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Cultural Beliefs and Stakeholder Affiliation Influence Attitudes Towards Responsible Research and Innovation Among United States Stakeholders Involved in Biotechnology and Gene Editing

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Biotech developers are concerned about the future of gene editing having experienced the contentious history of first-generation GM foods. They have also expressed desires to do better with public engagement in gene-editing innovation. The framework of Responsible Research and Innovation (RRI) may provide a way forward to act on their desires for greater public legitimacy. However, in the United States, -there has also been reluctance to incorporate RRI into biotechnology innovation systems like gene editing in food and agriculture. In this article, we investigate individual- and group-level factors, including demographic, sociographic, and cultural factors, that influence attitudes towards RRI among biotechnology United States stakeholders. Using the Advocacy Coalition Framework's (ACF) hierarchy of beliefs as a theoretical guide, biotechnology stakeholders (n = 110) were surveyed about their cultural (deep-core) beliefs and then about their attitudes towards principles (policy-core beliefs) and practices (secondary beliefs) of RRI applied to biotechnology innovation. Through statistical analysis of the results, we found significant relationships between stronger egalitarian cultural-beliefs and positive attitudes towards both the principles and practices of RRI. We also found that participants with higher levels of experience held more positive attitudes towards principles of RRI. In contrast, we found a significant inverse relationship between professional affiliation with industry or trade organizations and attitudes towards RRI practices. With these results, we present a model of factors that influence RRI attitudes for future testing. In closing, we interpret the results in the context of ACF to examine the potential for building cross-sector coalitions for practicing RRI within United States gene-editing innovation systems.

Keywords: responsible research and innovation, gene editing, genome editing, oversight, regulation, stakeholders, attitudes, advocacy coalition theory

INTRODUCTION

Scholars proposed the framework of responsible research and innovation (RRI) in the last decade to expand the governance of emerging technologies beyond traditional questions about the downstream risks of technological products to upstream questions about research and innovation processes themselves (Stilgoe et al., 2013). In particular, Stilgoe et al. (2013) notes that public controversies about science and technology "cannot be reduced to questions of risk, but rather encompass a range of concerns relating to the purposes and motivations of research" (p. 1569). RRI seeks to better align scientific and technological research and development with democratic processes, societal values and needs, and humility towards the future (e.g., Owen et al., 2012; Owen et al., 2013; Stilgoe et al., 2013). RRI arose out of a longer history of work on the ethical, legal, and social implications/aspects (ELSI in the United States or ELSA in the EU) of science and technology development (Felt 2018). RRI has been integrated into EU funding programs (Felt 2018) and has been the subject of much science and technology studies (STS) scholarship. However, it has not been significantly mainstreamed into S&T funding, research policy, or innovation systems in the United States.

Around the time that RRI emerged, the biotechnology sector underwent a revolution with the advent of gene-editing methods. Biotech developers are now concerned about the future of gene-editing having experienced the contentious history of first-generation GM foods (Marris et al., 2015; Kuzma 2016; Hartley et al., 2017; Kuzma 2018). For example, consumers are purchasing more non-GM and organic products, and food companies are seeking out non-GM ingredients (Malcolm 2016; Hartman Group, 2018). At the same time, biotech developers see gene-editing, such as through the use of CRISPR, as a way to alter crops for useful purposes while potentially avoiding public backlash and cumbersome regulation (Kuzma 2016; Kuzma et al., 2016; Kuzma 2018). Biotech developers indicate that they want to do a better job of bringing the public along with gene-editing innovation in comparison to how they proceeded with first-generation transgenic and GM crops (Kokotovich and Kuzma 2014; Kuzma et al., 2016; Kuzma 2018). They see gene-editing as potentially more acceptable to consumers, as gene-edited crops do not always include the introduction of foreign DNA into the final product. Some perception studies of GM crops and foods have shown that consumers indeed have fewer adverse attitudes towards the introduction of DNA from the same species (as can be achieved through gene editing) in comparison with the introduction of DNA from distantly related species (Mielby et al., 2013; Shew et al., 2018). A recent cross-national study of United States consumers concluded that people were more willing to consume CRISPR-based foods than 1st generation GM or transgenic foods, although both were viewed less positively than conventional foods (Shew et al., 2018).

Developers see gene-edited crops as a chance to start fresh with greater inclusion of public dialogue and education to address consumer acceptance issues. For example, in one study interviewing biotech stakeholders and developers, a majority expressed the need for the public to be engaged in gene-editing governance (Kuzma et al., 2016). In addition, a coalition of industry, non-profits, and trade organizations is emerging for verification of responsible practices for gene-editing in agriculture (Center for Food Integrity, 2020). At the same time, United States regulatory systems for gene-editing, like gene-edited foods, are evolving in different directions. For example, in 2020, the United States Department of Agriculture passed new regulations for GM crops which exempt many gene-edited crops from pre-market oversight (USDA 2020) and lack requirements for public disclosure when they enter agricultural or food systems (Jaffe 2019; Kuzma and Grieger 2020).

