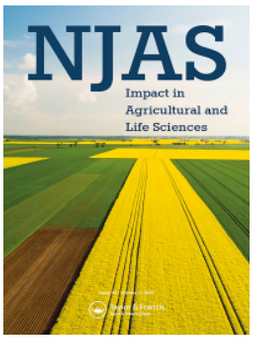

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Cultivating a bioeconomy: Risks, collaboration, and partnerships in agricultural innovation

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ABSTRACT

Threats associated with a changing climate elevate our collective need to reduce greenhouse gas emissions. Airlines are committed to reduce emissions by transitioning to sustainable aviation fuel. To build a thriving domestic bioeconomy, United States (US) federal agencies are promoting public–private partnerships (PPPs) to link public universities with industries to support local feedstock development and commercialization. Using an Agricultural Innovation Systems (AIS) framework, we explore a PPP in the Southeast US that aims to support the production of a regional biofuel feedstock, *Brassica carinata*. Utilizing a two-phased qualitative methodology, we analyse the kinds of risk posed to public and private actors in the partnership. The study highlights the reputational, commercial, and mission-related risks posed to actors engaged in innovation systems. In doing so, we offer a discussion of risks and their implications for PPPs, AIS, and future food systems.

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KEYWORDS Public–private partnerships; agricultural innovation systems; extension; innovation facilitators; risk

1. Introduction

Threats associated with a changing climate elevate our collective need to reduce greenhouse gas emissions (IPCC Intergovernmental Panel on Climate Change, 2023). As a pathway to reducing emissions, a key goal for federal agencies in the United States (US) is to develop and promote a domestic bioeconomy. Harnessing the power of the bioeconomy is envisioned to bring societal good, promoting climate change solutions, resilient supply chains, human health, and food and agricultural innovation (White House, The, 2023). The US Department of Agriculture (USDA) is focused on promoting production systems that emphasize biomass to be utilized as dedicated feedstocks

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for biomanufacturing, such as bioplastics, building materials, and biofuels (USDA United States Department of Agriculture, 2024). This view of the bioeconomy reflects a bio-resource vision, where the aim is to grow the economy by creating value in development and processing of bio-resources (Bugge et al., 2019). As a result, there are calls for airlines to adopt Sustainable Aviation Fuel (SAF), especially as opportunities for locally produced low-cost dedicated biofuel feedstocks become more readily available (EERE Office of Energy Efficiency and Renewable Energy, 2022). Continuing research, development, and demonstration of these biofuel feedstocks is a necessary component to support their emergence and local suitability (USDA United States Department of Agriculture, 2024).

El-Chichakli et al. (2016) note that knowledge transfer is a cornerstone of developing bioeconomies, and in the context of agricultural production systems this could mean increased involvement of agricultural advisory services, such as the cooperative extension system,[1] private crop consultants, and agricultural research institutions. Indeed, producing sufficient biomass to support the uptake of SAF will require support from both the public and private sectors (EERE Office of Energy Efficiency and Renewable Energy, 2022). Public–private partnerships (PPPs) are uniquely positioned to leverage the strengths of both public and private sectors while ensuring mutually added valued for each (Klijn & Teisman, 2003). Of particular interest to our study is a deeper understanding of the kinds of risks that are experienced by the different stakeholder groups in PPPs tasked with agricultural innovation.

In this paper, we utilize an Agricultural Innovation Systems (AIS) framework to explore a research- and development-oriented PPP deploying an innovative biofuel crop in the Southeast US: *Brassica carinata* (henceforth carinata). An AIS approach acts as an analytical framework to explore the innovation system supporting the emergence of alternative and novel agricultural technologies (Hall, 2006; Klerkx, 2023). Utilizing a two-phased, mixed methods approach, our study investigates the risks posed to four stakeholder groups in a PPP and how those risks affect collaboration and innovation capacity. As such, our research questions are:

(1) What risks did participants face when engaging with the SPARC program?
(2) How did these risks influence collaboration?

[1]The cooperative extension system is an outreach and educational institution based out of land-grant universities in every US state (Franz & Townson, 2008). There are over 3000 local cooperative extension offices, and they share the mission to improve the lives of communities through delivering research-based outreach (Franz & Townson, 2008).

2. Agricultural innovation systems

Agricultural Innovation Systems (AIS) provides both an analytical framework to explore agricultural innovations and how they emerge in addition to understanding the ways to strengthen innovation capacity of a system (Hall, 2006). Rajalahti et al. (2008) define an innovation system as a network that brings forth new products or processes that are accompanied by new knowledge. Early AIS explored linear models, such as transfer of technology, while more recent studies instead focus on the complexity embedded into the multi-actor and multi-institutional arrangements tasked with innovation (Klerkx, 2023). Innovation systems are described as complex adaptive systems, thereby they are not fully steerable and are subject to change due to the influences of outside factors (Klerkx et al., 2010). Furthermore, there is increasing attention to the transformation of food systems as we face what some scholars call a "fourth agricultural revolution" one fuelled by the roles of digital technologies and novel food production systems (Klerkx, 2023). A core tenet of this frontier is the role of the energy sector and the bioeconomy in food systems (Klerkx, 2020).

