Agricultural policy in the era of digitalisation

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Melf-Hinrich Ehlers *, Robert Huber, Robert Finger

Agricultural Economics and Policy Group, ETH Zürich, Zürich, Switzerland

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ABSTRACT

Digitalisation in the agricultural sector continues to expand. At the same time demands for an agricultural policy offering better support for sustainability become increasingly fervent. However, it is far from clear how digitalisation could make agricultural policy more effective in reducing undesired impacts and enhancing the benefits of farming. This article investigates the extent to which digital technologies can trigger different choices of agricultural policy instruments and novel design specifications that address problems of sustainability in farming more effectively and possibly more efficiently. It develops and applies an analytical framework that focuses on the effects of digitalisation in distinct policy dimensions, drawing on theoretical insights and examples from practice in a European context. We show that digital agricultural policy does not simply replace analogue technologies used in traditional agricultural policy. It offers new options for agricultural policy, including novel designs to address challenges more effectively. In particular, it offers opportunities for more effective spatial targeting and tailoring of instruments, including results-based subsidies. Digital data can be generated strategically using respective instrument designs to support policy learning and adaptation of designs. Information-intensive instruments and designs generally benefit most from digitalisation while transaction costs often go down. Digitalisation could also move agricultural policy from direct intervention to information-based governance. However, the analysis suggests that institutional constraints and interests, as well as the capabilities of the actors involved require attention in research and practice of digitalisation of agricultural policy.

1. Introduction

Digitalisation is expected to transform the food and farming industry radically as, for example, it assists production with precision agriculture and trade through online platforms and traceability systems (e.g. Aceto et al., 2019; Kamble et al., 2020; Poppe et al., 2013; Walter et al., 2017). Simultaneously, digital technologies are becoming part of the agricultural policy toolbox to aid compliance monitoring, data exchange and analysis (European Court of Auditors, 2020; OECD, 2019). However, despite forceful warnings of urgent needs to ramp up the effectiveness of agricultural policy (e.g. De Schutter et al., 2020; Gawith and Hodge, 2019; Grethe, 2017; Pe'er et al., 2014), it is still unclear just how the potential of digital technology could induce a change of agricultural policy in this direction.

This article investigates the extent to which digital technologies like remote sensing or integrated data analytics (1) can trigger different choices of agricultural policy instruments, (2) offer different choices in instrument designs and (3) enable novel design specifications to address problems more effectively and efficiently. We develop an analytical framework that focuses on key policy dimensions of digitalised instrument designs to explore effects of digitalisation on agricultural policy instrument and designs choices.

The use of digital technologies for agricultural policy remains patchy (OECD, 2019). It is unclear just how far their potential is being exploited and what issues arise from their application (Klerkx et al., 2019). The literature refers sporadically to digital aids in policy implementation (e.g. Coble et al., 2018; Finger et al., 2019; Zilberman and Millock, 1997). The expected benefits of using digital technology for agricultural policy include increased effectiveness and efficiency, due to its monitoring and targeting abilities (Weersink et al., 2018), and more efficient use of environmentally harmful farming inputs (Finger et al., 2019). It can also reduce information asymmetry and transaction costs of policy implementation. However, the policy instruments and implementation technologies currently applied are largely aligned, as choices and design

Abbreviations: ANCA, Annual Nutrient Cycling Assessment (of the Netherlands); CAP, Common Agricultural Policy; EU, European Union; GIS, Geographical Information System; IACS, Integrated Administration and Control System; MINAS, MINeralen AangifteSysteem (MINeral Accounting System of the Netherlands.

* Corresponding author.
E-mail address: mhehlers@ethz.ch (M.-H. Ehlers).

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specifications of agricultural policy instruments are restricted to what is deemed feasible considering dominant discourses, political constraints, administrative resources and technology (Erjavec and Erjavec, 2015; Henke et al., 2018; McCann, 2013; Weersink et al., 1998). Hence, to what extent can digital technologies break this alignment and open up new choices and designs of agricultural policy instruments? Relevant literature is only just emerging with an OECD report on digital agri-environmental policy (OECD, 2019). Further contributions do not focus on digital technology for agricultural policy specifically, but merely point out the merits of digitalisation for agricultural policy, including big data analytics and precision farming (Finger et al., 2019; Möckel, 2015; Weersink et al., 2018). Digitalisation is expected to support more targeted and outcome-oriented policy through improved monitoring possibilities. However, digital technology has not been linked explicitly to specific policy instruments and designs. Until now there has been no dedicated research on digital technology in agricultural policy.

We address this gap by examining how digital technologies could affect European agricultural policy in specific policy dimensions, such as degrees of spatial targeting and distribution of costs, and what this implies for the choice and design specifications of policy instruments. Our analytical framework draws on economic and policy analysis theories. Starting from the original work of Richards (2000), it conceptualises a set of dimensions that describes agricultural policy instruments and their designs systematically to evaluate the effects of digital technology. The policy dimensions concept allows a fundamental and comprehensive differentiation between policy instruments and their designs that goes beyond command-and-control versus incentive-based approaches (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 find that key digital technologies improve monitoring and facilitate integrated analytics across databases, georeferenced, where possible. Certain policy dimensions are particularly affected: Digitalisation can (1) improve measurement of correlations between farming inputs and policy-relevant outcomes, (2) enhance location-specificity of instrument designs and (3) affect the extent government controls practices at farm-level when implementing policy instruments. Digitalisation renders policy designs with high information requirements more attractive. It is not favouring specific policy instruments, like subsidies or taxes, as such. Policy learning opportunities arise for both farms and policy makers and can further inform instrument choice and design. 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.

In this paper, we first outline the scope of our analysis and define our understanding of digital agricultural policy. Then we develop our analytical approach by introducing the policy dimensions used to analyse the effects of digital technologies on agricultural policy instruments. Next, we present the implications of using digital technologies for these policy dimensions before moving on to the discussion of key findings and implications for policy and research.

2. Background and scope of analysis

We define digital agricultural policy as the use of digital technology for data generation, transmission, processing and analysis in framing, agenda setting, formation, implementation and evaluation of policy. The advent of computers in the 1950s marked a first step towards digital agricultural policy. However, use of digital technologies focused on data storage and to some extent on ex ante impact evaluations using linear programming (Jones et al., 2017). The distinction must be made, between mere digitisation of existing data and digitalisation which is more extensive, involving the generation of novel data, processing and analytics of large amounts of data, including automated feedback (Parviainen et al., 2017). While digitisation of existing data is well established and promises reductions in transaction costs without systemic changes, it offers few further benefits. However, digital agricultural policy does not simply replace analogue technologies used in traditional agricultural policy (e.g. for documenting compliance). While initial costs and risks may be higher, more encompassing digitalisation promises greater benefits, due to deeper systemic changes and transaction cost savings, especially in the long run. New, more effective options become available to address agricultural policy challenges with respect to environmental and food policy goals.

