

Concept Paper

Innovating in an Uncertain World: Understanding the Social, Technical and Systemic Barriers to Farmers Adopting New Technologies

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Abstract: The current geopolitical and socioeconomic landscape creates a difficult and uncertain operating environment for farming and agri-food businesses. Technological innovation has not been suggested to be a “silver bullet” but is one of the ways organizations can seek to reduce environmental impact, deliver net zero, address the rural skills and labor deficit and produce more output from fewer resources and as a result, make space for nature. But what barriers limit this promissory narrative from delivering in practice? The purpose of the paper is to firstly explore the reported social, technical and systemic barriers to agri-technology adoption in an increasingly uncertain world and then secondly identify potential research gaps that highlight areas for future research and inform key research questions. Socio-technical and infrastructural barriers have been identified within the context of the complex hollowing out and infilling of rural communities across the world. These barriers include seventeen factors that emerge, firstly those external to the farm (economic conditions, external conditions including bureaucracy, market conditions, weather uncertainty and the narratives about farmers), those internal to the farm business (farming conditions, employee relations, general finance, technology and time pressures) and then personal factors (living conditions, personal finances, physical health, role conflict, social isolation and social pressure). Adaptive resilience strategies at personal, organizational and community levels are essential to address these barriers and to navigate agri-technology adoption in an uncertain and dynamic world.

Keywords: agri-technology; socio-technical barriers; infrastructure; hollowing out; rural communities; silver bullet



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1. Introduction

Farmers have always been subject to factors that influence personal or business resilience including variability in weather, volatile and unpredictable commodity markets, changing governmental and environmental regulations, rural isolation resulting in financial pressures, unpredictable market prices, increased input costs, inadequate and/or irregular cash flow and high debt [1,2]. The current geopolitical and socioeconomic landscape creates a difficult operating environment for all global farming and agri-food businesses, and especially in the United Kingdom (UK). The Department for the Environment Food and Rural Affairs estimates that 472,000 people work in commercial agriculture across the UK, including farmers, farm workers and their households on an estimated 219,000 holdings, almost half of which are under 20 hectares [3]. After Brexit, the farming economy is transitioning away from the European Union (EU) Common Agricultural Policy and the previous Basic Payments Scheme to the rollout of the Environmental Land Management Schemes (ELMS). There are also increasing legislative and societal pressures for agricultural and horticultural businesses to be central to delivering national net zero emissions targets and these pressures are impacting on business and personal resilience [4]. In a survey of 650 members published by the UK National Farmers Union (NFU) in June 2023, a spike in input costs over the previous eighteen months, in part driven by the Ukraine/Russia

conflict was cited as having a negative impact on mental health in rural communities [5]. David Exwood, Deputy NFU President said:

“Our survey pinpoints some of the root causes affecting rural mental health, economic and political uncertainty, and we are calling on government to continue taking steps to address these issues to reduce the stress farmers are facing”.

The challenges of the rate of change, managing multiple roles, increasing complexity and risk, the corporatization of input supplies, and the need to embed technology and manage inputs into farming businesses are all cited as reasons for increasing levels of stress being reported in the farming sector [2]. Anderies et al. [6] p. 3 draw these themes together stating:

“Real-world systems not only exhibit complex nonlinear dynamics, they also exhibit complexity of a different sort: [due to] the sheer number of interacting elements that compose them”.

It is in this context, that in the UK, society and agricultural and horticultural businesses are looking to find appropriate solutions to many of these issues including technological innovation. Whilst technological innovation has not been suggested to be a “silver bullet”, it is one of the ways organizations can reduce environmental impact, deliver net zero, address the rural skills and labor deficit and produce output more from fewer resources and as a result, make space for nature. Indeed, gaining a better understanding of the context therein leads to the two key questions this iterative review seeks to address:

1. What are the socio-technical and infrastructural barriers to agri-technology adoption?
2. Is the discourse around rural development/rural decline itself a barrier to the adoption of agri-technology?

The purpose of the paper is to firstly explore the reported socio, technical and systemic barriers to agri-technology adoption in an increasingly uncertain world and then secondly identify potential research gaps that highlight areas for future research and inform key research questions. The paper is structured as follows: Section 1 is an introduction and Section 2 considers the social context of rural communities and the rural workforce in particular which is the lens through which this research reflects on agri-technology innovation and adoption. Section 3 reflects on two socio-technical barriers in particular: inertia and resistance to change. Section 4 concludes the paper and positions specific research questions for further empirical research.

2. Methodology

Using a grounded foundational literature review and then a series of iterative searches, a theoretical framing of themes has been developed within this paper that has been derived from the emerging secondary data rather than through deductive forcing of pre-existing theories. The search terms that emerged (Table 1) were then used in multiple iterative combinations in subsequent searches until data saturation was reached [7]. The first 100 items in each search were then considered for relevancy and any duplication. The papers were then read in full and screened for relevance and value in supporting a discursive primary narrative and argument until source saturation was reached. The following databases, Science Direct, Google Scholar and Google (to include gray literature) were used to ground the conceptual research and to inform the findings. It was important to seek gray literature as the emergent narratives are not all reflected in the academic literature. A limitation of this approach is that agri-food industry surveys cited may not be academically robust in terms of representativeness or generalizability, but they have been included to triangulate secondary evidence from a range of sources. Any inference derived from these sources has been framed within this methodological caveat. A total of 104 sources from the iterative review were used to support this paper.