Hekkert et al. (2007) and Hermans et al. (2019) illustrate how interconnected processes, formed by linked functions, outline how innovation occurs in iterative loops. They note seven distinct functions embedded in AIS: entrepreneurial activities, knowledge development, network formation and knowledge diffusion, guidance of search (i.e. technology selection), market formation, resource mobilization, and support for advocacy coalitions (Hekkert et al., 2007; Hermans et al., 2019). These functions may be arranged and linked in different ways depending on the "innovation motor" driving the system (Hermans et al., 2019). Interestingly, while this framework highlights the processes necessary to develop innovation, it obscures the actors tasked with doing so.

Strategic actors embedded within AIS that support adaptive management and learning, such as knowledge brokers and innovation facilitators, is a key area of study. For example, dedicated facilitators may utilize reflexive monitoring to (re)configure networks, capacities, and resources, as necessary, to respond to changing contexts (Turner et al., 2017). A critical voice for knowledge brokering and innovation facilitation in the agricultural sector are extension agents, who not only communicate research to producers but also may enhance dialogue between researchers and producers (Klerkx et al., 2012). Within AIS, extension is described as a bridging institution, linking farmers to markets or providing access to expertise (Rivera & Rasheed Sulaiman, 2009). Other scholars point to extension's capacity to connect institutions, producers, and other stakeholders in service of rural development (Siankwilimba et al., 2023). Furthermore, extension is frequently seen as a key partner to facilitation adaptation planning with producers on

topics such as climate change (Monroe et al., 2020). In the Southeast US, extension professionals are highly valued agricultural advisors who have deep roots in agricultural innovation programming. For example, research on biofuel innovation systems in the Southeast US indicates extension as a primary source of production information for farmers (Christ et al., 2020). Finally, success of innovation systems has been tied to alignment between people and disciplines within the system (Andrew & Sirkin, 2008). It is no surprise that scepticism has been reported regarding involving private sector actors into extension programming and may be due to extension specialists' credence and credibility based on their perception as objective purveyors of information (Krell et al., 2016).

2.1. Public–private partnerships as innovation mechanisms

Hall (2006) calls for embedding PPPs into innovation frameworks to highlight the role of public research institutions in supporting innovation development and deployment. Scholars posit that private-sector engagement promotes more effective resource utilization (Mukherjee & Maity, 2015); better market penetration (Fanzo & McLaren, 2020); and access to private intellectual property for public-good research (Hall, 2006). Critically, PPPs have been utilized to promote agricultural technology (Eastwood et al., 2017; Spielman et al., 2010) and support agricultural extension services (Mukherjee & Maity, 2015).

Indeed, PPPs have been implemented in agricultural systems for several decades. Early calls for private sector engagement into research and development stemmed from feeding a growing population and alleviating rural poverty (James, 1996). The role of PPPs in agriculture has since broadened, and so too have the benefits they can facilitate. For example, PPPs have been described as drivers of modernization in the agricultural sector and as promoters of sustainable agricultural development (Bruce & Costa, 2019). PPPs seek to engage private sector actors in activities that generate public good (Hermans et al., 2019), usually where both sectors work in tandem towards a shared goal with mutually added value (Klijn & Teisman, 2003). Some benefits of doing so may include moving public research into the marketplace (Spielman et al., 2010), developing frontier areas of science (Hall, 2006), and development and diffusion of technologies (Eastwood et al., 2017). However, other scholars find that PPPs for agricultural innovation still follow traditional transfer of technologies pathways between agricultural extension and farmers (Akullo et al., 2018).

2.2. Transforming food systems and risk

In recent years, a focal point of AIS research has been food system transformations, particularly how agriculture intersects with other sectors such as

energy or urban planning (Klerkx, 2023). Emerging frameworks explore power dynamics within innovation systems, the role of both human and non-human agents, and boundary crossing (Pigford et al., 2018). For example, Mission-oriented AIS seeks to understand how transformational change occurs in the agricultural sector, such as agroecology, introduction of digital technologies, or the bioeconomy (Klerkx, 2020). The inclusion of missions highlights the direction, assumption, or policy that is driving the innovation system (Klerkx & Begemann, 2020; Mazzucato, 2016).

Although these new directions derive fruitful insight into how agricultural innovation occurs within complex innovation systems, few scholars are examining the role of risks to the actors tasked with designing and facilitating innovation. Indeed, risk allocation and sharing are key indicators of success in PPPs and therefore projects must carefully manage them (Osei-Kyei & Chan, 2015). Spielman and von Grebmer (2006) provide some guidance. In their case study of CGIAR (formerly the Consultive Group for International Agricultural Research) PPPs, they state the primary risk to public and private partners arises from misuse of intellectual property. Further, in the same study, they indicate many respondents described reputational liability for public institutions who associate with multinational firms or controversial technologies (Spielman and von Grebmer 2006). In this paper, build upon the work of Spielman and von Grebmer (2006) by bringing the focus on risk to current frameworks of AIS and PPPs in the context of bioeconomies in the Southeast US.

3. Methods

3.1. Study context

Our study explores the Southeast Partnership for Advanced Renewables from Carinata (SPARC), a PPP with the mission of supporting the US bioeconomy. The partnership, funded by the USDA National Institute of Food and Agricultural (NIFA), links academia and industry partners to support research, development, and commercialization of carinata (George et al., 2021). SPARC is one of ten regional bioenergy grants awarded to develop regionally specific non-food dedicated feedstocks in conjunction with industry (NIFA (National Institute of Food and Agriculture), n.d.; IPREFER (Integrated Pennycress Research Enabling Farm & Energy Resilience), n.d.).