In the absence of federal mandates for public transparency and disclosure of gene-edited products, RRI principles and practices may provide a way forward for biotech developers to act on their desires for greater public engagement and legitimacy. The most cited article on RRI (according to Google Scholar) frames it according to four principles: anticipation, inclusion, reflexivity, and responsiveness (Stilgoe et al., 2013). *Reflexivity* moves governance of science and technology away from solely a risk-based approach to one that encompasses reflection on the underlying goals, motivations, limits of knowledge, assumptions, and alternative framings of problems. *Anticipation* incorporates considerations where potential future consequences can be analyzed and explored prior to technological development, allowing for improved consideration of downstream risks and impacts. *Inclusion* prioritizes opening up governance of research and innovation to incorporate the perspectives of diverse publics, which provides more varied, reflexive, and anticipatory approach than the traditional inclusion of subject-matter experts alone in governance systems. Finally, *responsiveness* demands the ability to alter the direction or scope of innovation given changing circumstances, new data, or emergent stakeholder and public values. The RRI framework based on these four principles is "deemed to be characteristic of a more responsible vision of innovation" than other frameworks centering on research ethics, diversity and inclusion in STEM fields, and interdisciplinarity and has been "operationalized by national funding bodies" and "integrated in research practice" in the EU (Wittrock et al., 2021, p. xi).

In previous work (Roberts et al., 2020), we developed quantitative survey questions to measure attitudes towards the four RRI principles from Stilgoe et al. (2013) and towards ways to put these principles into action. We found that United States stakeholders promoting or developing biotechnology innovations--industry, trade organizations, and academics--had more negative reactions to RRI principles of inclusion and responsiveness than the RRI principles of reflexivity and anticipation in comparison to government and advocacy groups (i.e., consumer or environmental non-profits). These results were further explained by qualitative focus group research with these stakeholders. We found that biotech developers and their proponents (i.e., biotech or commodity-crop trade organizations) were wary of giving voice or choice to groups outside innovation pipelines, which contradicts RRI principles of inclusion and responsiveness (Stilgoe et al., 2013). Biotech developers expressed fears that these facets of RRI would

slow their work down in the face of pressures to move quickly to compete for funding, capital, and national or international professional advantages (Roberts et al., 2020).

While this previous study observed differences in RRI attitudes among stakeholder groups and provided some insights into why stakeholder groups feel differently about RRI, it did not adequately describe what individual-level or group-level factors influence differences in attitudes for RRI among stakeholders. Thus, in this paper, we examine whether demographic, cultural, professional, or other sociographic factors affect individual and group attitudes towards RRI principles and practices. Our work is also guided by the Advocacy Coalition Framework (ACF). ACF is a theoretical framework from the policy process literature that examines how individual- and group-beliefs relate to the formation and operation of coalitions within policy arenas (Jenkins-Smith et al., 2014) (see more discussion on ACF and our survey questions below in Methods). In this study, we use the ACF structure for core, policy, secondary "beliefs" and the principles of RRI from Stilgoe et al. (2013) to develop survey questions in order to gain insights into factors that influence attitudes towards RRI among United States stakeholders in biotechnology innovation. We then use the ACF to hypothesize about the potential to form wider coalitions across United States stakeholder groups to incorporate RRI into United States gene-editing innovation systems.

To set the stage for this work, we first review key previous studies on RRI in biotechnology or related innovation systems and then turn to a deeper discussion of the ACF and how it relates to beliefs about RRI and United States stakeholder coalitions in biotechnology innovation systems.

Previous Work on Biotechnology and RRI

A few previous studies have specifically considered stakeholder attitudes towards RRI within United States biotechnology innovation systems. Two studies used interviews with academic researchers. Doezema and Guston (2018) interviewed United States biotech innovators within a single university research institute. In this study, RRI was framed according to areas of practice that could be put into place at the institute—that is, ethics, science education, open science, societal engagement, gender equality, and diversity. The study found that although ethics was of interest to biotech researchers at this institute, RRI was conceived as traditional "research ethics" such as reproducibility and misconduct, rather than according the Stilgoe et al. (2013) RRI principles. A second study (Glerup et al., 2017) interviewed eleven United States academics working in synthetic biology and nanotechnology using a Socio-Technical Integration Research (STIR) protocol where STS researchers embed themselves in laboratories (Fisher and Schuurbiers 2013). They found that the researchers thought of "responsibility" in more traditional ways, such as producing good science and taking care of employees, rather than broader obligations and responsivity to society (Glerup et al., 2017). Neither of these studies employed survey methods or empirically compared United States biotechnology stakeholder-group attitudes as we do in this article.

Other reports focus on attitudes of innovators in the EU, Canada, and United Kingdom towards RRI. Marris et al., 2015 identified engineers and natural scientists' conceptions of RRI within the synthetic biology community in the United Kingdom. They found that seeking greater public acceptance of synthetic biology was the primary motivation for RRI. Similarly, Hartley et al. (2017) interviewed university researchers across STEM fields working in the United Kingdom and found that various actors espouse different meanings of RRI, although a predominant theme was the protection of scientific research from politics. For example, several researchers felt that public inclusion and engagement would best serve to increase public understanding of science and thus garner support for GM work (Hartley et al., 2017); rather than serve to give publics a "voice" in the conduct of GM work, like "inclusion" is meant to do in Stilgoe et al. (2013).