We use the concept of the policy cycle (Fig. 1) to specify our contribution more precisely (Jann and Wegrich, 2007). A wide range of digital technologies can be used at the different stages of the agricultural policy cycle, i.e. agenda setting, problem framing, policy formation and implementation as well as policy evaluation (see OECD, 2019). Fig. 1 illustrates possible applications of digital technologies, such as remote sensing, sensors, data storage and sharing at different stages of the agricultural policy cycle. We pinpoint the formation and implementation stage of the agricultural policy cycle (Fig. 1, in blue and bold) by focusing on how digitalisation affects choices of individual policy instruments and their design specifications. This is where policy making and execution selects policy instruments and specifies their designs along along distinct policy dimensions, described in section 3. However, intersections with the evaluation stage must also be considered. Digital technologies, such as big data and remote sensing, are important when outcomes are monitored to evaluate the success of implementation (e.g. Bégué et al., 2018; Sitokonstantinou et al., 2018; Weersink et al., 2018). This monitoring feeds back directly into the implementation stage, particularly in terms of compliance, effects on desired outcomes and public and private costs. Our analytical focus ends here. However, short-term evaluations can inform problem framing and agenda setting in the long-term and thus flow in the formation and implementation stage at some point (Giest, 2017; Höchtl et al., 2016; OECD, 2019). In addition, digital developments, such as social media, also influence the framing of agri-food policy (Stevens et al., 2016, 2018). Although these developments are important from a broader policy design perspective (Howlett, 2009; Schneider and Ingram, 1997; Schneider and Sidney, 2009), our analysis focuses on the selection and design of policy instruments at the formation, implementation and evaluation stages of the policy cycle.

Currently, agricultural policy in Europe uses instruments that cover the full range of policy options from information provision to regulation and economic incentives. However, when implemented, they often fail to support environmental, economic and social sustainability effectively (Navarro and López-Bao, 2018; Pe'er et al., 2019). The EU's Common Agricultural Policy (CAP) is also criticised for a lack of indicators and systems that enable effective monitoring and enforcement (Pe'er et al., 2020). Digital technology can enhance the effectiveness and efficiency of agricultural policy by supporting instruments in targeting precise spatial and time-bound objectives and enabling instrument designs tailored to specific attributes of locations and farms (van Tongeren, 2008). It makes trade-offs and jointness of production more transparent, mitigates asymmetric information, facilitates monitoring and the search for technologies and practices, spatial targeting and the development of alternative policy instruments and designs (Jacobsen and Hansen, 2016; OECD, 2019). Thus, the analysis of digital agricultural policy must dissect policy into its individual instruments and their particular design specifications. It can then show clearly how digital technology works in combinations of instruments.

Policy can also target the use of digital technology on farms and in companies in the agri-food sector. Examples are precision farming technology or food quality tracking aimed at improving environmental footprints and food safety (e.g. Finger et al., 2019). The data and policy-relevant outcomes produced by these technologies can feed back into

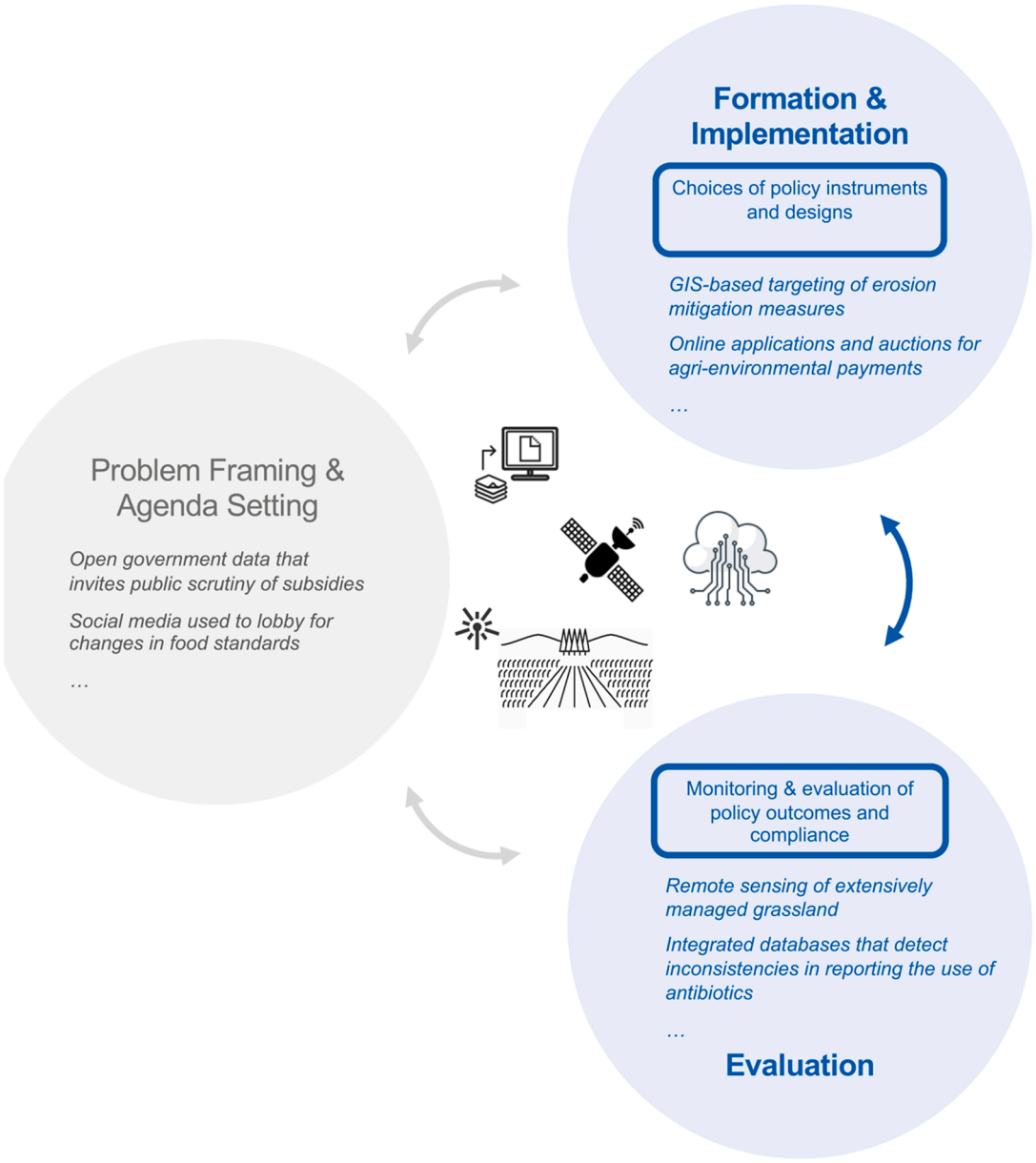

Fig. 1. Digitalisation in the general stages of the agricultural policy cycle, with example applications of technologies in italics and the analytical focus in blue and bold.

the policy cycle, also at the implementation and evaluation stages. However, we focus on the use of digital technologies for the design, implementation and evaluation of policy instruments and not on the use of digital technologies on farms and in agri-food business as a policy target itself. We also restrict the analysis to the governance of agricultural production.

3. Analytical framework

We analyse the use of digital technologies to support agricultural policy instruments and designs with reference to policy dimensions that describe instruments and design specifications analytically (see Richards, 2000; Weersink and Wossink, 2005). The interlocked policy dimensions define specific functions of both government and digital technology. Relevant functions of government involve decisions on quantities or prices of environmental impacts, including their locations. Functions of digital technology, in turn, can be estimating quantities or prices of environmental impacts and identifying their locations.

During policy formation and implementation, policy makers chose instruments and their designs according to these policy dimensions. Digitalisation affects policy dimensions directly or indirectly (Fig. 2). Our analysis explores in detail how digital technologies are implicated in these interlocked policy dimensions, which are summarised in the following paragraphs and analysed in detail, using European examples, in Section 4 and Table 1.

