering and lessen knowledge asymmetry, digital technology can access databases of input or output particular to a farm. The main distinction, though, is that it tracks exchanged permits and keeps an eye on their usage. In permit markets where transactions are frequent, this is beneficial. According to Aarts et al. (2015), the Netherlands, for instance, developed a new ANCA model for manure quota accounting that is easier to use than MINAS and promises less fraud, but it has a smaller scope. As a result, digital technology that facilitates tradable quota schemes can be modified based on experience. Digital technology can also monitor effects of allocation and trade of quotas on the spatial distribution of farming impacts to inform further policy measures. More generally, price-based and quantity-based instruments are becoming less distinguishable and more intertwined as digital technology generates and processes information relevant to their implementation.

3.6. *Cost distribution – allocation of policy instrument costs*

The distribution of policy instrument expenses and their magnitude may be impacted by digitalization. Particularly pertinent are transaction costs incurred by the government, farms, and businesses; compliance and abatement expenses borne by farms; public budget expenditures; and residual private and public costs resulting from farming impacts. Digital technologies usually impact multiple costs at the same time.

The distribution and quantity of transaction costs associated with policy instruments are impacted by digitalization. Even as new designs get more intricate, authorities can still benefit from reducing transaction costs across all instruments, particularly when digital technologies offer economies of scale and breadth. If the cost of technology investment is low enough, automatic reporting can lower transaction costs for both authorities and farms. For tradable quotas and subsidies, digital allocation, tracking, and monitoring systems can lower costs for farms, especially when transactions are frequent. For instance, the Netherlands' ANCA model for agricultural manure quota accounting looks to be straightforward (Aarts et al., 2015).

The more extensive MINAS system (Breembroek et al., 1996), which involved significant monitoring and enforcement expenditures for both farms and public authorities (Oenema, 2004; van Grinsven et al., 2016; Backus, 2017), entails higher costs for farms. Nevertheless, digitizing current data does not always result in lower overall costs. The latest Sentinel satellites, for instance, enhance data for tracking CAP payments. Nevertheless, if a new system based on preventing non-compliance and interacting with farms ex-ante is not implemented to replace the conventional processes of application, control, and subsequent payment or sanction, farms and authorities will incur increased administrative costs (Devos et al., 2019). This is because data accuracy must be guaranteed (Devos et al., 2018b, 2018a).

Overall, the effects of digital technology on transaction costs of policy instruments are cir- cumstantial and depend on technologies, attributes of the transactions and designs.

Other expenses may be significantly impacted by digitalization as well. Taxes, restrictions, and tradable quotas that are location- and time-specific suggest that not all farmers must pay for compliance and abatement, which lowers private costs overall. Digital sorting systems provide more focused allocation of subsidies to maximize the use of public budgets, and digitalized targeting rather than broadcasting subsidies also lowers public budget expenditure (Carpentier et al., 1998). Through web interfaces and database integration, payment providers can obtain information about farms and local eco-systems, enabling them to recommend only those actions that are most beneficial or that meet the preferences of a farm. Additionally, these technologies can lower the cost of application and search for farms (see Varian, 2009).

Lastly, farmers have the freedom to use strategies that minimize the cost of corresponding compliance or abatement across instruments thanks to digital monitoring that supports new outcome-based designs. For instance, a levy on nitrate balances would allow farms more leeway to save money than Denmark's digitally set nitrate standards for crop seasons. More government regulation typically results in less agricultural discretion and, hence, fewer chances for private cost reduction and innovation.

Cost considerations also apply to digital extension and advisory services. At potentially lower prices, they can offer farms information and an interactive exchange (Fielke et al., 2020; Klerkx et al., 2019; Science Hub, 2019).

Additionally, farms have greater access to information. The cost of achieving both private and policy objectives can be decreased by choosing options with reduced information costs and access to fresh data and analytics. However, whether these systems are open source, publicly available, or based on private commercial models also affects how costs are distributed.

3.7. *Degree of participation – Levels of involvement*

A variety of factors may influence how much farm participation in digitalized policy occurs. Georeferencing and digital database scanning can be used to pinpoint effect hotspots or to identify particular farms, places, and upstream or downstream businesses that should be the focus of a policy instrument. The advantages of digital technologies for farm management, such as lower private transaction costs or actionable input-outcome correlations from field to landscape level, serve as incentives for participation. Increased farm operations transparency, however, may have the opposite impact of what is intended. Digitalization can facilitate targeting and customization of subsidies and lower the cost of searching for and applying for them.