Along similar lines, Carrier and Gartzlaff, 2020 interviewed 80 researchers and research executives across the EU in a variety of technological fields across social and natural sciences, humanities, and engineering to investigate their understandings of RRI. While they found a welcoming attitude towards RRI in general, the interviewees were concerned about granting societal actors influence on the direction of research and innovation given public "ignorance and bias," the additional expenditures that may be required to engage societal actors, and the potential loss of autonomy for science. Another study in Canada interviewed 31 people who design, develop and commercialize health innovations about practices of RRI (Rivard and Lehoux 2020). The study found that although innovators generally agreed on the desirability of several principles of RRI, they were concerned about the feasibility of meaningful implementation of them. The findings in these last two studies are consistent with our previous study with United States biotechnology stakeholders (Roberts et al., 2020), in which we found greater agreement on RRI principles (i.e., anticipation, responsivity, reflexivity, and inclusion) among diverse stakeholder groups than on specific RRI practices for implementing these principles.

RRI for biotechnology has also been investigated in multiple case studies using anthropological approaches to observation (see Macnaghten, 2016). For instance, Macnaghten, 2016 used ethnographic work to identify RRI attitudes towards GM food crops in Brazil, Mexico, and India as well as among symposium attendees in the United Kingdom and EU (Carro-Ripalda and Macnaghten 2015). These studies report the cultural, institutional, and social challenges to enacting RRI and provide greater identification of the practicality of enacting RRI within synthetic biology research and innovation (Macnaghten, 2016). In the context of GM crops, they found that in situations where the crop was not culturally significant to the country, like soybean in Brazil, scientists had "clear and unqualified optimism . . . on the role of GM crop technologies, with little evidence of a structured and sustained debate with wider society" (Carro-Ripalda and Macnaghten 2015; Macnaghten, 2016, p.284). In India, they heard from crop scientists who argued that India "could not afford the risk of falling behind in the development of biotechnology" and that anti-GM groups were "ignorant" (Carro-Ripalda and

Macnaghten 2015, p 25). These results are similar to the barriers identified in our previous work with focus groups of United States biotechnology stakeholders (Roberts et al., 2020). Here we found 1) "cynicism" among innovators with regard to the public's ability to engage in informed conversation and 2) the predominance of "academic capitalism" in United States culture and institutions, through which any process such as RRI that might slow innovation down would reduce competitiveness and be seen as undesirable.

All the studies mentioned above used qualitative methods of inquiry, and only a few focus on United States biotechnology innovation systems. In contrast, in this paper, we use quantitative surveys to investigate the relationships between demographic, sociographic, professional, or cultural factors and their influence on attitudes towards RRI. Furthermore, this paper breaks new ground by merging RRI scholarship and quantitative survey methods with policy process theory (namely the ACF), where we evaluate survey data with a larger sample (n = 110) of multi-sector stakeholders in United States biotechnology innovation. To our knowledge, our study is unique in these regards in the field of RRI scholarship.

Relating RRI Attitudes to the Advocacy Coalition Framework

A significant challenge faced by those attempting to legitimize and implement the RRI framework is establishing processes, strategies, and norms that create shared goals, while also facilitating coordination and cooperation between actors involved with innovation processes (Tait, 2017). ACF is a policy process theoretical framework that describes how actors engage in the policy process to translate their belief systems, which are simplified constructs used to make sense of the world, into public policy-making and action (Jenkins-Smith et al., 2014). This paper uses the theoretical lens of the ACF framework to explore whether United States stakeholders share beliefs related to RRI and thus whether those beliefs may translate into shared policy action to implement RRI in United States biotechnology innovation systems.

The ACF provides a framework for understanding how coalitions of actors within a policy subsystem (e.g., biotechnology innovation) may interact to affect change or maintain the status quo (reviewed in Weible et al., 2009). The ACF provides a three–tier structure for describing the beliefs of actors (e.g., in this study, our biotech stakeholders) within a policy subsystem (e.g., in this study, biotechnology innovation) (Weible et al., 2009) (**Figure 1**). *Deep core beliefs* are the broadest category of beliefs, represent the most stable beliefs of actors, and are mainly normative. They transcend policy subsystems, or in other words, actors hold these beliefs across multiple policy areas. For example, deep core beliefs represent liberal and conservative political beliefs, whether responsibility for progress lies with individuals or communities, and beliefs about future generations. The next level in the ACF hierarchy of beliefs are *policy core beliefs* which are more moderate in scope and relate to the substance of particular policy subsystems (in our case, biotechnology innovation). These beliefs are thought to be important for forming more stable coalitions in policy subsystems, and although somewhat resistant to change, they are more malleable than *deep core beliefs* in response to new information and experiences. Policy core beliefs include how problems are defined, the ordering of priorities, and balance between values such as economics and ethics. At the most specific level of ACF beliefs are *secondary beliefs* (**Figure 1**). These are narrower in scope than *policy core beliefs* and are often formed in response to empirical information or experiences within the policy subsystem. Secondary beliefs are those related to specific public policy instruments used to achieve policy outcomes. The ACF predicts that *secondary beliefs* are the most changeable among coalitions and actors within them (Sabatier et al., 2007).