Digitalisation directly affects three policy dimensions. First, an instrument can target inputs, such as taxes on fertilisers, technologies and practices, such as buffer strips, or outputs, such as nitrate emission quotas. Moreover, instruments can target farm sub-units (e.g. fields) or higher levels (e.g. whole farms or catchments and landscapes) to achieve a correlating outcome, such as nitrate content in drinking water as a policy goal. This is described with the *input-outcome correlation* dimension, where digital technology can generate new data and establish stronger correlations between inputs, outcomes and targets. Second, digitalisation directly affects the policy dimension of *location specificity*, which is facilitated by digital georeferencing. Third, digital monitoring

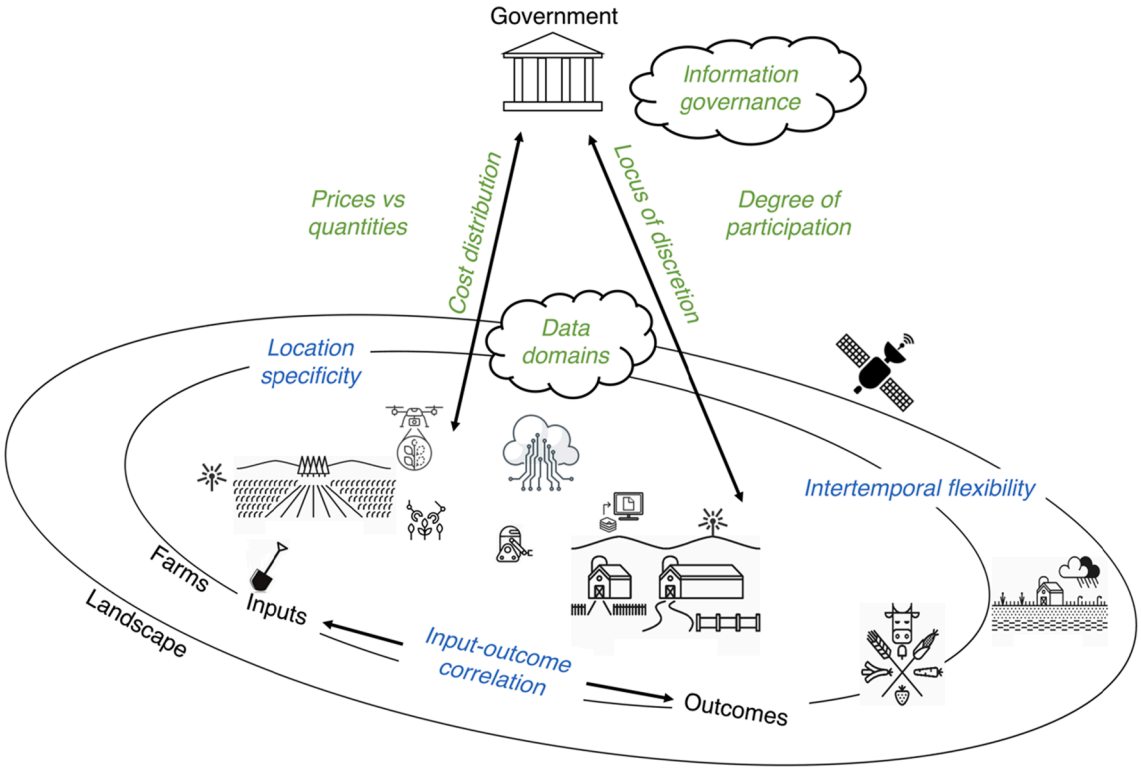

Fig. 2. Dimensions (in italics) of digitalised agricultural policy instruments and designs. Blue: dimensions directly affected by digital technology. Green: dimensions indirectly affected by digital technology.

and databases directly affect the *intertemporal flexibility* dimension, which involves intertemporal adjustments of regulated quantities and price levels of taxes or subsidies.

Digital technology influences the other policy dimensions more indirectly. These include the dimension of the *locus of discretion*, which captures farms' gain or loss of discretion in how to comply or achieve an outcome in relation to loss or gain of discretion of authorities, such as governments or food companies, who can impose quantities, technologies and practices on farms to differing extents. The dimension of *prices vs. quantity* specifies whether a policy instrument targets prices, e.g. through taxing farming inputs, or quantities, e.g. through directly regulating farming input quantities. *Distribution of costs* between government, farms and other actors is a further dimension. The dimension of the *degree of participation* describes whether instruments and designs affect farms universally. These can include exemptions and can be voluntary or disincentivise or incentivise farms to participate. Data is stored in and transferred to specific domains, ranging from private (e.g. farms, technology providers or food processors) to public. This is described with the *data domain dimension*. Finally, the *information governance dimension* specifies whether policy instruments are used to generate information on farming and its impacts, rather than to intervene in production and control impacts directly. Our analysis reveals how digital technology affects these interlocked dimensions individually. 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.

4. Effects of digitalisation in agricultural policy dimensions

The policy dimensions serve as analytical categories that delineate potential effects of digitalisation conceptually at the formation, implementation and evaluation stages of the agricultural policy cycle (Fig. 1). We determine how digital technology could theoretically affect each of these dimensions and, where possible, corroborate these findings with insights from documented practical cases and research literature. The effects of digitalisation in individual policy dimensions and key implications for instrument choice and design are summarised in Table 1. They are analysed in more detail in this section, which reveals trade-offs across the dimensions that are explored further in subsequent sections.

4.1. Input and outcome correlation – Targeting policy outcomes

Precise targeting of policy outcomes is challenging for agricultural policy (see Erjavec and Erjavec, 2015). Typically, policy instruments target inputs, practices and technologies or outputs of farms or their subunits (e.g. fields) as proxies for policy outcomes desired at farm level. Inputs or outcomes at higher spatial levels, such as catchments or landscapes, are rarely targeted, even if they improve ecosystem services (Gawith and Hodge, 2019). Agglomeration payments (Banerjee et al. 2017) or collective landscape management projects (Prager 2015) represent suitable approaches. In such contexts, digital integration of associated data sources, including direct monitoring of outcomes, can establish closer input-outcome correlations between different levels.

First, digital technology facilitates more efficient monitoring of practices that policy instruments aim to support as proxies for ecosystem services. It provides opportunities to monitor ecosystem service outcomes more directly, possibly even in real-time, for better identification of input-outcome correlations (OECD, 2019). This can lead to novel proxies that otherwise might not be established. Certain farming practices required to receive direct payments under cross-compliance in the CAP can already be sensed remotely (Sitokonstantinou et al., 2018) or logged in databases (Bertoni et al., 2018). Remote sensing of biodiversity is a source of great hope (Turner, 2014). Digital monitoring of cutting dates, soil cultivation or buffer strips seems to be the most advanced application of remote sensing that can correlate strongly with outcome goals (Bégué et al., 2018; Kolecka et al., 2018). Standard satellite and geographical information systems (GIS) technology can

Table 1
Digitalisation of policy instruments and designs within distinct policy dimensions at the formation and implementation stages of the agricultural policy cycle.