This may make participation more difficult or easier. Higher transaction costs may result from corresponding digitalization, particularly for farms with limited digitalization capabilities and expertise (Fielke et al., 2019). Furthermore, learning and technology might have significant upfront expenses. They may reduce the number of people who participate in policy initiatives, particularly if there are no incentives, universal mandates, or analog backup options for digital technology use.

Digital technology co-creation and co-design has potential for removing obstacles to its use in agricultural settings. Regional disparities, a lack of alternatives for data integration, a poor representation of the intended results, a failure to modify business methods, or inefficient digital content production are some of these obstacles (e.g. Ayre et al., 2019; Eastwood et al., 2017b; Ingram and Gaskell, 2019). When participation is voluntary, co-creation and co-design may entice farms to take part. Furthermore, digital tools like social media and cloud computing can facilitate the co-design and co-creation of digitalized technology for the use of agricultural policy instruments.

However, participation at this point (see Ortner et al., 2016) could only rise if the digital technologies' predetermined goals align with those of farms (see Knox et al., 2019). These tools provide access to landscape-level correlations between georeferenced inputs and results. They might lower the cost of coordination and encourage involvement in project-based instrument designs such as management collaboratives that aim for landscape-level results (Prager, 2015) or agglomeration payments (Bane-rjee et al., 2017). Farm costs may decrease and policy instrument efficiency may increase as a result of digitally enabled involvement.

3.8. *Data domains – Data ownership and transparency*

Participation by farms in digital agricultural policy tools typically means that more of their data enters the public or governmental sphere. Documenting compliance and monitoring and evaluating policies makes farms more transparent. If they are unable to limit data availability, the discretion of data-receiving domains usually increases while that of data-supplying domains decreases (see van der Burg et al., 2019). For instance, data domains are shifted to modellers when policy consequences are modelled. Authorities can already connect farming databases, such as the IACS, to environmental databases to assess the legality of land management activities, provided that doing so is permitted by data privacy laws (Nitsch et al., 2010).

As in Denmark, where farms record pesticide consumption in an online database connected to a pesticide sales database and the IACS, new data from private domains can be contributed. The Danish Ministry of the Environment and the Danish Ministry of Food, Agriculture, and Fisheries (2013) state that laws that fortify public data domains make this possible. Data domains transfer to the government and potentially to technology providers when such data flows automatically from farming software or equipment (Carolan, 2018; Kamilaris et al., 2017; Sykuta, 2016). Lastly, web interfaces, remote sensing, and database integration allow payment providers for ecosystem services and other subsidies to obtain information about farms and ecosystems. They can then transfer this information into their own domains, which can be private, governmental, or public.

Data is moved into government domains and potentially into public and other private domains, such food industries, by policy instruments that concentrate on information supply, such as the present regulations mandating the use of computerized animal movement databases. Changes in data domains are also implied by open-source data and technologies that support authorities' and farms' decision-making. As a result, there are changes in responsibility and openness for all parties involved (Attard et al., 2015; Kamilaris et al., 2017). While farm openness typically rises, data domains appear to become more dispersed as digitalization broadens the range of agricultural knowledge and advisory systems (Fielke et al., 2020). However, farms also gain access to government, public and private data domains when they use software or public monitoring services. Thus, digitalisation of policy instruments can imply multi-directional changes in data domains.

3.9. *Information governance – Targeting information provision*

Agricultural policy instruments are typically supplemented with information measures, such as providing policy information. They may also be different strategies, presented via tools designed to provide information. These include laws mandating the private distribution of information through food labels or public disclosure, as well as government-provided or contracted-out subsidies for research, teaching, counseling, and moral persuasion campaigns (Howlett, 2009; Richards, 2000; Vedung, 1998). Information provision can be made more affordable with the use of digital technologies. Therefore, rather than directly interfering in agricultural operations and markets, a government can utilize tools to regulate or encourage the release and use of information. This suggests that although data domains open up and become more visible, the government relinquishes some of its discretion. Open government and business activities can include the creation and distribution of digital data on the characteristics and impacts of farming that are significant to policy (Attard et al., 2015). Digital communication technologies can increase their effectiveness and influence, particularly when they encourage public and private players to support policy goals through outreach and actions. In order to deliver farm services that meet policy aims, such as providing crop protection services in place of pesticides, new business models may need to use digitalized information (Chappell et al., 2019).