The advocacy coalitions that exist within a subsystem are aggregated groups of actors that coordinate to a non-trivial degree in the pursuit of policy change (Sabatier et al., 2007). Under ACF, a shared set of motivations and beliefs are what bind coalitions together. Deep core beliefs, and to a lesser extent policy core beliefs, are seen under the ACF to hold advocacy coalitions together. Applying these ideas to the biotechnology policy subsystem, in this paper we wanted to see whether attitudes towards RRI principles, which relate to the ACF's level of policy core beliefs, and RRI practices, which relate to the ACF's level of secondary beliefs, were influenced by deep core beliefs and whether stakeholder groups differed in their deep core, policy core, and secondary beliefs (**Figure 1**).

Given the importance of deep core beliefs in understanding the behavior of advocacy coalitions within a policy subsystem, ACF scholars have devised a way to conceptualize and measure deep core beliefs that captures their normative and ontological nature, while also being testable and generalizable (Jenkins-Smith et al., 2014; Ripberger et al., 2014). These scholars used cultural theory (Douglas 1970; Douglas and Wildavsky 1982), to structure a scale for deep core beliefs that is generalizable across multiple policy subsystems. In this scale, twelve questions place survey respondents into four cultural archetypes--egalitarian, hierarchical, individualistic, or fatalistic (Ripberger et al., 2014). These cultural types, which are also considered "worldviews," have been previously defined by the intersection of the dimensions grid and group (Douglas 1970; Douglas and Wildavsky 1982). The grid dimension is a measure of beliefs about how society should be structured. It represents the degree to which individual behavior should be regulated by group pressure and structural constraints. The group dimension is a measure of feelings of group membership within society; for example, a high measure of group indicates that individuals have a strong feeling of association with others. In this study, we use the Ripberger et al. (2014) validated scale to probe whether our United States biotechnology stakeholders fall into the four cultural archetypes, as a measurement of deep core beliefs according to the ACF (see Methods and **Table 2**).

In our previous study (Roberts et al., 2020), we found significant differences among stakeholder groups especially in their attitudes to *secondary beliefs,* or in other words, ways of implementing RRI in biotechnology innovation. Industry and trade organizations rated inclusion and responsivity practices,

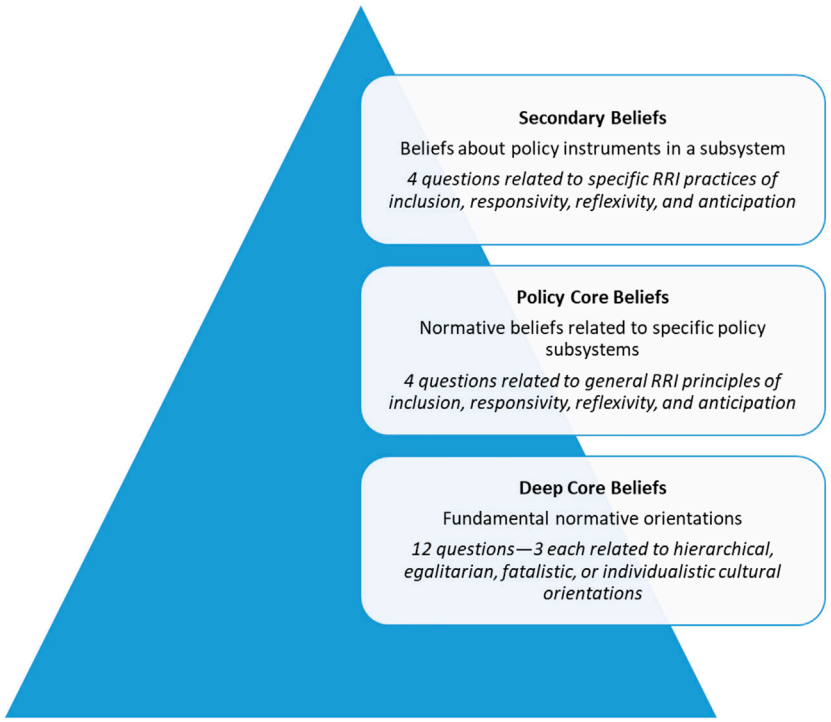

FIGURE 1 | ACF beliefs and relationship to stakeholder survey questions.

both which relinquish control to groups outside of biotechnology product development pipelines, less positively than government and advocacy groups. We found more agreement among stakeholder groups for the general principles of RRI, or *policy core beliefs,* applied to biotechnology innovation. As the ACF proposes that secondary beliefs are more flexible, and that shared policy core beliefs are important for stable coalition formation, we hypothesized that there are reasons to be optimistic about stakeholder groups in biotechnology innovation coming together to adopt RRI principles (which they share more agreement on) *if* better ways to implement them could be agreed upon (than those asked in the survey). However, in this prior study, we did not analyze whether *deep core beliefs* influence attitudes of biotechnology stakeholders towards RRI in the biotech innovation system. We also did not assess whether demographic (e.g., gender, race, age) or sociographic (e.g. income, education, experience in profession) factors influence RRI attitudes. We also did not address whether United States stakeholder groups share deep core beliefs and whether they are important for coming to agreement on RRI. Considering these gaps, this study addresses the following key research question:

> *What demographic, sociographic, professional, and cultural factors (deep core beliefs) best explain the variance of observed stakeholder's responsible innovation 1) policy core beliefs and 2) secondary beliefs?*

We further describe our methods for addressing this key question below, followed by our results. Finally, we discuss the meaning of our results for the possibility of implementing RRI in United States biotechnology innovation systems.