Table 1. Search terms used to develop the iterative review.

Level 1	Level 2 AND	Level 3 AND
Agri-technology OR Artificial intelligence OR Automation OR Robots	Agricultural productivity Barriers Farmers Farming Infrastructural Innovation Labor deficit Mental wellbeing Rural skills Silver bullet Socio-technical Technological Work conditions	Anxiety Coping strategies Depression Distress Mental health Mental wellbeing Stress Suicide levels Support
Rural communities	Displacement Hollowing out Infilling Levelling up Replacement Rural gentrification Unemployment	Human capital Labor outflow Migrant labor
Inertia	Adapt Barrier(s) Control Cultural dynamics Dominance Infrastructure Institutional arrangements Investments Organizational inertia Power (networks of power) Reinforcement Resistance to change Sluggishness Staff Stickiness Structural aspects Time	Norms Order Risk Routine Rules Policies Practices Work routines
Lock-in	Action Apathy Blockages Cognitive Culture Data Discursive Entrench Financial Infrastructure Insight Market Mechanisms Normative Psychological Social Soft Structural Systemic Technological and legal (technology) Unlocking strategies	

The geographical focus of the paper is predominantly the Global North as this is where most of the secondary evidence has arisen within the iterative searches. Whilst the majority focus has been on the UK, evidence has also been cited from countries including the US, Brazil, the Caribbean, Europe, Japan, New Zealand, South Korea and China.

This approach to literature synthesis provides a more flexible and reflexive approach compared to highly structured alternatives and more holistic, system-level outcomes [8]. The next section considers the social context of rural communities.

3. Social Context of Rural Communities

Farming requires farmers and farm workers to often live at their place of work, so it can be difficult for people to separate and contextualize their work, and personal and family dynamics [2]. Work conditions in the agricultural industry are often hazardous, involve long working hours, hard physical labor often with time pressures and high levels of stress driven by factors outside the workers' control [1,9]. Work-related and contextual factors create stress for farmers and farm workers with varying impacts depending on income, gender, age and sexuality [10]. Stress (physical and psychological) is a "strong predictor" of injuries on farms and the level of social support available for those experiencing mental and physical stress has been linked to the propensity for risky behaviors [11]. This dynamic is leading to a vicious cycle of mental health and in many cases severe financial difficulties [12]. Examples of situations where this "cycle" has been enacted include the Millennium Drought in Australia, and pesticide exposure and mental stress in countries including Brazil, China, Costa Rica, Egypt, India, Iran, Nepal, Pakistan, the Philippines and Tanzania [1].

Suicide levels are also high in the farming sector driven by many of the aforementioned stressors. Acute and chronic stressors can overwhelm an individual's coping capacity resulting in higher levels of psychological distress, mental health issues, and suicide [13,14]. More than one farmer a week in the UK takes their own life [3]. In the decade between 2011 and 2020 in skilled agriculture and related trades, males registered suicide deaths between 54 and 79 per year and 1 to 7 women [15], accounting for 2.2% of national suicides in 2019 [10]. Landscapes of support for farm workers include "formal through professional or volunteering services like mental health charities and clinicians [formal counselors] or more informal through family, auction marts, friends and professional contacts [accidental counselors] such as financial advisors, agronomists, veterinary professionals" [16] p. 120. These informal counselors may more easily understand the nature and stresses of farming compared with professional "clinicians" and familial support networks are very strong in rural areas [16] and spousal support is often used as a buffer to stress [11]. Three socio-technical aspects are considered here: mental wellbeing, hollowing out and filling in, and socio-technical innovation.

3.1. Mental Wellbeing

Mental wellbeing describes an individual's ability to cope with "the ups and downs of everyday life", but over a third of the UK farming community are said to be possibly or probably depressed, and over one in five (21%), based upon threshold points used by the NHS [3], are probably depressed compared to one in six (16%) of the general UK population [17]. Over half of respondents to the 2021 UK RABI survey [3] stated they felt they were experiencing anxiety. The 2023 UK House of Commons, Environment, Food and Rural Affairs Committee, Rural Mental Health report highlighted the need for leveling up in rural communities to improve rural communities' wellbeing and access to mental health services, firstly leveling up public transport and secondly, leveling up and improving access to digital connectivity [18]. The report [18] p. 3 explains:

"The available picture of rural mental health across England is complicated and incomplete due to gaps in health data, the suppression of demand by over-centralized services, and the under-reporting of rural deprivation which is inextricably linked to poor mental well-being".