In situations where alternatives are ineffective, digitalization can help information measures to make it easier to deploy other tools. When incorporated into digital technology used to apply agricultural policy instruments, information-based nudging (Just, 2017) enhances several information policy techniques. These include guidelines for farms or procedures for authorities and farms to engage online. For instance, planning tools and online information might encourage policy changes and persuade farms to sign particular subsidy contracts (Kuhfuss et al., 2016).

Additionally, in order to reach more farms more efficiently, digital extension and advisory services can use a variety of channels to deliver information to farms and promote interactive communication (Fielke et al., 2020; Klerkx et al., 2019; Science Hub, 2019). Farm management information systems are among the technologies that farms and their advisers can employ to accomplish policy goals, manage operations in accordance with broader sustainability objectives, and make compliance easier (e.g. Lindblom et al., 2017; Rose et al., 2016). Examples include soil carbon auditing software (de Gruijter et al., 2019) and the farm nutrient management system FaST, which is being considered for implementation of the EU's Nitrate Directive (European Commission, 2019). Although the present systems are not user-friendly enough, research conducted in Germany does indicate that farm management information systems are necessary to support compliance with regulations and certification schemes (Knuth et al., 2018). Additionally, they would need to work with advisors' technologies and capabilities, as they occupy these positions and require an update on their specialized knowledge (see Eastwood et al., 2017a, 2017b; Leventon et al., 2017). As a result, while the implications on instrument implementation are unknown, digitalization can have a significant impact on information governance.

4. OUTLOOK ON DIGITAL AGRICULTURAL POLICY

A broader perspective on how digitalization affects the selection of general agricultural policy tools and design options arises from the effects of digitalization that we found in the policy aspects. Systematic evaluation of the good and negative features of these consequences is not possible with our analytical technique. It does, however, raise certain ideas that go beyond simple digitization, which only lowers the transaction costs of agricultural policy tools. Above all, enhanced estimate of input-outcome correlations, location-specificity, and intertemporal flexibility in the application of agricultural policy tools are made possible by new digital data and technologies. This improves agricultural policy's accuracy and, thus, efficacy: Instrument designs that are outcome-oriented, geographically targeted, and represent intertemporal dynamics can be employed. They are complemented with new design options along the other policy dimensions:

- The *locus of discretion* can shift to farms to increase both farms' acceptance and the efficiency of instruments.
- *Costs distribution* between farms and public budgets can be aligned better to increase efficiency and acceptance of instruments by farms and the public.
- *Prices can replace quantity requirements* to a greater extent to improve allocative efficiency among farms and among traders.
- *Degrees of participation* in policy instruments can reflect cold and hot spots of farming externalities and opportunities to collaborate up to landscape levels.
- *Data domains* can move into public domains to increase transparency of farm activities and food supply.
- *Information governance* can complement instruments and extend design options through information release, advice and nudging.

The traditional classification of instruments into three categories—regulation, incentives, and in-formation provision—has a wide range of implications for decision-making. The creation of fresh data and integrated analysis through digitalization improves input-outcome correlations and creates new, outcome-focused opportunities. The results can be adjusted to fit certain farms, locations, and times of day. More effective monitoring shifts the distribution of discretion and costs by reducing the knowledge asymmetry between authorities and farms. This could make regulation more appealing to governments. These advantages, however, also apply to economic tools, which may be more alluring than regulation.

In general, they provide farmers greater freedom in deciding how to divide up their resources and participation levels. Dig-italization can also help participants communicate with one other. For example, farms that must coordinate landscape-level outcome accomplishment based on input-outcome correlations at their separate levels can benefit from this. When digitization creates strong relationships between price levels and outcome amounts, subsidies and taxes become more appealing to a government.

Digitalization-driven transaction cost reductions make information-intensive tools, such as tradable quotas, more appealing. Subsidies also include chances to compensate farms for farm data that has been transferred outside of their purview. Any specific instrument's design can then be improved by using the data for targeted learning, which may involve artificial intelligence. Lastly, since digitalization impacts the information governance dimension and challenges data domains, information provision and information-based nudging may become more and more helpful tools. Utilizing cutting-edge digital data and technological possibilities, it may possibly take the place of tools that directly intervene to accomplish comparable goals. For instance, transparency may expose farmers to social penalties or allow information to persuade them.