METHODS

Recruitment and Survey Participants

We used a purposive sampling approach to recruit a diverse group of study-participants comprised of a variety of biotechnology professionals from different sectors. Participants were recruited from a sample of United States stakeholders in the greater Raleigh-Durham-Chapel Hill area (Research Triangle, NC). Recruitment was prioritized among professionals working in areas related to biotechnology in agriculture, food, or the environment. Many of the biotechnology developers recruited in the study work on emerging methods of genetic engineering, such as gene editing. The geographic region of the Research Triangle provides a host of diverse biotechnology and bioscience organizations. The Research Triangle is among the most active scientific and development regions in the United States and ranks second behind Boston Metropolitan region for life science expertise and development (Rose 2015). Participants reflect a fair representation of biotech stakeholders in this highly active biotech region. However, the participants do not comprise a statistical or geographic representation of the United States.

In our search we prioritized balanced representation from academe, advocacy groups (i.e., consumer and environmental groups), government, industry, and trade organizations

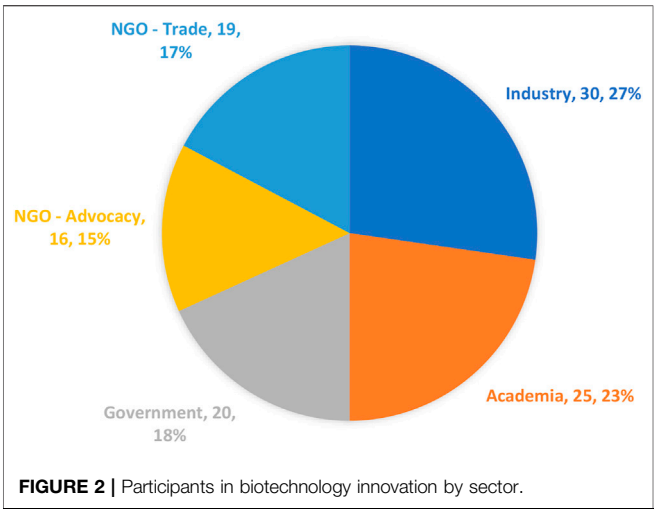

FIGURE 2 | Participants in biotechnology innovation by sector.

(i.e., industry and conventional farming non-profit associations), (**Figure 2**). We chose to split non-governmental organizations (NGOs) into advocacy groups and trade organizations to better reflect the abilities of each group--where advocacy groups may influence policy change and biotechnology oversight through media communications and legal precedence while trade organizations often seek change through more direct lobbying efforts on behalf of their constituencies (Kuzma 2013). Government representatives were engaged in biotechnology arenas related to policy-making, regulatory analysis, and risk assessment, within the topics of agriculture, food, health and the environment.

Participants were first identified from databases and listserves collated by the Genetic Engineering and Society (GES) Center at NC State and included professionals working in the Research Triangle Area. We used this group along with other collaborators and key contacts in a snowball sampling strategy to provide more names to expand our sampling frame. We also sought out website databases for non-governmental and governmental organizations in the region whose work relates to agricultural and environmental biotechnology as the existing database was lacking in these areas. The final sampling frame including over 700 professionals. Participants for this study were first emailed by a research team member to introduce the project and outline the opportunity for participation as well and review their rights as participants following university IRB guidelines (Exempt, NC State IRB Protocol Approval #6157). A second email was sent to those who did not respond and targeted phone calls were made to fill stakeholder groups that were underrepresented in previous invitation phases. The final sample included 109 completed responses. Each participant was offered a $50 dollar gift certificate for their time although some participants accepted less money or none at all in accordance with their agency rules. All processes of this study followed the IRB agreement as exempted by the host university.

Table 1 reports the demographic composition of the participant groups. Age ranged from 21 to 70 years old (M = 50.23, SD = 11.76) and professionals held a mean length of experience in their profession of 15.65 years (SD = 10.73). 34% were female, 14% considered themselves non-white, 60% held doctoral degrees, and median household income ranged between $101,000 - $125,000. **Figure 2** below also reports the sectors in which this group works. 100% of participants completed the agreed upon study and there was no apparent need for attention filter questions.