Factors in the literature noted as being associated with anxiety, depression and mental health issues with farmers have been synthesized (Table 2). Seventeen factors emerge, firstly those *external to the farm* (economic conditions, external conditions including bureaucracy, market conditions, weather uncertainty and the narratives about farmers), and those *internal to the farm business* (farming conditions, employee relations, general finance, technology and time pressures) and personal (living conditions, personal finances, physical health, role conflict, social isolation and social pressure). These can all play a role, singularly or in combination, as barriers to technology adoption. The lack of, or poor quality of, digital connectivity, exacerbated by a lack of rural digital infrastructure, has been highlighted as a key stressor that impacts negatively on farmers and rural communities. Karttunen et al. [19] p. 1 in their study in Finland found that the adoption of technology, in the case of automatic milking machines (AMS), had both positive and negative aspects:

“[it] brought flexibility to the organization of farm work, and it had increased leisure time, quality of life, productivity of dairy work, and the attractiveness of dairy farming among the younger generation. . . reduced the perceived physical strain on the musculoskeletal system as well as the risk of occupational injuries and diseases. . . however, working in close proximity to the cattle, particularly training of heifers to use the AMS, was regarded as a high-risk work task. . . [However] nightly alarms. lack of adequately skilled hired labor or farm relief workers, and the 24/7 standby for the AMS were issues that also caused mental stress”.

Multiple sources have suggested that the lack of connectivity and access to fast-speed broadband and the lack of digital skills is a stress for farmers and wider rural communities. In the United States (US) an association was found between download and upload speed and farm productivity highlighting that as access to the internet increased farm costs decreased and yield increased [20,21]. Accessibility to the Internet can decouple farmer purchasing processes for farm inputs, machinery and credit from spatial localized constraints allowing engagement with local, near local or national suppliers [20–22].

Table 2. Factors associated with anxiety, depression and mental health issues with farmers (adapted from [1,2,9,12,18,23–25]).

Factor	Examples
Bureaucracy	Paperwork driven by regulations, burden of paperwork
Economic conditions	Government export policy, trade agreements, government farm support mechanisms
Employee relations	Ability to secure reliable skilled employees, employer-employee conflict
Farming conditions	Heavy workload, overwork, stress, hazardous conditions
External conditions	Animal disease, crop disease machinery breakdown, rural crime (dog attacks, vandalism)
General finances	Input prices, income, profit, irregular/insufficient cash flow, high debt, taxes, low commodity prices, pressure, poor returns, competition between farmers
Living conditions	Poor housing, living where you work, insecurity of housing linked to tied accommodation to work role
Market conditions	Poor access to market information, market conditions, market prices, economic stress
Narratives	Media criticism, public criticism
Personal finances	Repayment of loans or financing retirement, limited access to capital
Physical health	Pesticide exposure, past injury, lack of sleep during busy times of year, risk of burnout
Role conflict	Working with family, conflict between family and work commitments, succession planning, inability to switch off, pressure to maintain generational capital and social expectations
Social isolation	Loneliness, lack of social relationships and social connectedness, poor accessibility to social support services
Social pressure	Lack of anonymity, sexism, misogyny
Technology	Lack of computer skills, poor broadband connections limiting access to emails and video calls
Time pressures	Due to reducing number of employees, working longer hours, caring responsibilities, time off the farm
Weather uncertainty	Climate change, climate variability, e.g., drought

For agricultural businesses, in this example with farmers in Kentucky, US, accessibility to broadband rather than dial-up connection can provide greater access to market and management information, email and video conferencing and weather information [21]. Indeed, lack of access to technology can create social exclusion in the agri-food sector driven in part by the inequality of sovereignty over data and hardware [26–28]. This is just one example of the social exclusion faced in rural areas, the next section considers the social exclusion created by hollowing out and filling in.

3.2. Hollowing out and Filling in

Park and Deller [29] use the term “hollowing out” to describe the loss of the “middle” in US agriculture and the polarization of farm size to the large or the small and niche. They ask what this trend will lead to in terms of the well-being of rural communities, arguing that technology adoption including robotics has in part driven this trend. Their study suggests that:

“higher rates of dependency on farming tends to be associated not only with lower earnings per job, lower business startup rates and poorer health outcomes [physical and mental], but also with higher rates of home ownership” [29] p. 308.

This hollowing-out process, alternatively described as regional shrinkage [30], has led to rural decline, the loss of traditional values, and increasing rural isolation [31], and has affected the ability of rural communities to be resilient to natural shocks such as floods in New Zealand [32]. Conceptualizing the loss of human capital through the “hollowing-out” of rural communities has been considered particularly in the US, in terms of the young leaving in search of better jobs and prospects more generally [33], and/or as the global trend for rural–urban migration [31]. In China, for example, the migration of rural laborers has left women, children and the elderly behind, in feminization and graying of agricultural production. This global phenomenon of hollowing out has led to the loss of educated and skilled young people, a “rural brain drain”, often driven by the communities themselves and their narratives about the lack of opportunity or better opportunities elsewhere, creating an aging population and weakening the local economy [33]. In Appalachia in the US, factors such as the facilitation of greater movement of labor, limited job opportunities, where the low-paid jobs available in the rural location are perceived as low skilled and low prestige and where those who have attained educationally at school can access greater opportunities elsewhere have led to this brain drain in rural locations across the world and an inflow of lower-skilled individuals looking for work [34]. Others have described this situation as the selective outmigration of the “best and the brightest” youth driven in part, but not wholly, by educators devaluing an attachment to the rural community, and rural occupations and wishing to remain local, where they perceive the future for those they educate to be elsewhere or that they need to go elsewhere to develop the human capital that is required by the community with which they can, if they chose to, return and utilize [33–35].