Dimension	Definition	Example	Key implications of digitalisation in specific dimensions for instrument choice and design
Directly affected policy dimensions			
Input and outcome correlation	Differentiates between using production inputs and production outcomes as performance measures at farm units or higher levels, such as landscapes. Performance proxies are inputs, technologies and practices or outputs that correlate with policy outcomes or goals.	Georeferenced modelling to establish correlation of digital catch crop area data (input) of farms with nitrate leaching in catchment (outcome) per season.	• Stronger identification of correlations between inputs, technologies or practices, outputs and outcomes of farming. • Possibility to establish policy outcomes at higher spatial levels such as catchments or landscapes linked to correlating inputs of farms. • New opportunities for instrument designs that target outcomes directly, or proxies only establishable with digital technology. • Better guidance for farms on how to achieve outcomes through inputs, technologies and practices.
Location specificity	Problems like erosion are very location-specific, while others like greenhouse gas emissions are not. The degree of location specificity co-determines the usefulness of targets of instruments related to locational attributes and problems.	Holders of tradable quotas tracked digitally to identify hotspots which are subject to location-specific ceilings for total quantities.	• Improved spatial targeting through new location-specific choices and designs of instruments at greater granularity. • Farms respond more efficiently to policy instruments across locations. • Location-specific targeting of compliance checks. • Facilitation of site-specific comparison of instrument designs and farming responses.
Intertemporal flexibility	Determines whether goal attainment can be moved temporally, banked or averaged over a period, in expectation of achieving it at lower costs in the future, or to reflect variable economic and environmental conditions.	Digital database logs seasonal nitrate surpluses of farms that are averaged across several seasons to meet a surplus maximum, or allows banking of surpluses to be mitigated with more efficient technology at a later date.	• Improved traceability and execution of intertemporal banking of quotas. • More precise intertemporal adjustment of current and new subsidies, regulated quantities and taxes to changing environmental or economic conditions. • Chronological trial-and-error learning of effectiveness of instrument designs and farms' responses.
Indirectly affected policy dimensions			
Locus of discretion	The extent to which government controls practices and technologies of those targeted with policy instruments. One extreme: Practices and technologies are prescribed and thus discretion lies with government. Other extreme: Government provides general incentives or prescriptions to achieve an outcome, leaving discretion to farms to choose suitable practices and technologies.	Government (digitally) monitors levels of pesticide and fertiliser residues in water body and leaves discretion to farms on how to reduce them or it assumes discretion and imposes buffer strips on farms to reduce pesticide and fertiliser influx in water body and monitors their maintenance, thus limiting discretion of farms to use alternative approaches.	• Farms can use own discretion on how to achieve an outcome goal, when input-outcome correlations are strong. • Government and food companies gain discretion in prescribing farms how to achieve an outcome goal, when input-outcome correlations are strong. • Farms lose discretion to deviate from regulation, evade taxes and claim more subsidies or quotas than allowed. • Government, food companies and farms lose discretion when digital technologies make their data more transparent or accessible to technology providers and modellers. • Diffuse loci of discretion, where complex interconnected digital technologies are used.
Prices versus quantities	Instruments that specify an outcome quantity aim to achieve a goal without knowledge of marginal costs. Instruments that set prices (taxes or subsidies) to incentivise farms to achieve an outcome imply efficient approximation rather than meeting the quantity precisely.	Government taxes nitrate surpluses as a price-based approach at levels established with digital models to approximate surplus quantities and farms abate at marginal costs, or it sets quantities of nitrate quotas established via digital models for farms that meet the quantity goal exactly.	• Digital technology supports price- and quantity-based instruments equally. • Improved correlations of price levels of taxes and subsidies with target outcome increases their similarity to quantity-based instruments. • New policy opportunities to link subsidies to regulatory requirements, e.g. greater cross-compliance. • Digitally supported trading and allocation of quotas and permits, renders these quantity-based instruments more attractive.
Cost distribution	Distribution of costs arising from a policy instrument among public and private entities. Achievement of a goal incurs costs for the producers, while the public or other parties bear (residual) costs.	Government taxes nitrate surpluses based on digital models and farms abate at individually efficient rates, or it sets nitrate standards for farms based on the models without incentives to save costs.	• More scope for farms to minimise costs of compliance and abatement, when digitalisation supports new price-based and tradable quota instruments or outcome-based designs. • Tighter monitoring reduces scope for cost savings at farms. • Reduced search, allocation, contracting and documentation costs of subsidies and tradable quotas. • Greater location, farm type and time specific targeting and tailoring reduces public costs as budgets are spent more effectively, and residual social costs as fewer undesired impacts remain.

(*continued on next page*)

Table 1 (*continued*)

Dimension	Definition	Example	Key implications of digitalisation in specific dimensions for instrument choice and design
Degree of participation	Policy instruments can target all farms or only certain types or numbers of them. Farms may freely enrol for a policy instrument and thus the degrees of participation vary according to attractiveness.	Digital screening of applications for subsidies selects those farms for which participation is desired or fulfils a goal of spreading a subsidy across a maximised number of farms.	• Increased short-term public costs of implementing digital technologies that decline in the longer run. • Improved spatial, farm type and other tailoring differentiates participation and implies less broad-brush participation. • New requirements to use digital technologies can limit participation where digital capabilities are lacking. • New designs that require participation of several farms benefit from digitalised coordination and collaboration support.
Data domains	Data for policy instruments can be generated, stored and used in private, government, public or community domains.	Compliance monitoring based on satellite data in the public domain or based on tractor-mounted sensors in private domains.	• More private farm data moving into government, public, community and private domains of other actors. • New subsidies in return for private farm data release.
Information governance	Whether government policy directly intervenes in farming to meet a goal or attempts to improve information relevant to goal achievement, such as research, education, facilitating information disclosure of private parties or non-financial nudging.	Disclosure of farm-nutrient balances on government website to decrease nitrate surplus as policy goal.	• New opportunities to provide information relevant to achievement of policy goals, rather than targeting goals directly with instruments. • Use of new regulations and subsidies to disclose digitalised information from farms and others. • New information-based nudging policies and farm management information systems either to complement instruments or stand-alone.

already assist in the monitoring and control of conversion of grassland into arable land, because observed outcomes at landscape level strongly correlate with the location and time-specific conversion practices (D'Andrimont et al., 2018). However, efficient monitoring of proxies for ecosystem services does not strengthen input-outcome correlations as such. They are only strengthened when farms learn best management practices through causally linking outcomes at specific levels to actions (Stupak et al., 2019; Uthes and Matzdorf, 2013). Digitalised options include chronological trial-and-error and site-specific comparison of a range of environmental factors using sensors, remote sensing or big data analysis approaches (Weersink et al., 2018; Wolfert et al., 2017).

Second, modelling outcomes can be more feasible, where digitalised monitoring of outcomes is challenging and especially when measurement costs are high (Bartkowski et al., 2019). For example, to implement its current nitrate policy, Denmark uses models that estimate outcomes at catchment levels and correlations to inputs at farm levels with the aid of various digital data. These include the EU's Integrated Administration and Control System (IACS), animal stock and movement, fertiliser sales, manure trading and climate databases that are largely georeferenced (DEPA, 2017; 2012;; Gault et al., 2015). However, Denmark still relies on manual entry of spraying records to monitor outcomes of pesticide policy (Kudsk et al., 2018). Alternatively, automated data which feeds directly from field application equipment or from field management software could provide data to estimate correlations with outcomes at very granular, but also higher, spatial levels like catchments, including heterogeneous inputs, such as manure. In turn, farm management software can help farms to manage compliance with legislation and pursuit of broader policy goals such as sustainability (Knuth et al., 2018; Lindblom et al., 2017; Rose et al., 2016). It can often import respective data, but again strong input-outcome correlations are essential to support decision-making with actionable rules (Kuhlmann and Brodersen, 2001; Sørensen et al., 2011).

4.2. Location specificity – Spatial targeting

Geo-referenced tracking of agricultural input use, technologies, practices, outputs or outcomes facilitates spatial targeting through location-specific policy instrument choices and designs. Digital monitoring or database integration is increasingly pursued for the location-specific identification of pollution levels and ecosystem services. It helps to implement established and new instruments. For example, Denmark integrates multiple databases, which are georeferenced or linked to individual farms, to digitally determine location and farm-specific nitrate-fertiliser accounts and compliance, as well as to target on the spot controls and to tailor 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). Georeferenced data generated by field management software or application equipment can inform location-specific risk assessment and the application of farming inputs in ways that exceed the simple digitisation currently in use. Novel instrument designs, like new spatially targeted subsidies, can be based on such technology. Digitalised auctions, for example, can allocate quotas and subsidies according to spatial targets, reflecting ecosystem services (e.g. Hanley et al., 2012; Reeson et al., 2011). Effects of allocation and trade of quotas on spatial distribution of farming impacts can then be monitored digitally to inform complementary quota ceilings or taxes in pollution hotspots.