Data Collection

In order to assess our research question, data were collected using a pretested survey questionnaire (see Ripberger et al., 2014; Roberts et al., 2020). Survey questions were designed based on predominant elements of RRI (Stilgoe et al., 2013) and the application of cultural theory to test ACF deep core beliefs (Ripberger et al., 2014) as described above (**Table 2**). The survey was administered online using the Qualtrics platform. Participants were asked to complete the questionnaire which included the items reported on in this analysis (**Table 2**). The survey also elicited responses to open-ended qualitative questions relating to RRI, which we do not report in this paper. These qualitative results are being prepared for additional analyses.

Independent Variables

Independent variables tested are listed in **Table 1**. Demographic independent variables (IVs) include age, gender, and race (white/non-white). Sociographic IVs included on the survey and tested were education and income. Professional sector variables tested were sector affiliation (Trade, Government, Advocacy, Academe, and Industry) within the biotechnology innovation system and years of experience.

ACF deep core beliefs were measured based on cultural theory and the previously reported and tested scale (Ripberger et al., 2014) (**Table 2**; **Figure 1**). This independent variable represents the personal and cultural-value orientation held by individuals. We used deep core beliefs (aka cultural worldview) as an independent variable to see whether they predicted RRI attitudes—either towards general RRI principles (policy core beliefs) or suggested RRI practices (secondary beliefs) (**Table 2**). We also subsequently assess if deep core beliefs align with certain United States stakeholder groups. ACF posits that deep core beliefs are important for tight policy coalitions and are the least malleable. Given the contentiousness of the agricultural biotechnology domain and our previous findings of differences in stakeholder attitudes towards RRI (Roberts et al., 2020), we expected to observe differences in deep core beliefs among stakeholder groups and that they would strongly influence attitudes towards RRI.

Four distinct deep core value-orientations were measured based on Ripberger et al. (2014): *egalitarianism, fatalism, individualism* and *hierarchy* (**Figure 1**). Note that the questions that Ripberger et al. (2014) and we use do not directly measure group and grid dimensions from cultural theory (Douglas 1970; Douglas and Wildavsky 1982) but rather use twelve questions to place people into these four cultural types. We measured the four worldviews by asking respondents to identify their level of agreement with three 7-point Likert-scale items (1 = "strongly disagree," 7 = "strongly

TABLE 1 | Descriptive statistics for variables.

Descriptive Statistics of Independent and Dependent Variables	
Independent variables	
Age	M = 50.23; SD = 11.76
Gender	34% female; 66% male
Race	14% non-white; 86% white or caucasian
Education	Median "doctoral degree"
Annual income	Median "$101,000—$125,000 dollars per year"
Sector: Industry	27% (N = 30)
Sector: Academia	22% (N = 25)
Sector: Government	18% (N = 20)
Sector: NGO—advocacy	15% (N = 16)
Sector: NGO—trade association	17% (N = 19)
Years of experience within sector	M = 15.65 years; SD = 10.73
Core values: Egalitarianism	M = 4.26, SD = 1.36; Cronbach's α = 0.78
Core values: Fatalism	M = 3.15, SD = 1.22; Cronbach's α = 0.82
Core values: Hierarchy	M = 3.06, SD = 1.16; Cronbach's α = 0.73
Core values: Individualism	M = 3.43, SD = 1.12; Cronbach's α = 0.63
Dependent variables	
Responsible innovation policy core belief strength	M = 5.53; SD = 0.92; Cronbach's α = 0.69
Responsible innovation secondary beliefs	M = 4.89, SD = 1.26, Cronbach's α = 0.77

TABLE 2 | Survey questions to probe three tiers of ACF beliefs.

Deep core beliefs		**Policy core beliefs (principles)**	**Secondary beliefs (practices)**
12 questions (3 each)		***four questions (combined into one composite variable for RRI policy core beliefs)***	***four questions (combined into one composite variable for RRI secondary beliefs)***
1–7 Likert scale		***1–7 Likert scale***	***1–7 Likert scale***
Hierarchical	Inclusion	Maximizing public participation leads to better biotechnology policy.	Innovators should consult with consumers and advocacy groups during R and D in biotech.
Individualistic	Reflexivity	Reflecting on the underlying purposes, motivations, and uncertainties that surround biotechnology products is important.	Social scientists, environmental and health risk analysis and ethicists should be involved from the early stages of biotech innovation.
Fatalistic	Anticipation	Considering potential environmental and social implications of biotechnology products is important in the planning stages of research.	There should be a standard of at least 10% of public funding for research in biotechnology that goes to environmental, social, legal, and ethical implications research.
Egalitarian	Responsiveness	The innovation process should respond to changes in public attitudes or values.	The innovation process should respond to changes in public attitudes or values even if this means delaying, modifying or terminating the project.