Carinata is a non-food oilseed and dedicated feedstock for producing renewable jetfuel, biodiesel, and other bioproducts (Seepaul et al., 2023). The crop is seen by researchers and industry alike as an opportunity for Southeastern US farmers to adopt a cash-based winter crop that offers similar soil health benefits and ecosystem services as traditional cover crops, such as rye (Christ et al., 2020; Seepaul et al., 2023). The offtake of carinata is seen to

Table 1. SPARC network composition as of 2022 (reproduced from Rigsby and Bartels forthcoming).

	Participants	Percentage
Public Sector	**55**	**81%**
University of Florida	24	35%
University of Georgia	7	10%
North Carolina State University	7	10%
University of South Florida	3	4%
Auburn University	3	4%
Other Universities	2	3%
USDA National Institute of Food and Agriculture	3	4%
USDA Applied Research Service	4	6%
Other Government Offices	2	3%
Private Sector	**13**	**19%**
Seed Developer	7	10%
Engineering Firm	2	3%
End-user Representatives	4	6%
Total	**68**	**100%**

have potential downstream effects, including the development of industrial infrastructure (i.e. biorefineries), and potentially revitalize rural economies (private conversation with USDA representative, 2023). As of 2024, carinata is commercially produced in Argentina and the southeast US.

SPARC focuses on research, development, and demonstration of carinata in the aim to support crop commercialization across the Southeast US. The public partners that make up the consortium include land-grant institutions and cooperative extension representing the states of Alabama, Georgia, Florida, Mississippi, North Carolina, and South Carolina; in addition to federal government administrators and researchers. Meanwhile, the private partners were composed of the seed developer, engineering firm, and airline representatives. Table 1 provides an overview of group composition.

Table 2. SPARC workstreams and objectives (adapted from George et al., 2021).

Workstream	Objective
Feedstock development, risk management, and decision-support	Generate feedstock in the SE US using superior, high-yielding carinata genotypes and mest management practices.
Meal efficiency	Evaluate carinata seed protein as an animal feed supplement and source of bioproducts
Fuels and coproducts	Demonstrate conversion of carinata oil to SAF, biodiesel, renewable diesel and other coproducts
System metrics and modeling	Conduct a systems-level life cycle analysis integrated with a techno-economic analysis
Supply chain, commercialization, and policy engagement	Demonstrate commercialization potential by leveraging existing industry partnerships
Extension	Through outreach programs, develop and implement processes to ensure that all stakeholders realize value
Education and workforce development	Provide education for K-12, undergraduate, and graduate students and prepare the bioenergy workforce of the future

To avoid siloed work and foster integration, the project is structured into eight boundary-spanning teams, called workstreams, which convene subject-matter experts. Each workstream examines a different expertise area, such as feedstock development, co-product development, and animal meal efficiency (George et al., 2021). Table 2 outlines the eight workstreams and their specific objectives. Collaboration was structured around monthly workstream-specific planning meetings, quarterly cross-workstream meetings, and an annual summit.

The project was active from 2017 to 2022 and received an additional 3 years of funding. Project membership changed over time with group composition peaking at 100 active participants and a regular core group of roughly 40 individuals. Most SPARC participants were from public institutions, approximately 80%, and of those most were researchers. SPARC engaged more regional extension specialists as compared with county and regional agents. Very few farmers participated aside from invited speakers for panels at annual meetings or at grower field days.

3.2. Data collection and analysis

Qualitative data for this study was collected between September 2022 and March 2023 over two phases: semi-structured interviews ($n = 13$) and an online survey ($n = 39$). In the first phase, the authors categorized SPARC participants into four stakeholder groups: agricultural extension agents, university researchers, industry professionals, and government actors.

3.2.1. Phase 1: Semi-structured interviews (n = 13)

Semi-structured interviews were conducted with three to four key actors from each group to capture the range of perspectives held by the different groups. Interviews lasted between 60 and 120 minutes. Eleven interviews were conducted over Zoom, one conducted over phone and another in-person. The interviews explored four themes, including group composition, roles, trust, and risks, the latter topic being the focus of this paper. During interviews, key informants were asked about the risks related to participating in SPARC, how those risks manifested, and how they affected collaboration. Responses were then used to develop eight statements about risk that were evaluated in the survey as part of phase two of this study.

All quotes derived from the semi-structured interviews have a code number, date, and retrieval tool. A thematic analysis was conducted by coding transcribed interviews (Bernard et al., 2016). Examples of codes include “risk”, “threat”, and “collaboration”.

3.2.2. Phase 2: Survey (n = 39)

In phase two, an online survey was distributed to 68 active members of the SPARC team. Survey respondents were asked to evaluate the risk statements generated from semi-structured interviews on a five-point Likert-scale from strongly agree to strongly disagree. Our survey response rate was 57% with 39 respondents (of $n = 68$). Institutional affiliation was captured to delineate the perspectives of different populations. These data were analysed using descriptive statistics and are visualized as frequency charts in the results. The study was IRB reviewed and received an exempt status (IRB201701894).

3.3. Study limitations

The results of our study are not generalizable across the study populations due to a small sample size. Therefore, perspectives associated with stakeholder groups should not be considered representative of all members of those populations.