Georeferencing generally facilitates site-specific comparison and tracing of a range of environmental impacts to identify hot and cold spots and inform implementation and evaluation of location-specific designs and farm responses, as well as compliance. It also helps to improve spatial levels of targeting from small to great granularity. For example, the Land Parcel Information System of the EU aids detection of location-specific compliance and correct areas as part of the IACS for current CAP payments (Devos et al., 2018b; Tóth and Kučas, 2016). Combined with further data and authority-farm interfaces, it could be used to design and promote new spatially targeted agri-environmental measures. Online information and GIS-based planning tools can then help farms to identify suitable agri-environmental measures. Moreover, payment providers can acquire farm and local ecosystem data through online interfaces and integration of databases. They can then suggest only those measures for which a location is eligible, or which provide the greatest benefit at a location. Farms and their advisors can also learn location-specific policy responses through causally linking outcomes to

actions, based on site-specific comparison of environmental and farming factors. Finally, the monitoring of outcomes, for example through remote sensing, can facilitate location-specific payments based on results.

4.3. Intertemporal flexibility – TTime-bound targeting

In the dimension of intertemporal flexibility, digital technologies track policy outcomes and their drivers to facilitate intertemporally flexible responses. Digitalised analysis and modelling based on integrated databases, for example, already supports time-specific nitrate standards in Denmark. These that are changed yearly, depending on impacts (DEPA, 2017; Gault et al., 2015). Real-time monitoring and database analytics offer new opportunities ranging from intertemporally flexible subsidy and tax levels and quota ceilings to intertemporal banking of quotas or compliance activities (see e.g. Cullenward et al., 2019; Maron et al., 2012). These can reflect desired, intertemporally changing outcomes, including temporally contingent ecosystem services. For example, digitalised monitoring of pesticide use over years can inform intertemporally flexible approaches to reduce pesticide loads, pesticide resistance management and pesticidovigilance (Kudsk et al., 2018; Milner and Boyd, 2017). Moreover, intertemporally changing nutrient influx from farming into water bodies could be monitored real-time (Yeshno et al., 2019). Finally, digital monitoring and analysis can support chronological trial-and-error activities and outcome comparison to facilitate learning and consequently adjustments of instrument designs over time.

4.4. Locus of discretion – Levels of prescription

Digitally strengthened input-outcome correlations lead to two principal options: 1) the locus of discretion lies with farms that can draw on the improved correlations to comply more confidently with instruments targeting outcomes, or 2) the locus of discretion lies with an authority (e.g. government or food company) that relies on the improved correlations to approach outcomes with instruments targeting correlating inputs, technologies or practices.

Implementation of policy instruments entailing information flows from farms to authorities for compliance and policy monitoring reduces the discretion of farms, while it increases that of the authorities. For example, the new Sentinel satellites improve data for monitoring current CAP payments, which increases the discretion of a government and its analysts (Devos et al., 2019). Proposals to release payments automatically, insofar as the IACS confirms eligibility (Deutscher Bauernverband, 2018), entail a form of algorithmic governance that reduces discretion of farms. They have less discretion to engage in moral hazard to depart from regulations, evade taxes or claim more subsidies or quotas than rules allow, as digitalisation renders monitoring more precise and strengthens input-outcome correlations. Novel behavioural nudges (e.g. Just, 2017; Kuhfuss et al., 2016) could also reduce farms' discretion relative to authorities and technology providers since digital technology makes farms more transparent. In addition, farm management software designed to guide farms can include automated data feeds from field management software or machinery to technology providers, thus increasing the discretion of providers of algorithms and software to the farms' disadvantage. Finally, modelling of outcomes shifts discretion to modelling contractors whereby they can use models and data in different ways, for example to relax or tighten nitrate standards, as currently in Denmark (Veihe et al., 2006). Consequently, instrument designs can become more prescriptive, leaving farms less discretion for cost saving and innovation. However, farms' discretion can also increase with a move to instrument designs targeting outcomes directly as they then have more leeway in how to reach outcomes.

In general, authorities relying on external software provision, data analytics and information release to pursue policy goals lose discretion when technology providers set up and maintain the artificial intelligence and algorithms involved. More accurate data handling in authorities can facilitate implementation, but its discretion diminishes, when they are obliged to use a certain decision-support system (Lemmen et al., 2015). Likewise, the use of digital technology to organise bidding procedures at auctions and for checking constraints, for example of novel agri-environmental measures, lessen an authority's discretion to implement individual arrangements with farms. In this context, increased decentralisation of agricultural knowledge and advisory systems driven by digitalisation imply more diffuse loci of discretion (see Carolan, 2020; Fielke et al., 2020).

4.5. Prices versus quantities – Financial incentives or regulation

Both price-based instruments, like taxes and subsidies and quantity-based instruments, like regulatory standards and tradable quotas, benefit from stronger identification of input-outcome correlations established with digital technology. Current CAP payments include quantity-based constraints like greening measures, which are supported by the IACS and accompanying digital technologies for determining areas and locations and for monitoring, including remote sensing (Devos et al., 2019; European Court of Auditors, 2020). Similar technology, further databases and digital trading platforms can support quantity-based quotas and permits. These reveal prices through initial allocation via auctions and through trade. They help to achieve a comprehensive quantity standard at lowest cost. Digital technology has similar effects where it improves correlations of tax and subsidy levels with target outcomes.

Quota regimes used to be popular in agricultural policy, but many like milk and sugar quotas have been abandoned. They rarely involved trading, while tariff-rate quotas remained important for agricultural imports and exports. More recent agricultural quota regimes govern environmental quantity standards. However, despite high data management demands, incentives for fraud in initial allocation and trading can arise, as experienced with the costly Dutch manure quota accounting system MINAS (Oenema, 2004; van Grinsven et al., 2016; Backus, 2017), which comprehensively integrated nutrients and financial audits (Breembroek et al., 1996). Likewise, no progress has been made in the integration of agriculture in carbon trading, because transactions costs are regarded as high (e.g. Ancev, 2011; Grosjean et al., 2018).

Correct enforcement and thus monitoring are particularly critical for tradable quotas, because trade leads to changes of ownership and the sum of quotas should be the overall standard. Digital technology can draw on databases of farm-specific input or output to support grandfathering and reduce information asymmetry. However, the key difference it makes is the tracing of traded permits and monitoring their use. This is advantageous in permit markets with frequent transactions. The Netherlands, for example, established a new ANCA model for manure quota accounting that is simpler to use than MINAS and promises less fraud, but is narrower in scope (Aarts et al., 2015). Thus, digital technology supporting tradable quota schemes may be adapted according to experiences. 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.

4.6. Cost distribution – allocation of policy instrument costs

Digitalisation can affect sizes and distribution of the costs of policy instruments. Transaction costs incurred by government, farms and companies, farms' compliance and abatement costs, public budget expenditure and residual private and public costs arising from farming impacts are particularly relevant. Typically, digital technologies affect several costs simultaneously.