This analytical perspective demonstrates how decisions and designs for agricultural policy instruments might develop along interconnected policy dimensions in a digital age. Input-outcome correlations, or the certainty of aiming for a desired policy outcome at a particular level (such as farm or landscape), and locus of discretion, or whether farms or authorities selected the precise actions required to reach a desired policy outcome, are two important dimensions that stand out as crucial for the design of future agricultural policy instruments. These dimensions' interdependencies suggest significant trade-offs. Results are rarely the direct focus of current agriculture policy. It tends to limit farms' ability to create unique solutions and lessens their incentives to innovate, particularly when it comes to regulating or subsidizing practices and technologies.

Digital technology must, however, be in line with the intended results, inputs, and management techniques of the farms it is monitoring. If not, farms find it difficult to get the intended results. Even when these correlations involve non-point sources and end targets at the landscape level, digital technology helps with the estimation process. Theoretically, farms have the most discretion when results are targeted (outcome-based policy design in Fig. 3). However, this discretion is curtailed when digital technology creates strong relationships between inputs, technologies, and practices. This suggests trade-offs because authorities might just as easily move to inputs, technology, or practice recommendations, giving them more power at the expense of the farms (see Fig. 3 for a practice-based policy design).

Consequently, two generic and diverging options arise: (1) Agricultural policy could make use of digitalised outcome-based policy designs with the locus of discretion at farm level. Examples could involve digitally allocated and traded quotas or voluntary agri-environmental measures monitored above farm level.

(2) Agricultural policy could apply practice-based policy designs. Here the locus of discretion lies with the authorities, as they prescribe and control farm inputs and management. Examples are regulation and taxes with specific rules and standards, possibly location-specific for non- point source problems. But when farmers' discretion wanes, so are their incentives to innovate and adjust to local conditions that are invisible to authorities. Farming might become less resilient and more standardized. It is crucial that sufficient consideration be given to such broader trade-offs and hazards that go beyond the policy dimensions and policy cycle stages we have discussed here, even though our analysis is agnostic in this respect. The broader implications and hazards of digital technology that influence the selection and layout of agricultural policy tools are covered in the next section.

5. DISCUSSION

Our results demonstrate how decisions and design specifications for agricultural policy tools can be influenced by digital technologies. Future agricultural policy tools will likely be more digitally integrated and digitized, according to general advancements in digital information management. Digital technologies, however, have the potential to improve all agricultural policy tools currently in use. At the implementation stage, they have the biggest impact since digitalization not only facilitates targeting, tailoring, monitoring, and control, but it also produces new data that improves on existing policy assessment technologies. Four important aspects of our findings are discussed below. First, the adoption of digital technologies in the agricultural sector is a prerequisite for the digitalization of agricultural policy. The capabilities of farms and authorities, analog backup choices, user-oriented design, and exemptions or support for small farms are significant obstacles to utilizing digital technologies. Furthermore, farmers' involvement in digital agricultural policy tools may be impacted by costs and loci of discretion since their allocation may be viewed as unjust and exclude particular farm groups. Additionally, farms might not be able to adapt to outcome-based designs effectively. All of this highlights the concerns related to technology access, data ownership, control, and security, as well as the significance of the digital divide in agricultural policy (Klerkx and Rose, 2020; Regan, 2019; Rotz et al., 2019). Nonetheless, incentives for participation might be included in approved legislation and subsidies for the use of digital technology. Likewise, designs of taxes, regu- lations and tradable quotas can incorporate benefits of digital technol- ogy, for example to farm management. Subsidising the use of digital technologies for agricultural policy instruments also increases chances of participation. Advisory services traditionally assist farms in policy implementation and support participation (e.g. Leventon et al., 2017; Sutherland et al., 2013). Advisors may be required to facilitate collective action (e.g. Prager, 2015; Westerink et al., 2017) and mediate between digital technology and farms and their practices (Eastwood et al., 2019; Lundstro¨m and Lindblom, 2018) when digitalization implies the targeting of outcomes at the farm and landscape level. Digital technology may enhance advisory services, but it may also raise expenses and replace human advice with online instructions (Rijswijk et al., 2019; van der Burg et al., 2019). This may provide the government and tech companies more discretion. Discretion can enter algorithmic governance in this situation, as well as in other situations outside of advisory systems, with dubious outcomes (Klerkx et al., 2019).