At the same time as this trend of hollowing out, there has been a process of “filling-in”, i.e., the development of new economic development functions and political arrangements that extend beyond a narrative of the rural economy that is purely focused on economic output linked to agri-food production. As a result, in Ireland, this has led to a movement of assets into rural locations unlocking the overall economic potential of people and property as human and physical capital [36]. Rural gentrification has been much studied. Phillips [37] p 124 describes rural gentrification as “a change in the social composition of an area with members of a middle class group replacing working class residents. . . . [or] one middle class fraction [with a different outlook] replacing another”. In rural gentrification, the movement of capital assets including human capital has flowed from the urban back to the rural as a strategy to “buy-into” a particular lifestyle, as a manifestation of unequal division or circulation of capital [37]. Others describe this trend in the US context, as a rural renaissance or rural rebound where those with professional occupations move to live in rural locations but still work in urban areas, raising house prices and creating a greater disparity between

local housing costs and the salaries associated with local jobs [38], leading to a form of exclusionary displacement [39]. This form of rural gentrification can then become focused on current and future land use, exercised through local planning policy potentially creating conflict [38], through middle-class representation which is “translated into spatial forms” [40]. There are multiple forms of displacement occurring in rural locations linked to investment/disinvestment and pressures of exclusion, even rural abandonment [39]. Whilst the impacts, both positive and negative, of eco-gentrification have been considered in urban environments, especially displacement effects and exclusion [41,42] this has yet to be studied in any depth in the rural setting [43]. The impact of eco-gentrification on rural social exclusion is worthy of further study.

Another form of infilling has been the continued global reliance on migrant labor within agri-food economies. In the UK agri-food sector, since EU expansion in 2004 and 2007, the centrality and dominance of the inflow of EU temporary (seasonal) or permanent migrant labor filled the rural labor shortage. This has realigned especially post-Brexit but there remains a focus in the associated discourse on the type of worker rather than the structural conditions of the labor market and the potential for reconfiguring the conditions of the work itself [44]. Marinoudi et al. [45] describe the labor outflow from the agricultural sector in the UK over the last century and the need for technology, automation, and robotics to fill the labor shortage, and also the challenges that presents. They argue:

“Low levels of agricultural productivity can “trap” labor in the sector, reducing their mobility into more rewarding and the higher skilled roles required to support advanced economies. To avoid unemployment when releasing the “trap”, it is critical that society creates economies with sufficient and more rewarding jobs whilst enabling mobility via skills and development programs”. [45] p. 112.

Mutascu [46] differentiates between a *replacement effect* where technologies such as artificial intelligence (AI) generate productivity, but also have a negative effect on the labor market reducing job availability and secondly, a *displacement effect* where existing employment opportunities are displaced by technology and the labor force needs to move to other roles. Replacement of people with equipment can mean the labor force may move from agricultural jobs to manufacturing jobs and then when these jobs are automated, they move to service jobs, but ultimately they may be replaced by robots and automation in every role [46]. While the term techno-gentrification has been used sparingly in the literature it will be interesting to see how this concept is considered and evolves.

Studies have considered the interaction between economic and social wellbeing, gentrification and the consequences of displacement pressure [47]. Factors of influence that lead to displacement pressure are detailed in Table 3. These can be infrastructural, economic and social potentially affecting the health and wellbeing of individuals and collectively affecting the displaced community.

Table 3. Factors associated with economic and social wellbeing, gentrification and displacement pressure (adapted from [47]).

Factor	Examples
Economic	Direct displacement, exclusionary displacement, benefits in terms of better access to a greater range of products and services but may be economically excluded. Loss of local services as local shops or local schools close
Health/wellbeing	Health impacts, stress related to displacement pressures, psychological impacts, fear
Infrastructural	Infrastructure changes and accessibility to infrastructure
Social	Community effects, impact on networks, loss of feeling of place, emotional connection, dislocation and identity, lack of engagement with the new cultural identity

3.3. The Socio-Technical Silver Bullet?

The notion of a silver bullet to address a flaw in the current socio-technical paradigm is conceptually distinct from that of seeking to deliver a specific technological fix to a distinct technical problem [48]. Scott [48] cites the example of the past narrative framing of the silver bullet of genetically modified organisms (GMOs) and the social backlash that occurred when the technological fix was not considered within the wider politico-socio-technical food system. More recently, similar silver bullet promissory narratives have come to the fore concerning alternative proteins and cultured meat [49]. The cultured meat study captured UK farmers' perspectives on the impact of technological innovation on existing ways of doing and the implications [49]. Decision-makers favor the silver bullet narrative because it proposes simplistic, politically expedient solutions that often postpone the need for an effective response to complex, often wicked, problems [50]. Further, they argue the proposal of silver bullets in highly disconnected systems shifts the cost from elites to marginalized communities, and decision-makers can then deny responsibility for negative externalities blaming and attributing governance failures to these "scapegoats" or villainous others, in this case, to farmers [51]. This narrative then removes the apportioning of blame to consumers demanding products with characteristics that create incentives to overexploit or lobby for regulations that allow overexploitation [52]. Good farmer–bad farmer narratives have been explored in the literature in association with cultured meat [49], animal welfare [53], or bovine tuberculosis policy [54], especially the symbols and artifacts of "good farming" and how they are associated with economic viability [55]. Bronson [56] p. 5 states that:

"social actors working in private and public contexts to shape these [technology] innovations hold a narrow set of values about [what it is to be a] good farmer, farming and good technology and their data practices privilege large-scale and commodity crop farmers. . . . [and] suggest the need for an responsible research and innovation rubric to guide the digital agricultural transition, ensuring that innovations are designed to deliver benefits such as improved productivity and/or eco-efficiency that can be widely shared".