See text (Methods) for survey questions to assess Deep core beliefs according to Ripberger et al. (2014) using cultural theory archetypes Hierarchical, Individualistic, Fatalistic, or Egalitarian.

agree"). These were subsequently transformed into composite measures as below:

- *Egalitarianism* is the philosophical perspective which emphasizes equality and equal treatment of all people regardless of, religion, economic status, or political belief. People in this worldview seek strong group identities but prefer minimal prescriptions imposed from outside the group (high group, low grid). Consequently, they see value in more collective decision-making. The measures used to create this composite measure were: 1) What society needs is a fairness revolution to make the distribution of goods more equal, 2) Society works best if power is shared equally, and 3) It is our responsibility to reduce the differences in income between the rich and the poor (Ripberger et al., 2014). The three items were averaged to create a single composite measure of egalitarianism where a higher score indicated stronger identification of this philosophical belief (**Table 1**; M = 4.26, SD = 1.36; Cronbach's α= 0.78).
- *Fatalism* is the perspective that people are powerless to influence the future or the consequences of their own actions and that events are determined by fate. People in this group seem themselves as subject to binding external constraints, yet they feel excluded from membership in important social groups (low group, high grid). As a result, they see little control over their lives and that one's fate is much more a matter of chance than choice.

Similar to egalitarianism, we measured this variable asking respondents to identify their agreement with three items: 1) The most important things that take place in life happen by chance, 2) No matter how hard we try, the course of our lives is largely determined by the forces beyond our control, and 3) For the most part, succeeding in life is a matter of chance (Ripberger et al., 2014). From these three questions, we created a composite variable (**Table 1**; M = 3.15, SD = 1.22; Cronbach's α = 0.82) where higher scores indicate stronger fatalistic beliefs.

- The third grouping of cultural worldviews, *hierarchical*, (high group, high grid) reflects high group attachments and binding external prescriptions. Accordingly, they place weight on the welfare of the group yet are keenly aware of whether other individuals are members of their own group. They prefer that organizations and relationships be stratified according to externally defined rules. Hierarchy was similarly measured with three items: 1) The best way to get ahead in life is to work hard and do what you are told to do, 2) Society is in trouble because people do not obey those in authority, and 3) Society would be much better off if we imposed strict and swift punishment on those who break the rules (Ripberger et al., 2014), and from these three, a composite variable was created (**Table 1**; M = 3.06, SD = 1.16; Cronbach's α = 0.73).
- *Individualism* is the philosophical belief that advocates for independence and freedom to promote one's goals and desires over the needs of the group or society. Individualists tend to attach little weight to group affiliation and reject externally defined prescriptions (low group, low grid). We measured individualism with three items: 1) Even if some people are at a disadvantage, it is best for society to let people succeed or fail on their own, 2) Even the disadvantaged should have to make their own way in the world, and 3) We are all better off when we compete as individuals (Ripberger et al., 2014), and also created a composite variable for subsequent use (**Table 1**; M = 3.43, SD = 1.12; Cronbach's α = 0.63).

Dependent Variables

For policy core beliefs and secondary beliefs about RRI, we developed, tested, and administered our own survey questions (Roberts et al., 2020; **Table 2**). Our policy core beliefs questions are based on the general principles of RRI (inclusion, anticipation, responsivity, and reflexivity) from Stilgoe et al. (2013), as they apply to biotechnology innovation as the policy subsystem (Roberts et al., 2020) (**Table 2**). For secondary beliefs, we designed questions to implement RRI principles according to ideas from Stilgoe et al. (2013). These represent specific policy practices that could be taken in biotechnology innovation to implement RRI (**Table 2**). The survey questions in**Table 2** were pre-tested and used in a prior peer-reviewed study that investigated United States biotechnology stakeholder attitudes towards the four tenets of RRI (policy core beliefs) and ways to implement them (secondary beliefs) (Roberts et al., 2020).

Responses to the four questions of RRI policy-core beliefs or to the four questions of RRI secondary beliefs (**Table 2**) were compiled into two separate composite scores, and then each composite score was used as the dependent variable to examine whether demographic, sociographic, and professional factors, or deep-core beliefs from cultural theory (independent variables—**Table 1**) influenced attitudes about RRI principles or practices (**Table 2**). *Responsible Innovation Policy-Core Belief Strength* was measured using a composite from the four items (**Table 2**) (each item on 7-point Likert scale). These items were averaged to form the composite index, with higher scores indicating more agreement with the tenets of responsible innovation (**Table 1**; M = 5.53, SD = 0.92, Cronbach's α = 0.69). *Responsible Innovation secondary beliefs* were similarly measured using four items on 7-point Likert scales (**Table I**). A composite index was created from these items where higher score indicates more agreement with the secondary belief statements (**Table 1**; M = 4.89, SD = 1.26, Cronbach's α = 0.77).

We utilized ordinary least squares (OLS) hierarchical regression modeling, ANOVA, and Chi-squared analysis in SPSS software to test our research questions and explore relationships among the independent and dependent variables as discussed in the Results (*Results*).