4. Results

4.1. Risks present in SPARC (RQ1)

When discussing whether participants faced risks when collaborating in SPARC, key informants articulated three principal types of risk: reputational, commercial, and mission-related risk. While not every key informant identified a type of risk for each stakeholder group in SPARC, their responses illustrate the different types of risk incurred by each stakeholder group. For example, when asked whether there was any risk to participating in a project like SPARC, one agricultural advisor linked extension to the risk of losing one's credibility with their clients:

> I think of extension … the relationships that they have with their growers are really important … It's a risk for them because it could affect their livelihoods if a producer says, "I'm not going to use you anymore because you led me astray" … and they[extension] don't want to do anything to affect that relationship. (EX3, November 7, 2022, via Zoom)

The participant quoted above emphasizes how different stakeholder groups might face specific types of risk. In the case of extension, these professionals may be concerned about possibly harming relationships with producers. Table 3, below, outlines the types of risk, affected groups, frequency, and characteristics found in this study. In the next subsections, we provide exemplary quotes to explore how these types of risk were characterized by study participants.

Table 3. Risk types as described by key informants in semi-structured interviews.

Risk type	Affected groups	Reported by Key Informants (n = 13)	How risks are characterized by informants
Reputational	Agricultural Advisors & Extension Agents	46% (*n* = 6)	Reduced credibility, loss of grower relationships, perception of bias due to association
	University Researchers	31% (*n* = 4)	Perception of bias due to association
Commercial	Industry	69% (*n* = 9)	Release of competition sensitive information/lack of competitiveness, miscommunication of data
	Producers	15% (*n* = 2)	Unable to yield a profit
Mission related	Government Funding Agencies	38% (*n* = 5)	Unable to fund future projects
	University Researchers	15% (*n* = 2)	Unable to publish certain data, unable to publish in a timely manner

4.1.1. Reputational risk

Key informants expressed that reputational risk was most associated with extension agents and, to a lesser extent, researchers. The reputational risk that extension professionals face stems from their relationship with growers, who rely on them as their primary agronomic advisors. One government representative framed extension's risk around their credibility from the perspective of farmers, and highlighted the importance of their engagement:

> It's all about the credibility, and [extension is] in the front-line hot seat right there. At the end of the day, those are the guys that are going to make it or break [carinata], because that is a very diverse audience you have to interact in between. The farmers have a certain culture and a way of doing things, and corporate America has their own culture and way of doing things, and to be able to build a bridge and successfully walk that bridge between the two is where extension is. (GV3, Feb 9, 2023, via Zoom)

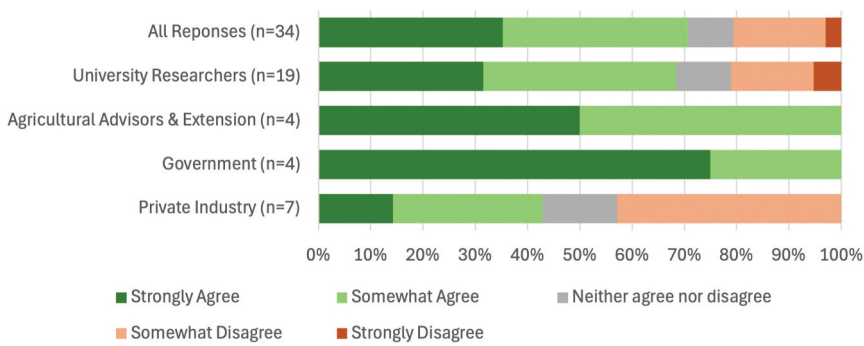

Figure 1. Agricultural advisors risked their credibility and reputation with growers when they promoted carinata during SPARC.

The key informant above highlights the complex role that extension plays in facilitating carinata adoption. These individuals are called to both support farmers' interests and align with the corporate commercial goals embedded in the project. Survey results further illuminate the reputational risk that agricultural advisors and extension agents experience. Figure 1 outlines survey responses, segmented by affiliation, to the prompt "Agricultural advisors risked their credibility and reputation with growers when they promoted carinata during SPARC". Notably, 63% of survey respondents agreed with the statements, including all agricultural advisors and extension respondents. However, many private industry respondents were in disagreement, suggesting contention around reputational risk posed to agricultural advisors.

Reputational risk is also associated with academic researchers, linked to their scholarly credibility. Researchers indicated that connections with industry could be perceived as influencing or biasing research data. One academic stated, "It [the project] puts academics and extension … in kind of a tight situation. It is great having the industry partner, but, because of that, there's always this perception of: Are we promoting [named industry partner]?" (UR1, 28 September 2023, via Zoom). Here, the key informant weighs the potential benefits and detriments of collaborating with an industry partner. They emphasize that the partnership helped secure government funding but may have come at the cost of potentially appearing biased when supporting a specific product.

4.1.2. Commercial risk

Key informants associated commercial risk to industry actors and growers. Generally, this risk was conceptualized by participants as a threat to profits for private industry, specifically those who own intellectual property. This is how one industry representative articulated it:

> [industry partner named] has to protect their commercial position. That's what we do. We're not a nonprofit organization, we are for profit, so we have to protect our commercial interest. So, if there is anything that could jeopardize that then that would raise a flag. (IR2, Oct 24, 2023, via Zoom)

Other key informants spoke of specific ways in which this type of risk could manifest, such as through the loss or misuse of intellectual property (i.e. seed germplasm or chemical processes) that could threaten the commercial partners and hurt their profits. For example, "I think the other major element of risk is people being concerned about intellectual property escaping the project somehow, or someone on the project being able to take advantage of that in some way. And that clearly can happen in these kinds of projects" (PI3, 9 November 2022, via Zoom). Additionally, industry participants identified commecial risk stemming

how different stakeholder groups disseminated information, deemed as competition-sensitive:

> I see some of the biggest risk where different organizations have different opinions on communicating to growers. Somebody within extension or the universities talking about grower information stuff, they're not working with the processors, or know where the end product goes, and then nitpick verbiage when walking growers through the contracts. That's the biggest risk, maybe something getting discussed wrong. And it goes both ways. (PI1, October 21, 2022, via Zoom)

This quote illustrates how misalignment between parties may influence the commercial risk posed to industry's commercial position and competition-sensitive information.