Indeed, social actors who are shaping innovation can create a narrow frame for what good farming, good farmers and good technology "look like" [57], whilst the farmers themselves can be social agents of change through co-creating innovation but the processes involved often hinder this interaction [8]. Innovation in terms of new products, services, technologies, processes or ideas can be an important mechanism for promoting economic growth and societal well-being [57]. For innovation to be inclusive, it requires dynamic, participatory and anticipatory governance that shapes the direction and context of the innovation [58], leading to more robust, relevant and desirable outcomes [59]. A UK Parliament POSTnote 707, [60] p. 13 states that:

"Stakeholders agree that the horticulture sector will require technological innovation, but many highlight that innovation is not a "silver bullet" to all challenges in the sector. Some argue that to tackle these issues, a systems approach will be required that considers horticultural policy alongside wider health and environmental policy".

The UK Defra Automation in Horticulture Review (2022) stated that technology alone cannot address the issues facing the sector and that a more system-level approach is required to address all the challenges that need to be overcome [61].

3.4. Summary

Automation in particular can address a labor gap and replace both low-skilled and high-skilled manual tasks. It is important to distinguish between a job role and an individual task when considering automation. Automation technologies, such as robotics and AI are designed so that for specific tasks they can replace human labor with machine input [62–64]. Rapid developments in artificial intelligence (AI) and automation technology

will potentially disrupt rural labor markets [65], but as new technologies are adopted, new opportunities for employment, exploiting different human skills, will arise [46]. Thus, innovation may displace the least well-qualified employees causing inequalities [57,66]. The impact of process innovation and product innovation on employment is complex and interconnected especially where there is a migration of low-skilled workers to undertake certain tasks [67]. Indeed [67] p. 1008 states:

“product innovation might create jobs by promoting new products or reduce jobs by replacing old products; process innovation might reduce jobs by rising productivity or create jobs by decreasing the cost of old products”.

Process innovation requires specific investment wherein innovation can either be disruptive or incremental moving in stages from manual activity to mechanization, to semi-autonomation, to full automation and then full autonomy. Robotics and the adoption of software can reduce the demand in the economy for low- and medium-skilled workers, the young and women, and raise the demand for older workers and men, especially in non-manual roles [68]. Thus, in the absence of an inclusive national, regional or local innovation strategy for addressing displaced and replaced low-skilled workers, unemployment rates may rise as technology is adopted, especially AI. As a result, highly skilled workers will disproportionately benefit from such innovation, necessitating policymakers to continually seek to deliver new employment opportunities for others [46]. AI can both negatively impact employment opportunities generally and also “augment” job roles, for example by increasing productivity, and the balance of work opportunities is the key aspect that needs to be considered [69]. They explore evidence suggesting that automation favors job roles that involve non-routine skills and that there is a “hollowing-out” of middle-skill roles. The non-routine jobs may be low-skilled, affording the opportunity for automation or replacement in the future, or may become more high-skilled, but these roles are vulnerable too to an acceleration of the application of AI to complex tasks in the future. The theoretical innovation transmission channel from AI to increased productivity and as a result a loss of employment can be absorbed within an economy that is expanding, however, an economy that is in decline, brittle or stagnant cannot absorb this transition so easily [46]. Thus [46] argues adoption of AI has far-reaching implications from transitioning employment opportunities, creating more inequality and reimagining productivity in its economic, environmental and social aspects. These factors impact the functional and structural aspects of rural resilience/decline and the development of new economic activities that have the capacity to respond to changing situations and markets through the development of social capital namely skills, capabilities, and knowledge [70]. Transformation requires change and one factor that proves a barrier to change is inertia and resistance to change and this is considered within the paper.

4. Inertia and Resistance to Change

Faced with change and uncertainty in internal (organizational) or external environments, self-renewal of organizations, or indeed whole supply chains and systems, is essential to ensure viability, resilience and growth and this requires the dissolution of existing organizational control structures and the creation of new patterns of order and control [71]. The creation of new organizational order also influences networks of power and inter-dependent factors such as institutional arrangements, work and organizational practices, staff and cultural dynamics, relationships and reinforcement processes that exist at the micro (individual), meso (business) and macro level (supply chain) simultaneously [72,73]. Indeed, organizational practices are constructed through routines and habits that inform behavior, work routines and practices. Over a period of time, inertia can become attached to work routines, leading to them becoming rigid, bound by past experience, internally resistant to change, and as a result, inertia reinforces the status quo [74–76].