Therefore, rather than establishing path-dependencies of agricultural policy digitalization, attention must be taken to ensure that farmers, advisers, and authorities maintain their ability to innovate and produce creative solutions (see Fly-verbom and Murray, 2018; Saetra, 2019). Digital path-dependency may make farmers, advisors, and the government less robust by limiting their capacity to respond to unforeseen issues. Therefore, the question of whether to invest in less sophisticated but more broadly oriented technologies or in specific technologies for certain instruments that facilitate variety and learning is a strategic policy challenge. Similar to digital farming, responsible research and innovation could be used to approach digital technologies that assist agricultural policy in order to minimize risks and balance trade-offs (e.g. Bronson, 2018; Klerkx and Rose, 2020; Rose and Chilvers, 2018).

Second, our research was predicated on the enduring objectives and difficulties of European agricultural policy, including information asymmetries and the dispersed sources of farming impacts. These issues are somewhat resolved by digitalization, particularly when it promotes learning and adaptability. However, with assessment and framing based on new data brought about by digitalization, new objectives might surface. Agricultural policy digitization can also lead to new issues like interoperability (Phillips et al., 2019; To´th and Kůcas, 2016), data ethics, including privacy concerns (Sykuta, 2016; van der Burg et al., 2019), and making sure the actors involved can use the appropriate digital technology (Regan, 2019).

Third, data provision, sharing and analysis, including their co- benefits and risks, are critical Third, the creation of digitalized agricultural policy tools depends on the availability, exchange, and analysis of data, as well as the risks and advantages associated with each. Data domains are frequently impacted by digital technology applications for agricultural policy that increase transparency in farms and the ecosystems they work in. The involved data is no longer kept confidential. While some are preserved or accessed by various private domains, including technology providers or decentralized blockchains, others become public (Miles, 2019; Rotz et al., 2019). Reluctance to open farm data domains can then constrain participation in digitalised agricultural policy instruments. Scope for automation would therefore be more likely to emerge where data and legislation are unambiguous, whereby this might imply the exclusion of certain data and farming practices (Miles, 2019). In addition, the analysis of geore- ferenced farming, environmental and behavioural data, generated and linked via digital technologies could support the redesign of instruments and selection of new instruments in order to generate behavioural in- sights and to render behaviour accordingly (Varian, 2014; Zuboff, 2019). Preemptive regulation may benefit from this (Yeung, 2018). In this case, voluntary actions offer chances to produce data that farms would not otherwise be willing to contribute. The information may be used to train models that provide ex ante measure evaluation to guide decisions and the creation of agricultural policy tools. Such applications of digital technology in agricultural policy require careful consideration. Farms benefit from digitally facilitated policy learning, for instance, when outcome-oriented designs provide them greater latitude to create procedures and tools that effectively produce results.

Fourth, the question of how legal and political viability will evolve emerges when analyzing the policy environment of instrument design and choice that is subject to digitalization. Since digitalized policy instruments should be politically more viable when farms and other policy stakeholders gain from digitalization, there should be a relatively significant scope for digitalizing subsidies. However, legal viability may be very contextual in the absence of appropriate framework legislation. As is already evident in internet search habits, the policy cycle may make more use of opportunities for real-time evaluation and feedback into conceptualization and development (Schaub et al., 2020).

As policy actors and systems rely more on digitalized data supply and analysis, one result can be complicated entanglements between policymaking and digitalization. When agricultural policy is incorporated into the governance of food systems, as is the case with the EU Farm-to-Fork plan (Schebesta and Candel, 2020), this complexity rises even more (De Schutter et al., 2020). A government might regulate food chain corporations and certifiers in place of farms as they can produce a lot of data about farms and oversee them through private contracts (Poppe et al., 2013). However, such methods could jeopardize adaptability and widen the divide between farming and society and the government (Miles, 2019).

In essence, the availability of knowledge determines whether the government is required to function as a regulator that establishes and upholds objectives or whether it can assign and decide rights and duties (Richards, 2000). Since digitalization significantly lowers the costs of regulating property rights among the parties involved, the first role may be appealing to a government. When it is feasible to determine proxy values for the parties' damages, the government may additionally impose liability standards.