The potential commercial risk is echoed by survey findings, where participants identify threats to intellectual property as a risk to industry partners. Survey respondents were asked to evaluate the statement (see Figure 2): "Threats to intellectual property posed a risk to industry partners", to which 40% disagreed, 33% agreed, and 26% neither agreed nor disagreed, with no discernible pattern across stakeholder groups.

Further, commercial risk is also associated with producers who may face financial risks cultivating carinata in a relatively new geography. When acting as early adopters, farmers may lose money due to poor yields or disease pressure. Figure 3, below, illustrates respondents' high levels agreement regarding the financial risk posed to growers.

4.1.3. Mission-related risk

Key informants articulated risks related to stakeholder groups' capacity to fulfill its mission. Two missions were described by key informants in interviews: the government's mission to fund projects and academia's mission to developing public repositories of knowledge. On the government's side, informants suggested that if integrity was lost and the project dissolved, it

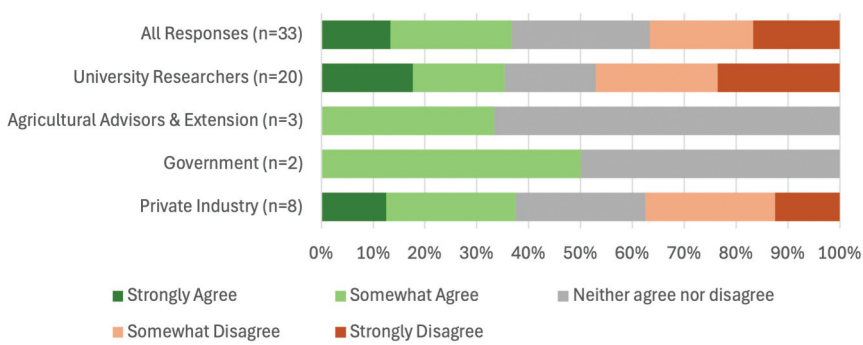

Figure 2. Threats to intellectual property posed a risk to industry partners in SPARC.

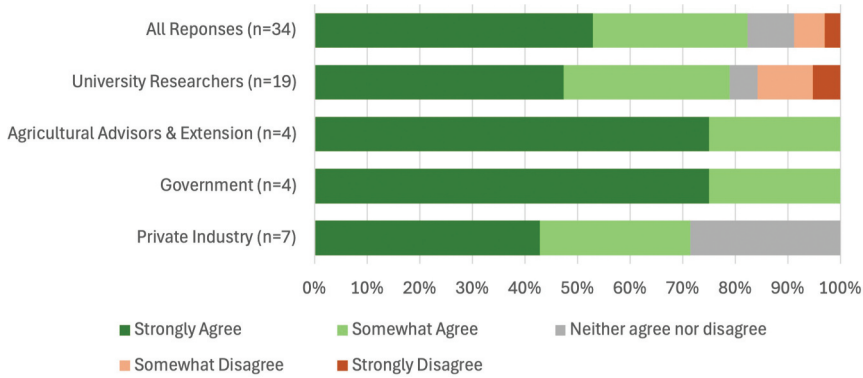

Figure 3. Producers may have faced financial risks when they pioneered carinata expansions on their properties during SPARC.

would impact the funder's ability to provide future grants for similar projects. As one informant stated, "I mean the risk is, if one of these initial [projects] like SPARC was not successful, the funding would have been reduced or eliminated immediately. We would never have an opportunity for this in agriculture and in development … That was a huge risk that was taken" (GV3, 9 February 2023, via Zoom). This quote reflects the informants' perception of the broader significance for future funding of other similar projects by the USDA. Building on this finding, survey respondents were asked "If a public-private partnership (like SPARC) were to fail, it would impact the government's ability to offer similar funding opportunities (like CAP and AFRI) in the future", see Figure 4. When disaggregating the sample by affiliation, private industry and university researchers' responses do not closely align with the government, suggesting their belief that failure would not impact future

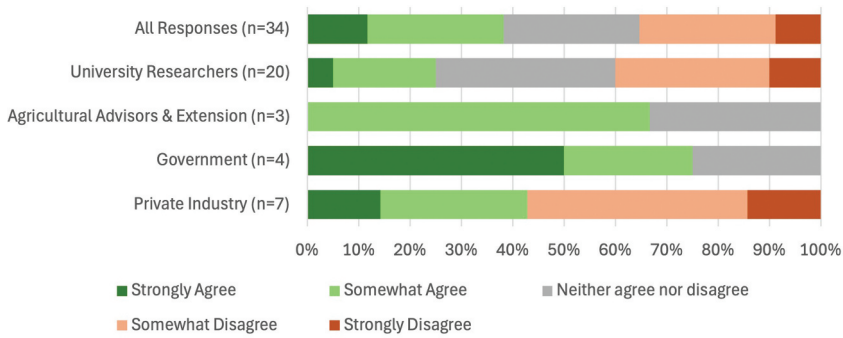

Figure 4. If a public–private partnership (like SPARC) were to fail, it would impact the government's ability to offer similar funding opportunities (like CAP & AFRI) in the future.