Organizational inertia theory does not position that organizational change never occurs, but rather that the changes that are made reinforce inertia [76]. Indeed, organizations can have high levels of inertia either in the routines employed, in the defined rules used

to transition between routines, or within their organizational memory [74]. Organizational inertia has characteristics of sluggishness [77], stickiness [76,78]; or viscosity where information and innovations fail to flow [79]. Stickiness can be driven by the impact of previous investment in technology becoming a barrier to change and then influencing organizational willingness to implement, adapt or innovate [76]. The concept of stickiness could be extended to infrastructural aspects too where significant investment may have previously occurred (within a wider portfolio of resource allocation), and then the historic investment strategy in physical structure, or indeed within given agricultural enterprises then drives status quo and impinges on change.

Inertia can be described with respect to the structural aspects of the business (internal environment) and the external environment that are barriers to change [80]. Inertia can also be framed temporally as the speed of adjustment of an individual, organization, or supply chain relative to the environment in which it operates and the rate of change or degree of environmental turbulence in that environment [75]. This means that an organization may be deemed to have inertia in a highly turbulent environment such as a product recall scenario, whereas previously it was perceived as agile or dynamic in a less turbulent “business-as-usual” environment. In this context, change within a “business-as-usual” context, what [81] describe as incremental day-to-day adaption or *first-order change*, is completely different from *second-order change* where comprehensive, radical, high-entropy, often as a result of externally imposed, organizational change is required [77], e.g., as a result of the turbulence of the Ukraine–Russia conflict. Factors that increase inertia include forces that are resistant to change or are embedded within organizational complexity [82].

Unlocking strategy is a novel term used in this paper. Previous research has considered the unlocking of business potential, or innovation potential through new approaches and the notion of unlocking technologies [83], especially within industry 4.0 [84], and digitalization [85]. The narratives associated with the digital transformation of agriculture and horticulture position a “win-win strategy” for all stakeholders, but the digital economy as with existing food supply chains can be considered as including monopoly structures market concentration, and corporate power where the distribution of value is not equitable or just [27]. Concerns over power balance, inequality, centralized control of agri-food production systems and intellectual property (IP) issues during the disruptive transition have also been raised in other contemporary studies [49,86]. Indeed, one UK study concluded that responsible development and implementation of technology in agri-food chains cannot be achieved “without also acknowledging and addressing the power imbalances that characterize modern food systems and the actors and institutions within it” [49] p. 10.

Lock-ins are “blockages” that promote singular views and practices, to the exclusion of other alternatives, and as a result sustain, even entrench, the established trajectory [87–90]. Lock-in mechanisms support the maintenance of business-as-usual and restrict adaptation activities [91]. In technology adoption, for example, this can include the non-standardization and lack of interoperability of technology [92], or as previously described in this paper, no access to technology at all. Unlocking strategies can reduce inertia at all politico-socio-technical levels and are essential to drive economically, environmentally and socially sustainable food supply chains. In the agri-food context, the authors of [27] determined six types of lock-ins that reinforce existing power relations and farmers’ lack of agency in corporatized agro-industrial farming models: these are data, discursive, legal, systemic, soft, and technological lock-ins. These are summarized in Table 4.

Table 4. Types of lock-ins in agri-food supply chains (adapted from [27]).

Type of Lock-in	Summary Detail
Data	Data availability and accessibility. Data distribution channels. Data grabbing from farmers to service providers.
Discursive	Discursive power uses a variety of ideological strategies to shape public discourse, for example, to confer legitimacy on contested problem definitions and obtain public support for preferred solutions, i.e., preferred narratives and framings, e.g., the discourses associated with farm efficiency, sustainability of practices, etc. Discursive power can influence regulation and market standards. Discursive narratives using precision as a proxy for sustainability via the digital fix, or the technology fix drowning out other discourse.
Systemic	Institutionalized drivers through structural systems which drive end to end supply chain practice. System level drivers such as reliance on fossil fuels and artificial fertilizer, agrochemicals, etc., to deliver yield. The technological developments reinforce current systems and power dynamics.
Soft	Valorization packages can drive lock-in, e.g., linked benefits for agricultural inputs combined with use of proprietary technologies. If farmers opt-out later, they may lose services and knowledge repositories they have come to rely on. Promissory valorization that is not fulfilled in practice, but the farmers have already locked into the technology, e.g., work rates of robots.
Technological and legal	Lack of legally secured and enforceable rights over their farm data. Weak bargaining position to negotiate access to data held by big corporate actors in machinery or tech industry. Lack of interoperability. Incompatibility of systems. Lack of universal data standards. Unequal access to data infrastructure. Prescribed technologies that drive dependencies in specific systems. Technological lock-ins can drive market dominance for large players preventing new entrants.

More widely across the literature, structural inertia, a form of lock-in, has been described as either internal within organizations or external within the wider environment [74]. Structural inertia has two main aspects, namely that the factors that may have the benefit of driving resilience and survival advantage can also make the organizations resistant to change. Resistance to change can be enacted when such personal or organizational change is perceived as being risky, disrupting routine, existing competencies, organizational memory or notions of institutional legitimacy [93]. Table 5 synthesizes factors cited as driving structural inertia, which has also been described by others as forms of resistance [89].

Table 5. Factors that drive structural inertia (adapted from [74,89,94]).