Digitalisation affects the amounts and distribution of transaction

costs of policy instruments. Across instruments, authorities can benefit from lower transaction costs, even when new designs become more detailed, and especially when the digital technologies have economies of scale and scope. Automatic reporting can reduce transaction costs for both farms and authorities, if technology investment costs are sufficiently low. Digital allocation, monitoring and tracing systems for tradable quotas and subsidies can reduce costs for farms, particularly when transactions are frequent. For example, the ANCA model for farm manure quota accounting in the Netherlands, promises to be simple (Aarts et al., 2015). Farms face lower costs than with the more comprehensive MINAS system (Breembroek et al., 1996) that entailed high monitoring and enforcement costs for both farms and public authorities (Oenema, 2004; van Grinsven et al., 2016; Backus, 2017). However, digitisation of existing data does not necessarily lead to an overall cost reduction. For example, the new Sentinel satellites improve data for monitoring CAP payments. However, farms and authorities face higher administrative cost, if the traditional procedures of application, control and subsequent payment or sanction are not replaced by a new system based on prevention of non-compliance and interaction with farms ex-ante (Devos et al., 2019). This is due to the need to ensure correctness of data (Devos et al., 2018b, 2018a). Overall, the effects of digital technology on transaction costs of policy instruments are circumstantial and depend on technologies, attributes of the transactions and designs.

Digitalisation can also have significant effects on other costs. Location-specific and time-specific taxes, regulations and tradable quotas imply that not all farms bear the costs of compliance and abatement, leading to an overall reduction in private costs. Digitalised targeting instead of broadcasting subsidies also saves public budget expenditure (Carpentier et al., 1998) and digital sorting systems facilitate more targeted allocation of subsidies to optimise use the of public budgets. Payment providers can acquire data on farms and local ecosystems through online interfaces and integration of databases which allows them to suggest only those measures that provide the greatest benefit or match a farm's preferences. These technologies can also reduce farms' search and application costs (see Varian, 2009). Finally, digital monitoring that supports new outcome-based designs leave farms discretion to deploy measures that minimise the cost of respective compliance or abatement, across instruments. For example, in Denmark the digitally determined nitrate standards for growing seasons currently leave less discretion for cost saving on farms than a tax on nitrate balances would. Usually more governmental prescription implies less discretion for farms and thus fewer opportunities for private cost savings and innovation.

Digital extension and advisory services also have cost implications. They can provide farms with information and an interactive exchange at possibly lower costs (Fielke et al., 2020; Klerkx et al., 2019; Science Hub, 2019). Farms also have more opportunities to access information. Options with lower information costs and access to new data and analytics can reduce costs of meeting policy and private goals. However, cost distribution also depends on whether these systems are provided publicly, are open source or build on private business models.

4.7. Degree of participation – Levels of involvement

Diverse mechanisms can affect the degree to which farms participate in digitalised policy. Digital database scanning and georeferencing can identify impact hotspots or help to determine specific locations, farms, upstream or downstream enterprises to be targeted with a policy instrument. Incentives to participate include the benefits of digital technologies for farm management, like reduced private transaction costs or actionable input-outcome correlations from field up to landscape level. However, increased transparency of farm operations can have a disincentivising effect. Digitalisation can make the search and application for subsidies cheaper and facilitate targeting and tailoring of subsidies. This can either restrict or facilitate participation. Respective digitalisation can entail higher transaction costs especially for farms that lack capacities and skills in digitalisation (Fielke et al., 2019). Moreover, the upfront costs of technology and learning can be high. They can lower participation in policy measures, especially if there are no analogue fallback options, incentives or universal requirements to use digital technology.

Co-creation and co-design of digital technology promises to address barriers to using digital technologies in farming contexts. These barriers include regional differences, lack of data integration options, poor reflection of desired outputs, lack of adaptation of business practices or ineffective digital content provision (e.g. Ayre et al., 2019; Eastwood et al., 2017b; Ingram and Gaskell, 2019). Co-creation and co-design could encourage farms to participate where participation is not compulsory. Moreover, digital technologies, such as social media and clouds can support co-creation and co-design of digitalised technology for agricultural policy instrument implementation. However, participation at this stage (see Ortner et al., 2016) could only increase, if the aims predefined in the digital technologies correspond with farms' aims (see Knox et al., 2019). These technologies include access to georeferenced inputs and outcomes and their correlations at landscape level. They could reduce coordination costs and incentivise participation in project-based instrument designs like agglomeration payments (Banerjee et al., 2017) or management collaboratives that target landscape level outcomes (Prager, 2015). Costs for farms could sink and efficiency of the policy instruments rise due to digitally facilitated participation.

4.8. Data domains – Data ownership and transparency

When farms participate in digital agricultural policy instruments it normally implies that more of their data move into public or government domains. Transparency of farms increases due to the documenting of compliance and policy monitoring and evaluation. Typically the discretion of data receiving domains rises, while that of data supplying domains declines, if they cannot constrain data availability (see van der Burg et al., 2019). For example, modelling of policy outcomes shifts data domains to modellers. If permissible under data protection regulations, authorities can already link farming databases, like the IACS, to environmental databases to examine the legality of land management practices (Nitsch et al., 2010). Novel data from private domains can be added, as in Denmark, where farms log pesticide usage in an online database, linked to a pesticide sales database and the IACS. This is enabled by legislation that strengthens public data domains (Danish Ministry of the Environment, Danish Ministry of Food, Agriculture and Fisheries, 2013). When such data flow automatically from farming software or equipment, data domains move to government and possibly also to technology providers (Carolan, 2018; Kamilaris et al., 2017; Sykuta, 2016). Finally, payment providers for ecosystem services and other subsidies can acquire data on farms and ecosystems through online interfaces, remote sensing and integration of databases, thus transferring data into their own domains, which can range from private over governmental to public.

Policy instruments that focus on information provision, such as current requirements stipulating the use of digital animal movement databases, shift data into government domains and possibly further into public and other private domains, such as food companies. Likewise, open-source data and software that aid decision-making of authorities and farms imply changes in data domains. Consequently transparency and the accountability of those involved also changes (Attard et al., 2015; Kamilaris et al., 2017). As digitalisation increases diversity in agricultural knowledge and advisory systems, data domains seem to become more diffuse, while farm transparency generally increases (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.

4.9. Information governance – Targeting information provision

Information measures usually complement agricultural policy instruments, for example to inform about policy. They can also be distinct approaches, delivered through instruments that target the provision of information. These include regulations requiring private release of information via food labels or public disclosure, subsidies for research, education, advice and moral suasion campaigns through contracts or provided directly by the government (Howlett, 2009; Richards, 2000; Vedung, 1998). Digital technologies can reduce the costs of providing information. Therefore, a government can extend instruments to regulate or incentivise information release and use, instead of intervening directly in farm operations and markets. This implies that the government surrenders some of its discretion, while data domains open up and become more transparent.

Digital generation and provision of data on policy-relevant attributes and effects of farming can be part of open government and business initiatives (Attard et al., 2015). Digital communication tools can enhance their impact and make transparency effective, especially when they promote outreach and actions of private and public actors supporting policy goals. This can involve new business models using digitalised information to provide farm services that support policy goals, such as offering crop protection services instead of pesticides (Chappell et al., 2019).

Digitalisation can support information measures to facilitate implementation of other instruments and in areas where alternatives fail. Information-based nudging (Just, 2017) complements many information policy approaches, when integrated into digital technologies used for implementing an agricultural policy instrument. These include instructions for farms or online interaction steps for authorities and farms. Online information and planning software can, for example, both promote policy measures and nudge farms into specific subsidy contracts (Kuhfuss et al., 2016). Moreover, digital extension and advisory services can use multiple avenues to provide farms with information and facilitate interactive exchange with the aim of reaching more farms more effectively (Fielke et al., 2020; Klerkx et al., 2019; Science Hub, 2019). Technologies include farm management information systems to be used by farms or their advisors to achieve policy objectives or to manage businesses in line with wider sustainability goals and facilitate compliance (e.g. Lindblom et al., 2017; Rose et al., 2016). Examples are the farm nutrient management system, FaST, under consideration for implementing the EU's Nitrate Directive (European Commission, 2019), or soil carbon auditing software (de Gruijter et al., 2019). Research in Germany does indeed suggest a need for farm management information systems to aid compliance with regulation and certification schemes, although the current systems are not user-friendly enough (Knuth et al., 2018). They also would have to be compatible with the technologies and capabilities of advisors, who fill these roles and need an update of their respective expertise (see Eastwood et al., 2017a, 2017b; Leventon et al., 2017). Consequently, digitalisation can have a marked effect on information governance, although effects on instrument implementation are unclear.