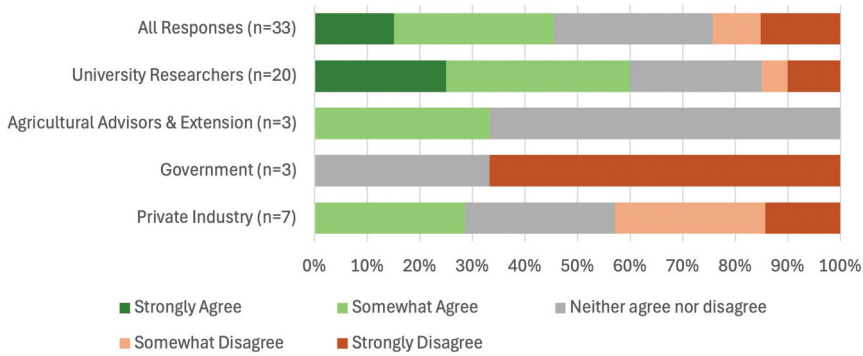

Figure 5. Working with a private corporation constrained academic information sharing in SPARC.

grant opportunities. Meanwhile, 75% of government respondents either strongly or somewhat agreed with the statement, suggesting government actors may perceive it to be a greater risk to their participation than others surveyed.

Moreover, academic actors also discussed facing mission-related risks through their participation in SPARC. Specifically, when working on the project, there was a perceived risk associated with information access and sharing, as described by this academic, "Academia is here to develop new knowledge, and the only way they get credit is by publishing their work and open public access. Working with industry, you are constrained. So, there was risk in whether their work would be for nothing, so we had to mitigate that risk" (UR2, 13 October 2023, via Zoom). Other key informants spoke of similar tensions, often unsure on how to navigate industry partner expectations with research and educational goals. Survey results echo these tensions, as university researchers identify information sharing in SPARC as a constraint. Figure 5, below, illustrates how 60% of university researchers either somewhat agreed or strongly agreed with the prompt: "Working with a private corporation constrained academic information sharing in SPARC." Government and industry respondents, however, were not in agreement with university researchers.

4.2. How risk influences collaboration (RQ2)

In addition to identifying the types of risk present in SPARC, we explored how those risks may influence participation in the partnership. Findings indicate that these types of risk can act as an opportunity to collaboration. Although the previous section highlighted how types of risk created

constraints, key informants perceived risk mitigation as an opportunity for partnering, stating:

> Risk generates fear. In human psychology, fear is both an impediment and an opportunity . . . It incentivizes us to get together with others to minimize the risk. We can benefit from that. But at the same time, if something represents a higher risk to one of the stakeholders it puts that stakeholder under a different set of stressors. That may affect the interest and willingness to continue participation or perhaps reduce or increase their involvement. (UR3, Oct 18, 2022, via Zoom)

Building on the construction of risk as both an opportunity and a limitation, survey participants were asked to rate the statement "The need to overcome risks created the opportunity for better collaboration among stakeholder groups in SPARC" (see Figure 6). Survey participants concur, with 84% of project participants either strongly or somewhat agreeing to the statement.

Opportunities were framed by participants as emerging from the project partners' various goals. For instance, one agricultural advisor discussed how different groups articulated goals and success: researchers aim for successful plantings for research purposes, extension desires their farmers to see on-farm success, industry wants to generate intellectual property value, and the government wants to incentivize local biofuel production. Once risk is taken on by participants, some key informants identify the fear of failure as a crucial incentive for collaboration. At one point in the interview, a key informant

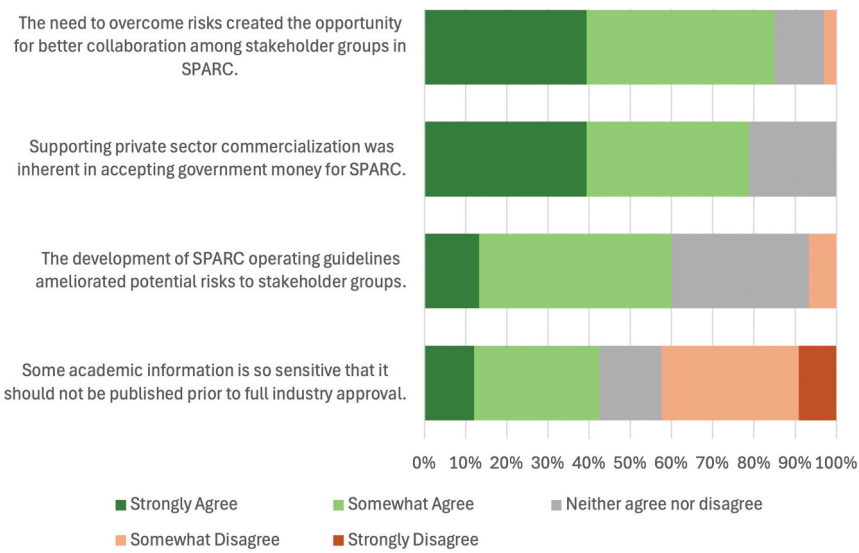

Figure 6. Likert-scale evaluation of factors influencing risk.

stated, "Once production starts, the fear and level of risk is going to actually help collaborations work better because everyone wants it to work, especially when you have investments that have been made and seed in the ground. I predict there could be a synergy with collaboration just to ensure success" (EX3, 7 November 2022, via Zoom). This key informant suggests that by bringing the various parties together under the program, there is a multidimensional vested interest in the success of the partnership.