Categories	Factors
Financial	Historic investment in plant, equipment, personnel. Exchange relations with external actors that will lead to financial penalties/cost if altered or cease. Industry cost structures embed inertia. Lack of funds to invest in change/innovation.
Infrastructure	Infrastructural rigidity.
Market	Lack of market incentives to overcome inertia. Vested interest in the status quo. Market barriers that prevent access and exit from different activities.
Normative	Influence of precedents (routines, habits, practices) on current standards, practices and processes. Threat to legitimacy from structural change. Existing assumptions embed inertia. Vested interest in the status quo. Regulatory barriers that prevent access and exit from different activities.
Social	Dynamics of political coalitions and loss of institutional support. Exchange relations with external actors that embed existing networks and social practice. Weak knowledge management, transfer, exchange. Vested interest in the status quo. Misaligned institutional settings, policies and incentives. Attitudes and culture that drive an aversion to change.
Technology	Lack of appropriate technology to support change/innovation. Technological persistence. Dominant research agendas, narratives and priorities.

Three elements are proposed in the literature that influence organizational inertia: insight inertia, action inertia and psychological inertia [74,95]. Godkin and Allcorn [95] p. 82, consider firstly, apathy to change and secondly, lethargy toward taking action that leads to organizational resistance and failure, and an

“inability to think ahead and anticipate or failing that to respond to internal and external demands for adaptation and change”.

Psychological inertia has been linked to farmer decision-making on investment and disinvestment, i.e., the withdrawal or reduction of an investment; adoption and disadoption and a slow response to adopting new ideas or technology [96]. Cognitive inertia, which is linked to culture and norms in work routines, technological inertia driven by pre-existing investments and subsequent challenges with interoperability between the technology used and other potential innovations; resource allocation inertia arising from previous decisions on infrastructural investment and political inertia driven by the positions taken and influence of individuals, e.g., senior management, all play an interlinked and complex role leading to resistance to change [76]. Why agri-food systems are resistant to new directions of change is a question posed in the literature [89]. The findings reveal three distinct areas of research agricultural systems, food systems and politico-socio-technical systems, and argue the following aspects influence resistance to change:

- Dominant technologies persist in crowding out better alternatives because they are reinforced by being socially embedded and alternatives may require new skills and new practices;
- Institutions and policies create misaligned regulatory and price-driven incentives that promote resistance to change;
- Dominant innovation, narratives and associated discourse embed the status quo or only incremental change pathways;
- Mindset, attitudes and cultures drive an aversion to change.

Whilst all industrial revolutions have instigated economic growth, increased productivity and social change, Industry 4.0 as the “smart revolution” is suggested to bring

significant technological change and socioeconomic impact [97]. These industrial revolutions are characterized by:

- Innovation in the use of technologies and introduction of new technologies;
- Innovation in the systems employed, i.e., the processes for organizing and financing activities;
- Innovation in the organization of labor (places and ways of working);
- Innovation in processes and operationalization of consumption [98].

Industry 4.0 has been reframed as Agriculture 4.0 in the academic literature. Agriculture 4.0 has been said to encompass gene editing, nanotechnology, synthetic foods [99], biophysical, LIDAR and light sensors, drones, geospatial characterization of farms, precision agriculture, robotics and AI, computer vision and machine learning and breeding techniques for crops and animals [49,100].

Ensuring resilience during the transition at personal, organizational and community levels is essential. Resilience, in the personal context, has been described as a coping mechanism, a learned experience, and an ability to “thrive in the face of adversity” that helps to protect against occupational stresses and mental illness [24,101]. Resilience is also:

“a dynamic process wherein individuals display positive adaptation despite experiences of significant adversity or trauma” and is not “a personality trait or an attribute of the individual” [102] p. 858.

Robustness is a different capability to resilience associated with attributes such as strength, and ensuring the entity is unlikely to break. At the farm level, robustness is the capacity of the farming business to withstand shocks and stresses [103]. However, the capacity to cope or withstand is not the sole attribute of interest here. O’Meara et al. [104] p. 100594 state that:

“resilience it is not merely about withstanding stressors and shocks but more importantly the ability to build capacity to anticipate, prevent, absorb, and adapt from these experiences”.

This suggests that the ability to adapt lies at the heart of resilience building within people and organizations especially in uncertain times. Agility underpins resilience extending beyond coping, withstanding and surviving shocks to adapting to grow and evolve, especially when faced with rapid change, volatility and uncertainty [105]. Whilst inertia and resistance to change may seem appropriate strategies to adopt, it is the ability to adapt and pivot that underpins resilience [106]. Indeed, in the face of transition and technological innovation, there are four aspects of resilience building that inform our further research questions here [105,107]. They are:

Agency—how people and organizations mitigate risks and respond to change, disruptions, and crises;

Buffering what resources people and organizations can use when faced with shocks and stressors (financial, physical, and social) [108–110];

Connectivity what infrastructural resources and the interconnection of, and communication within support networks support resilience and adaptivity;

Diversity how people and organizations use diversity strategies to underpin resilience.

In summary, when seeking to overcome barriers to the adoption of agri-technology as an innovation, factors that drive lock-in and inertia need to be considered, as well as how they specifically impact personal and community resilience.