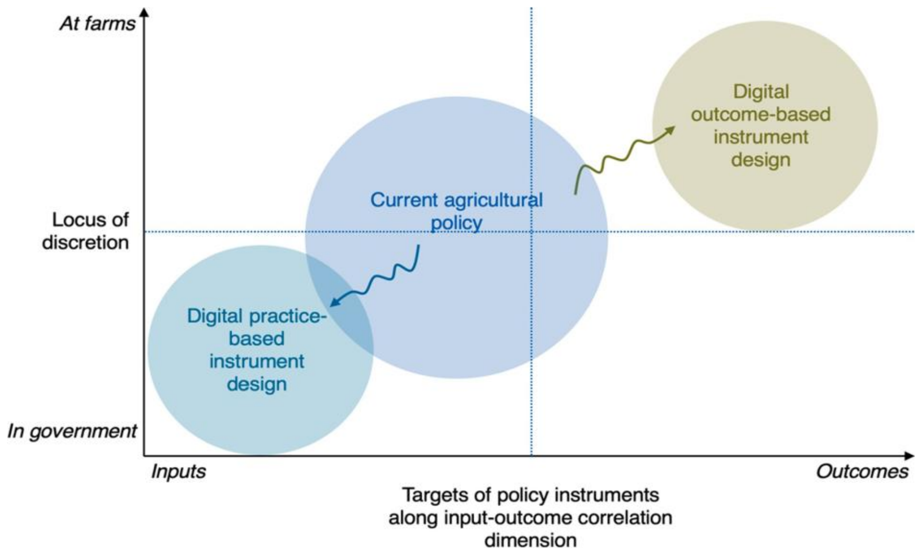

Fig. 3. Digital agricultural policy options in key policy dimensions: inputs or outcomes as targets of policy instruments in relation to the locus of discretion that ranges from government authorities to farms.

Digital technology can make adjudication easier by lowering the expenses of evaluating the individual cases and determining such values. These options suggest changing the government's primary function from one of regulation to one of assisting in the settlement of agricultural disputes.

6. CONCLUSIONS

There is still more to be done to properly utilize the promise of the digital technologies being considered for agricultural policy. We establish a framework for analysis that focuses on the policy dimensions that digitalization can impact during the stages of policy creation and implementation, and we place the digitalization of policy instruments within the policy cycle. The following analysis shows how digitalization has affected important aspects of agriculture policy tools and designs. In order to assist policymakers in identifying alternative policy instruments and designs that emerge with digitalization, it offers an outlook on the options and designs of digitalized agricultural policy instruments.

Digitalized policy instruments in additional policy domains could be subject to the analytical framework. Instead of examining empirical data on digitalized agricultural policy, we focus on theoretical implications. The examples we cite from Europe are illustrative and not all-inclusive. In the future and in different contexts, the issues facing agriculture and the objectives of agricultural policy may alter. But according to our data, digital technology generally improves the precision of instruments, mostly by making it easier to identify location-specificity and significant input-outcome correlations. Additional consequences may be unclear, such as those pertaining to data domains, cost distribution, and the judgment of authorities and farms.

Our findings has two key policy implications. First, because agriculture is complex, there will always be a variety of policy tools available, and digitalization does not favor any one of them. It does, however, expand their design possibilities. It makes it easier to customize instruments to particular agricultural issues, boosting the efficacy and efficiency of agricultural policy. Therefore, even if they are initially based on trial projects, governments and interest groups could strategically explore digitalized design possibilities to strengthen the legitimacy of policies. Second, low-hanging fruits appear, particularly in the areas of control and monitoring, where digitization lowers transaction costs. Agricultural policy, which depends on stakeholders who are proficient in digital technology and appropriate institutions, cannot be fully digitalized with this type of digitization.

Planning for digitalization requires active participation because learning and capacity building throughout the entire sector are necessary to realize the benefits of a digitalized agricultural policy. To create suitable digital agricultural policy innovations, the government could incorporate the perspectives of food, farming, and other stakeholders using the responsible research and innovation strategy. Since digital data on the inputs, outputs, and results of policy instruments can expand the scope to test various design possibilities, digitalization can also be helpful in this regard. Particularly when digital agricultural policy moves from direct intervention in agricultural production to information governance—where the government only uses, recommends, or incentivizes digital technology to generate and disseminate agricultural information—experimentation and strategic learning are required.

Whether farms, interest groups, and the government are ready and able to handle the consequences of a more comprehensive digitalization of agricultural policy is a crucial subject for both study and policy. The ability and willingness of the government, farms, and other stakeholders to use digital technologies would determine this. Additionally, it relies on how future policy demands and digitalization evolve. Therefore, it is necessary to systematically anticipate conceivable futures for digital agricultural policy

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