Despite characterizing risk as a driver for better collaboration, participants mention the challenges when navigating expectations between the communication of research data and promotion of privately held intellectually property. Communication of data, as one informant suggests, may be a key point of friction:

> Researchers . . . simply want to report the facts and that gets you into an area of sensitivity. Maybe that is another risk: people being more truthful than another partner wants them to be. It's not a risk of giving away intellectual property, it's the risk of communicating too much before its time, right?. . . A lot of university researchers lose sight of the need to be proprietary . . . and that can create friction. (PI3, November 9, 2022, via Zoom)

A critical element that came out this friction surrounding information management was including private sector partners in the review process for academic publications. Doing so provided the private partners with an opportunity to protect competition-sensitive information from being released. As a result, some academics felt it compromised research integrity. When asked to evaluate of the statement: "Some academic information is so sensitive that it should not be published prior to full industry approval" half of university researchers either strongly or somewhat disagreed, while over two-thirds of industry respondents strongly or somewhat agreed, further highlighting the diverging perceptions on information sharing, review, and publishing.

This friction born out of the risks posed needed to be appropriately managed. Describing the mitigation of risks, one survey respondent wrote, "I thought the team did a reasonable job identifying and mitigating competing forces. . . Clarifying goals and scope helped to understand where parties could address risk or develop different approaches to managing teams and information" (SR41 via Qualtrics). For example, during meetings, facilitators engaged participants in vision-setting activities to develop clearcut goals and objectives for each year. These vision-setting activities also allowed for participants to provide input and clarify roles in project programming.

In addition to clarifying goals and scope, the project also utilized institutional mechanisms, such as operational guidelines, to manage expectations and promote collaboration among project participants:

> The first step we took was setting up an operating guideline . . . Because [SPARC] was a transdisciplinary project, people were taking data from each other which risks people writing papers without giving due acknowledgment. So, we set up that operating guideline where transparency, authorship, communication, conflict resolution—all of those pieces were written into that operating guideline very clearly. (UR2, October 13, 2022, via Zoom)

Survey responses support the importance of operational guidelines, with 60% of respondents either strongly or somewhat agreed with the statement: "The development of SPARC operating guidelines ameliorated potential risks to stakeholder groups" (see Figure 6). Findings also indicate that academic researchers were not opposed to working in constrained conditions with industry so long as certain conditions were met, illustrated by this statement:

> Openly recognizing the inherent differences in how private industry & university programs utilize and distribute information allowed the development of mutually acceptable protocols for dealing with the information in SPARC. As a university participant, I can accept the need to delay release of some information, as long as this is not misleading or substantially increasing the risk to the production agriculture clientele (service industry & producers) served by extension. (SR4, via Qualtrics)

This academic informant prioritizes the ethical commitment to generate information that will support extension's role and agricultural production down the line.

Despite the attempts to manage risks for project partners, not all risks are equally avoidable and, therefore, the unmitigated risks impact some stakeholder groups' willingness to participate in the project more than others. In the case of extension professionals and academics, reputational risk presents multiple challenges. For example, early in the project, a misalignment surrounding the appropriate planting date had significant consequences for crop development and damaged the credibility of county-level extension agents who vouched for the crop. A survey respondent from extension highlights how the dismissal of scientific data impacted their reputation:

> Extension's role at the county-level was to help farmers grow the crop and make sound decisions. The crop was consistently stated to need planted during the first two weeks of November, yet year after year the [previous industry partner] approved growers or contracts for late plantings . . . This resulted in poor yields which alienated farmers and also hurt extension's reputation of making sound recommendations for their farms. (SR36 via Qualtrics)

Not only is extension's reputation at stake, but so are the investments made by farmers who followed said recommendations. Ultimately, this may dissuade some potential collaborators from similar projects. One extension agent in our study indicated as such, highlighting their

resistance to supporting programming that does not have clear benefits for farming communities:

> I don't want to leave the farmer in a bad area. I don't want them to lose money. I see these men more than [industry partner] and the specialist will ever see them. So, I think that's where we might be a little bit more concerned is that we have a more personal relationship. I'm not going to lead a farmer into a bad time. I'm here to try to bring them good stuff. (EX2, November 3, 2022, via Zoom)

These data highlight the multi-dimensional dynamics of risk and collaboration in the context of developing PPPs for agricultural research, development, and innovation.

5. Discussion

5.1. Reputational, commercial, and mission-related risks (RQ1)

Our findings indicate there are three risk types present in the SPARC case study, articulated as reputational, commercial, and mission-related risks. The way in which participants characterize reputational and commercial risks align with the work of Spielman and von Grebmer (2006) who describe salient risks as the threat of misuse of privately held intellectual property (commercial) and reduced credibility due to association with the private sector (reputational). Respondents articulated similar concerns in our study, with reputational risk being referenced most frequently, unlike Spielman and von Grebmer (2006) who identify a primary risk as commercial. We suggest that the more public leaning group composition in SPARC led to elevated reputational risk. Our findings also expand on the characterization of reputational risk. Although Spielman and von Grebmer (2006) contend that reputational risk emerges from association with the private sector, our study provides additional nuance to the case of extension's reputational risk. This risk was not solely due to association but also borne out of the liability associated with providing bad agronomic recommendations to their clientele, either due to a perception of premature or potentially misleading data from the project and diminishing their status as objective purveyors of information (Krell et al., 2016).