5. Discussion

The current geopolitical and socioeconomic landscape creates a difficult and uncertain operating environment for farming and agri-food businesses. Farmers too are subject to a number of personal- (micro), organizational- (meso) and system-level factors (macro) many of which are outside their control [73]. Multiple factors have come together in recent years which have created economic, social and geopolitical uncertainty and it is in this

setting that UK agricultural and horticultural businesses are looking for solutions to create greater resilience and agility in the face of reducing environmental impact, delivering net zero and addressing the rural skills and labor deficit and produce more output. The purpose of this iterative review was to first identify the reported social, technical and systemic barriers to agri-technology adoption and to consider whether the discourse around rural development/rural decline is itself a barrier to technology adoption. The work has also identified potential research gaps that highlight areas for future research and inform key research questions that can be addressed by future empirical studies. The social context of rural communities, globally, but specifically in the UK outlines high levels of mental stress, long work hours, and seeking to operationalize business activities when many factors of influence are outside their control. Coping strategies have been explored. Seventeen factors have been shown to be of influence. Factors external to the farm include economic conditions, external conditions including bureaucracy, market conditions, weather uncertainty and the narratives about farmers. Those factors internal to the farm business that may be of influence include farming conditions, employee relations, general finance, technology and time pressures. Personal factors identified include living conditions, personal finances, physical health, role conflict, social isolation and social pressure. These factors can influence farmers and farming businesses either singularly, or in combination. These findings address the first research question outlined in the introduction.

Innovating through agri-technology adoption in an uncertain world is disrupted by some key infrastructural factors such as lack of access to rural digital infrastructure, and system-level characteristics such as rural isolation and decline, regional shrinkage, loss of rural facilities and support networks and the loss of human capital through the hollowing out of rural communities with migration to urban locations where it is perceived that there are greater work and life opportunities [33]. Rural gentrification has also led to contested visions of what rural life is, and as house prices rise compared to the salaries of local jobs there is an enacting of spatial displacement and social exclusion. The UK has relied on transient migrant labor to fill the gap in skills and labor within agri-food economies, but there is an emergent discourse that migrant and local labor can be replaced and displaced by technological solutions such as artificial intelligence and autonomous harvesting machines. The discourse around rural development/rural decline, loss of direct subsidies post Brexit in the UK, or a lack of personal and business opportunities in rural economies can influence decisions for investment or disinvestment, adoption or disadoption and pressures of exclusion. A particular narrative has emerged around “finding a silver bullet” to address multiple aspects of the uncertainty and contestation of the meeting of the agricultural system, the food system and the politico-socio-technical system. However, the ability to find a single technological fix has been refuted [60,61].

Inertia and lock-in and the need for unlocking strategies have been explored in this paper and the need to develop “win-win” strategies through reducing power imbalances, leading to exclusion and inequality of opportunity. Five types of lock-ins have been considered in the context of agri-food supply chains: data lock-in, discursive lock-in, systemic lock-in, soft lock-in and technological and legal lock-in [27]. Specific unlocking strategies need to be designed and implemented to address structural inertia connected with financial, infrastructural, market, normative, social and technology dimensions. Unlocking strategies also need to address cognitive inertia associated with culture, norms, practices and routines especially where they impact negatively creating resistance to change that is needed to unlock inclusive innovation, resilience and adaptive capacity.

This study has highlighted a number of research gaps worthy of further exploration. Using Miles’s typology [111], the following research gaps are noted:

- *Knowledge gap*—there is a void in the extant literature with regard to how the socio-technical and infrastructural barriers cited interact to prevent agri-technology adoption.
- *Methodological gap*—developing an understanding of how new methodological approaches can generate new insights and understandings in the context of the barriers to agri-technology adoption.

- *Empirical gap*—there is a lack of empirical evidence that provides research findings that have been empirically validated and verified.
- *Theoretical gap*—there is a lack of theoretical framing of the barriers to agri-technology adoption and their interconnection.
- *Population gap*—there are multiple farming populations that are under-researched leading to a lack of evidence base in the UK context.

These research gaps can inform the direction of future research. The limitations of this work are that although 104 papers underpin the narrative and argument within this paper, within each individual section of the paper the evidence base that was synthesized was not extensive. However, this paper serves to draw together a number of themes and positions future research opportunities.

6. Conclusions

The purpose of this research was to first identify the reported social, technical and systemic barriers to agri-technology adoption and potential research gaps that highlight areas for future research and inform key research questions that can be addressed by future empirical studies. The nature of the context and the research gaps means that an interdisciplinary research approach is required with researchers from disciplines such as agri-technology, agriculture and food supply, and social and psychological sciences. Three research questions arise for future research with given populations and contexts (types of farming enterprise, nature of the technology to be adopted, etc.):

RQ1. What social, technical and systemic factors internal and external to a farming business promote inertia and lock-in and prevent technology adoption?

RQ2. What interventions and strategies will enable agri-technology adoption in given agri-food supply and farming contexts?

RQ3. What interventions and strategies can be adopted, so individuals, organizations and rural communities can become more resilient, adaptive, and capable of facing socio-economic and geo-political challenges and maintaining positive, enabling connections and relationships?

Future research is now being planned to explore these questions in a specific geographic location in the UK and the research findings will inform future policy and methodological approaches.

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