5. Outlook on digital agricultural policy

Based on the effects of digitalisation we identified in the policy dimensions a more general outlook emerges regarding the effects of digitalisation on choices of generic agricultural policy instruments and design options. Our analytical approach does not allow systematic appraisal of the positive and negative aspects of these effects. However, it does suggest possibilities that exceed the scope of mere digitisation that just reduces transaction costs of agricultural policy instruments. Most importantly, new digital data and technologies expand opportunities to improve estimation of *input-outcome correlations*, achieve *location-specificity* and support *intertemporal flexibility* in the implementation of agricultural policy instruments. This increases the precision and therefore the effectiveness of agricultural policy: Outcome-oriented instrument designs can be used that are spatially targeted and reflect intertemporal dynamics. 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.

There is a varied range of implications for choices among the traditional categorisation of instruments into regulation, incentives and information provision. Digitalisation represents the generation of novel data and integrated analysis that strengthens input-outcome correlations and opens up new, outcome-oriented options. The outcomes can be regulated to suit specific locations, farm types as well as points in time. More efficient monitoring reduces information asymmetry between farms and authorities, thus shifting distribution of discretion and costs. For governments, this could enhance the attractiveness of regulation. However, these benefits also accrue to economic instruments, which can be more attractive than regulation. They generally allow farms more flexibility in allocating their resources and levels of participation. Digitalisation can also facilitate the exchange among collectives of participants, such as farms who have to coordinate outcome achievement at landscape level based on input-outcome correlations at respective levels. Subsidies and taxes gain in attractiveness for a government when digitalisation establishes close correlations of price levels with outcome quantities.

Savings in transaction-cost due to digitalisation enhance the attractiveness of information-intensive instruments, like tradable quotas. In addition, subsidies entail opportunities to pay farms for farm data moved out of their domain. The data can then be used for targeted learning, possibly involving artificial intelligence, to improve the design of any given instrument. Finally, provision of information and information-based nudging could become increasingly useful instruments, since digitalisation affects the information governance dimension and challenges data domains. By drawing on advanced digital data and technology options, it could even replace instruments which intervene directly to achieve similar outcomes, for example, where transparency means that farms are exposed to social sanctions or they can be convinced directly by information.

This analytical outlook shows how agricultural policy instrument choices and designs can unfold in an era of digitalisation along interlocked policy dimensions. Two key dimensions emerge as critical for the design of future agricultural policy instruments: *input-outcome correlations,* i.e. the certainty of targeting a desired policy outcome at a certain level (e.g. farm or landscape) and the *locus of discretion,* i.e. whether farms or authorities chose the specific actions needed to reach a desired policy outcome. The interlinkages of these dimensions imply important trade-offs. Current agricultural policy rarely targets outcomes directly. It tends to give farms little discretion to develop individual responses and reduces incentives to innovate, especially when it regulates or subsidises technologies and practices. However, regardless of whatever digital technology monitors, it must correlate with the desired outcome, inputs and management practices of the targeted farms. Otherwise, farms struggle to produce the desired outcome. Digital technology assists in

estimating these correlations, even when they include non-point sources and outcome targets at landscape level. In theory, targeting of outcomes leaves most discretion to farms (outcome-based policy design in Fig. 3), but their discretion is limited when digital technology establishes close correlations with inputs, technologies and practices. This implies trade-offs as authorities could equally well switch to input, technology or practice prescriptions, thus gaining discretion at the expense of the farms (practice-based policy design in Fig. 3). 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. However, as farms' discretion declines, their incentives to innovate and adapt to local circumstances unobservable to authorities also weaken. Farming could become more standardised and less resilient. Although our analysis is agnostic in this regard, it is essential that adequate attention is given to such wider trade-offs and risks that extend beyond the policy dimensions and policy cycle stages we have covered here. The next section deals with the wider implications and risks of digital technology that affect choices and designs of agricultural policy instruments.

6. Discussion

Our findings show how digital technology can influence choices and design specifications of agricultural policy instruments. The general developments in digital information management suggest that future agricultural policy instruments will be embedded deeper in digital technology and more digitised. However, all currently used agricultural policy instruments can benefit from digital technologies. They make the greatest difference at the implementation stage, where digitalisation not only supports targeting, tailoring, monitoring and control, but also generates novel data that advances established policy evaluation technology. In the following, we discuss four critical aspects of our findings.

First, digitalisation of agricultural policy is contingent on the use of digital technologies in the agricultural sector. Important barriers to engaging with digital technologies include capacities of farms and authorities, analogue fallback options, user-oriented design and exemptions or support for small farms. In addition, costs and loci of discretion can affect farms' participation in digital agricultural policy instruments as their distribution can be perceived as unfair and certain groups of farms be excluded. Farms may also lack the capability to respond efficiently to outcome-based designs. All this reflects the role of the digital divide in agricultural policy and risks associated with technology access, data ownership, control and security (Klerkx and Rose, 2020; Regan, 2019; Rotz et al., 2019). However, incentives to participate can be incorporated as sanctioned requirements of regulations and subsidies to use digital technologies. Likewise, designs of taxes, regulations and tradable quotas can incorporate benefits of digital technology, 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). When digitalisation implies the targeting of farm and landscape level outcomes, advisors could be needed 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; Lundström and Lindblom, 2018). While digital technology could improve advisory services, costs might increase and technology, such as online instructions, replace interpersonal advise (Rijswijk et al., 2019; van der Burg et al., 2019). This can shift discretion to government and technology providers. Here, but also in other cases apart from advisory systems, discretion can move into algorithmic governance, with questionable consequences (Klerkx et al., 2019). Therefore, care must be taken that farms, advisors and authorities retain freedom to develop creative solutions and innovate, rather than establishing path-dependencies of agricultural policy digitalisation (see Fly-verbom and Murray, 2018; Sætra, 2019). Digital path-dependency could limit the abilities of farms, advisors and government to respond to