Our study identifies a third risk type: mission-related risk. Although reputational and commercial risk were aligned with Spielman and von Grebmer conceptualizations (2006), a third theme emerged in the ways participants described the risk to fulfil their different institutional missions. This risk was most associated with academics whose mission was to develop a public repository of knowledge and the government's mission to continue funding these biofuel initiatives. In this way, our paper extends Spielman's and von

Grebmer's (2006) risk types by both broadening them to include mission-related and deepening understandings of reputational risk.

5.2. Risks, partnerships, and collaboration (RQ2)

We concur with Spielman and von Grebmer (2006) and Fanzo et al. (2021) that risk can hinder the delivery of PPP objectives. Our findings suggest that reputational and mission-relate risks can hamper collaboration by limiting participation (in the case of extension) and reducing publishing capacity (in the case of academia). Our results also suggest that risks can be mitigated with appropriate mechanisms. For example, operational guidelines and one-on-one conflict resolution were cited as mechanisms to reduce risk and support partnership development and collaboration.

However, not all risks are given the same level of mitigation, specifically the reputational risk posed to extension agents. Although we support Markell et al. (2020) who identify PPPs as potential partnership structures for extension, we find that more research is needed to understand which strategies may alleviate this risk and how best they can be implemented. If we are to build better PPPs for agricultural innovation deployment, evidence points to a more thoughtful engagement of extension professionals in project programming. We posit that efforts to institutionalize county- and regional-level extension agents in project leadership positions with associated budget allocations could change perceptions about extension's valued contribution. Allocating budget for structuring knowledge exchange spaces among extension and other agricultural advisors could help identify programmatic and agronomic opportunities and challenges. Such feedback loops would highlight novel research questions to further guide knowledge dissemination (Turner et al., 2017). Extension and agricultural advisors play key roles as knowledge brokers and situating them appropriately for successful outreach may enhance innovation capacity (El-Chichakli et al., 2016; Turnhout et al. 2013). Furthermore, these strategies align with Klerkx et al. (2010), who argue for specialized innovation facilitators as support structures for innovation systems. Although our case study suggests that reputational risk is limiting participation, we agree that additional research with a larger sample of extension agents is required to clarify this phenomenon.

Promoting PPPs as a mechanism for developing AIS poses an interesting conundrum in the context of risk. On the one hand, the riskiness of some agricultural innovations provides an opportunity to develop PPPs and galvanize collaboration. Carinata in the southeast US encapsulates this risk: commercializing a Canadian summer crop into an existing row-crop rotations in a new geography with a different climate, a different socio-cultural context, and different institutional arrangements. Therefore, SPARC exemplifies how PPPs are conceptualized as a policy mechanism for AIS (Hall 2006; Hermans

et al., 2019). Our study situates this mechanism around commercial risk's capacity to incentivize private sector partners to collaborate in a PPP. On the other hand, when actors tasked with innovation functions, such as knowledge development and dissemination (Hekkert et al., 2007), face these risks, they may experience a reducted capacity to fulfil these functions. Acknowledging risk as a potential disrupter of the innovation motors that connect functions within the system and taking mitigation strategies could add a layer of resilience to existing AIS frameworks, especially in the context of transformational change in the agricultural sector (Hermans et al., 2019).

Our study has implications for emerging AIS frameworks and the future of food systems. A key question facing AIS is understanding how pathways towards transformed food systems affect advisory services, such as extension (Klerkx, 2020). In this sense, SPARC is an exemplary case study since the project aims to transform a food system to include a dedicated biofuel crop, highlighting the intersections of the agriculture and energy sectors (Klerkx, 2023). Our study emphasizes how in addition to "underlying paradigms, societal values and socio-economic value propositions, technology configurations, and forms of social and economic organization" future food systems have risks associated with their transformation (Klerkx, 2020, p. 132) and managing risk is critical to success (Osei-Kyei & Chan, 2015). Furthermore, conceptualizations of Mission-oriented AIS could benefit from a cataloguing of risk to institutional missions, aligning with the mission-related risks identified in this study. Specifically, when building a knowledgebase with academic input, building consensus around knowledge dissemination pathways (such as publishing) may allow for better alignment between public and private partners. We posit that further exploring AIS from a lens of risk may provide fruitful theoretical implications by framing the system around people tasked with innovating and how relationships enable them to do so.

6. Conclusion

Risk is an important factor in both public–private partnerships and agricultural innovation. Our study outlines risks involved a PPP whose mission is to develop a novel biofuel crop. We emphasize how those risks work for and against collaborative efforts in the partnership and highlights the value of risk as a component of future AIS frameworks focusing on transformational food systems. Given cooperative extension's positioning as knowledge brokers, they represent a critical partner in the landscape of innovative technology adoption and PPPs would benefit from engaging them accordingly. Future research could expand the sample of extension agents to assess their views on facilitating innovation within PPPs as well as the structural challenges they face in doing so, such as reputational risk. A systematic analysis comparing

the experiences of multiple USDA-funded PPPs could inform our understanding of how different stakeholder networks from various regional contexts promoted innovation, navigated risks, and fostered collaboration. Considering the current national favourable policy arena, a burgeoning global demand for SAF, and demonstrated commitment from US federal agencies to support the development of a domestic bioeconomy, the time is ripe for extension to play an important role in cultivating the bioeconomy.

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