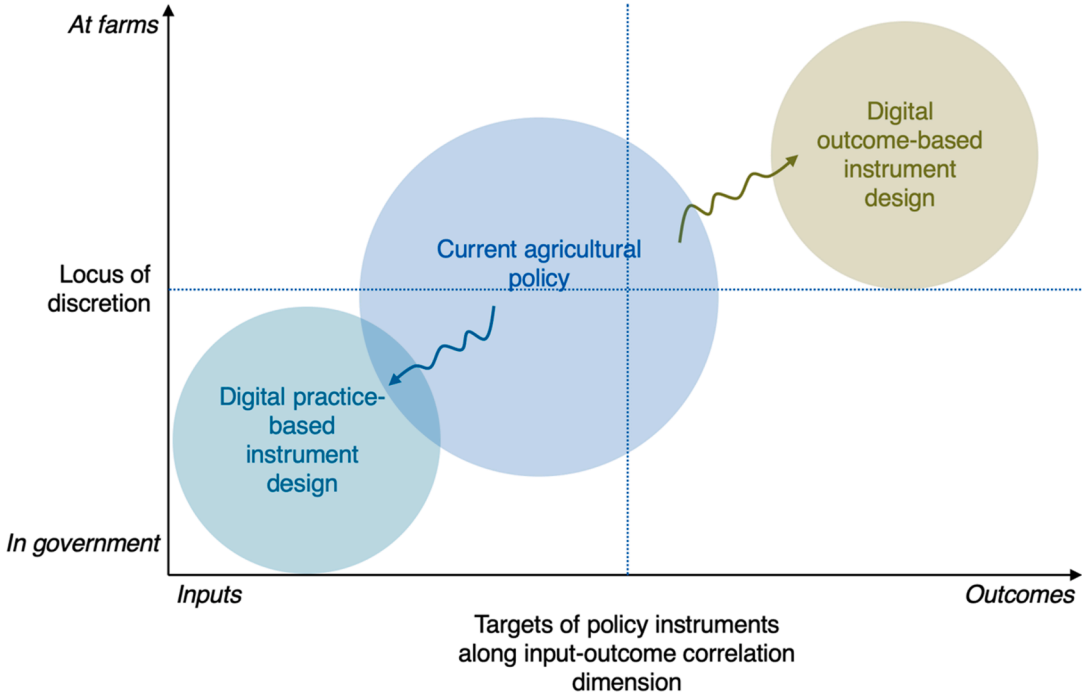

Fig. 3. Digital agricultural policy options in key policy dimensions: inputs or outcomes as targets of policy instruments in relation to the locus of discretion that ranges from government authorities to farms.

unforeseen challenges, rendering them less resilient. Therefore, a strategic policy problem is whether to invest in specific technologies for specific instruments that enable diversity and learning, or to invest in technologies that are less advanced, but broader in purpose. As in the case of digital farming, digital innovations to support agricultural policy could be approached with responsible research and innovation, to prevent such risks and balance trade-offs (e.g. Bronson, 2018; Klerkx and Rose, 2020; Rose and Chilvers, 2018).

Second, our analysis assumed persisting agricultural policy goals and challenges in Europe, such as information asymmetries and diffuse sources of farming impacts. To a certain extent, digitalisation resolves these challenges, especially when digitalisation facilitates learning and adaptation. However, new goals could emerge with evaluation and framing based on new information provided by digitalisation. Digitalisation of agricultural policy can also trigger new challenges, such as ensuring that the actors involved are capable of utilising relevant digital technology (Regan, 2019), interoperability (Phillips et al., 2019; Tóth and Kučas, 2016) and data ethics, including privacy concerns (Sykuta, 2016; van der Burg et al., 2019).

Third, data provision, sharing and analysis, including their co-benefits and risks, are critical for the establishment of digitalised agricultural policy instruments. Applications of digital technology for agricultural policy that make farms and the environments in which they operate in more transparent often affect data domains. Data involved are no longer kept private. Some become public, while other are accessed or kept by different private domains, such as technology providers or become decentralised in blockchains (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 georeferenced 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 insights and to render behaviour accordingly (Varian, 2014; Zuboff, 2019). This can support pre-emptive regulation (Yeung, 2018). Here, voluntary measures provide opportunities to generate data which farms are otherwise reluctant to supply. The data could help training models that assist the evaluation of measures, ex ante, to inform choices and designs of agricultural policy instruments. Due attention must be given to such uses of digital technology in agricultural policy. Digitally facilitated policy learning is important to farms, for example when outcome-oriented designs give them more discretion to develop practices and technologies that generate outcomes efficiently.

Fourth, when examining the policy context of instrument choice and design that is subject to digitalisation, the question arises of how legal and political feasibility will develop. The scope for digitalising subsidies should be comparatively large as digitalised policy instruments should be politically more feasible when farms and other policy stakeholders receive benefits from digitalisation. However, without supportive framework legislation, legal feasibility could be very circumstantial. Opportunities for real-time evaluation and feedback into framing and formation could be exploited to a greater degree in the policy cycle, as it is already visible in online search patterns (Schaub et al., 2020). One outcome could be complex entanglements of policy making and digitalisation, as policy actors and systems become dependent on digitalised data supply and analysis. This complexity increases further when agricultural policy becomes integrated in food systems governance (De Schutter et al., 2020), as currently being attempted with the EU Farm-to-Fork strategy (Schebesta and Candel, 2020). Instead of farms, a government could also regulate food chain companies and certifiers, which can generate ample data on farms and govern them via private contracts (Poppe et al., 2013). However, such approaches may increase the gaps separating government and society from farming and endanger adaptability (Miles, 2019). Basically, the availability of information determines whether government can assign and adjudicate rights and duties or is obliged to act as a regulator that sets and enforces goals (Richards, 2000). The first role can be attractive for a government, where digitalisation greatly reduces costs of governing property rights among the parties involved. Government can also add liability rules when it is possible to establish proxy values of damage to the parties. Digital technology can facilitate adjudication where it reduces costs of examining the respective cases involved and of establishing such values. These possibilities imply transforming the fundamental role of government from that of a regulator to a facilitator of agricultural conflict resolution.

7. Conclusions

The full potential of the digital technologies under consideration for agricultural policy is far from being fully exploited. We locate digitalisation of policy instruments in the policy cycle and develop an analytical framework that focuses on policy dimensions that digitalisation can affect at the policy formation and implementation stages. The subsequent analysis reveals effects of digitalisation on key dimensions of agricultural policy instruments and designs. It provides an outlook on choices and designs of digitalised agricultural policy instruments that can help policy makers to identify alternative policy instruments and designs that arise with digitalisation.

The analytical framework could be applied to digitalised policy instruments in other policy fields. We emphasise theoretical implications rather than scrutinising empirical evidence on digitalised agricultural policy. The European examples to which we refer are indicative and not exhaustive. Problems facing agriculture and goals of agricultural policy can be different in the future and in other settings. However, our analysis finds that digital technology generally increases the precision of instruments, mainly because it can improve the identification of strong input-outcome correlations and location-specificity. Further effects can be ambiguous, for example relating to the discretion of authorities and farms, cost distribution and data domains.

Two major messages for policy emerge from our study. First, since agriculture is multifaceted, policy instruments will remain mixed and digitalisation does not favour specific policy instruments. However, it does increase their design options. It facilitates the tailoring of instruments to specific agricultural problems, thus increasing efficiency and effectiveness of agricultural policy. Therefore, governments and interest groups could pursue digitalised design options strategically to increase policy legitimacy, even when they are initially based on pilot projects. Second, low-hanging fruits materialise especially in monitoring and control, where digitisation reduces transaction costs. However, this kind of digitisation is not an encompassing digitalisation of agricultural policy, which depends on digitally competent stakeholders and suitable institutions. Active engagement in planning digitalisation is essential, because the benefits of a digitalised agricultural policy can only be realised by learning and capacity building in the whole sector. Government could use the responsible research and innovation approach to integrate views of food, farming and other stakeholders to develop appropriate digital agricultural policy innovations. Digitalisation can help here too, as digital data available on inputs, outputs and outcomes of policy instruments can increase the scope to test different design options. Experimentation and strategic learning are needed especially when digital agricultural policy shifts from direct intervention in agricultural production to information governance where government merely uses, prescribes or incentives digital technology to generate and publicise agricultural information.

A key question, both for research and policy, is whether farms, interest groups and government are willing and able to cope with the ramifications of a more encompassing digitalisation of agricultural policy. This would depend on the capabilities and the willingness of government, farms and the other actors involved to use digital technologies. It also depends on developments in future policy demand and

digitalisation. Systematic anticipation of plausible futures of digital agricultural policy is therefore needed.

CRediT authorship contribution statement

Melf-Hinrich Ehlers: Conceptualization, Methodology, Investigation, Writing - original draft, Visualization. **Robert Huber:** Conceptualization, Writing - review & editing, Visualization, Funding acquisition. **Robert Finger:** Conceptualization, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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