Study Limitations

Our study is limited in the number of participants (n = 110) and their geographical location as we sampled from stakeholders in United States biotechnology innovation located in the Research Triangle NC area (as discussed above in *Recruitment and Survey Participants*). Our study is also limited in the design of the survey questions (**Table 2**; *Dependent Variables*). All studies are limited by the choice and number of survey questions, and our study is no exception. When we designed the survey for RRI principles and practices (in 2016), to our knowledge, there were no survey instruments for assessing agreement with RRI in the literature. We focused on Stilgoe et al. (2013) in our survey design as it is the most highly cited paper when one searches for "responsible innovation" in Google Scholar. Specifically, we drew our questions from Stilgoe et al. (2013) textual descriptions of the four elements—anticipation, reflexivity, inclusion, and responsiveness--for the RI principle statements (aka policy core beliefs; **Table 2**) and from their "Indicative techniques and approaches" (Stilgoe et al., 2013, p. 1573) for the questions about secondary beliefs or practices (**Table 2**). We made particular choices for both sets of questions based on our understanding of the RRI literature and experience with the field of science and technology policy and RRI (see also Roberts et al., 2020 for discussion of this limitation). However, across the eight total RRI questions (**Table 2**), we feel the set captures the spirit and expression of RRI as articulated in Stilgoe et al. (2013).

Regardless, other choices could have been made for the survey questions. Thus, our results are constrained by the use of Stilgoe et al. (2013) to derive the principle questions and by our desire to use a reasonable set of questions for implementing RI. We mitigated this limitation by combining four questions into one construct for each dependent variable (8 questions total—4 for policy core beliefs or principles of RRI and four for secondary beliefs or practices of RRI; **Table 2**). We believe this to be a reasonable set for our novel, quantitative exploration of attitudes

TABLE 3 | Quantitative regression model for predicting RRI policy core and secondary beliefs.

		Model 1: RRI policy core beliefs as dependent variable[a]		*Model 2: RRI secondary beliefs as dependent variable*[b]	
	Question	***Stand. β coeff.***	***p-value, sig***	***Stand. β coeff.***	***p-value, sig***
Block 1: Demographics					
	Age	−0.125	*0.324*	−0.104	*0.356*
	Gender	+0.039	*0.706*	+0.081	*0.378*
	White/non-White	−0.155	*0.103*	−0.020	*0.813*
	Incremental R^2 (%)	6.0%		11.7%	
Block 2: Sociographics					
	Highest level of education	+0.165	*0.141*	−0.026	*0.796*
	Annual income	−0.039	*0.703*	+0.033	*0.716*
	Incremental R^2 (%)	8.3%		12.2%	
Block 3: Profession-related					
In what sector do you work?	Industry	−0.676	*0.120*	−0.798[b]	*0.041*[b]
	Academia	−0.501	*0.219*	−0.546	*0.136*
	Government	−0.379	*0.333*	−0.440	*0.210*
	Advocacy	−0.213	*0.542*	−0.329	*0.294*
	Trade	−0.451	*0.232*	−0.662[b]	*0.050*[b]
Length worked in sector	Years in sector	+0.223[a]	*0.073*[a]	+0.007	*0.947*
	Incremental R^2 (%)	18.7%		29.8%	
Block 4: Deep core beliefs					
	Egalitarian	+0.321[c]	*0.006*[c]	+0.360[d]	*0.001*[d]
	Fatalist	−0.054	*0.627*	+0.008	*0.933*
	Hierarchical	−0.090	*0.472*	−0.067	*0.552*
	Individualistic	−0.079	*0.535*	−0.084	*0.461*
	Incremental R^2 (%)	29.6%		43.5%	

Bolded text emphasizes the categories of the analyses.
[a]$p < 0.1$.
[b]$p < 0.05$.
[c]$p < 0.01$.
[d]$p < 0.001$.

towards RRI and their relationships to demographic and cultural factors. In addition, the two 4-question constructs are the same ones used as dependent variables for testing all relationships with the independent variables of demographics, sociographics, affiliations and cultural (core) beliefs, so the comparative results about factors that influence RRI attitudes within this exploratory study are valid.

RESULTS

Regression Model for Factors That Influence RRI Beliefs

To investigate our research questions, we conducted two hierarchical ordinary least squares regression models. Specifically, we asked what demographic, sociographic, professional, and cultural-worldview (deep core beliefs from ACF) factors best explain the variance of observed stakeholder's RRI 1) policy-core beliefs and 2) secondary beliefs? For the regression models, variables were entered into the model according to their assumed causal order by separate blocks and according to our research questions. Control variables (demographic variables) were included in the first block, whereas the second and third blocks were comprised of sociographic variables (educational level, household income) and professional variables (including sector affiliation and length of professional experience). The final fourth block incorporates deep core beliefs from ACF and cultural theory (Ripberger et al., 2014). As the IBM SPPS guide (2009) notes, this form of regression modeling adds these blocks in order to statistically control for the other variables, allowing researchers to evaluate the variables in concert with one another to note if "adding variables significantly improves a model's ability to predict the criterion variable and/or to investigate a moderating effect of a variable."

In **Table 3** below, Model 1 pertains to responsible innovation policy-core beliefs (RRI principles) while Model 2 provides comparison among the same factors with regards to secondary beliefs (RRI practices). The factors tested in Model 1 accounted for 29.6% of the variance in RRI principle beliefs (policy core beliefs), whereas those factors tested in Model 2 explained over 43% of the variance in RRI practice beliefs (secondary beliefs) (**Table 3**).

ACF theory would predict that deep core beliefs influence attitudes towards policy-core beliefs, (in our case RRI principles applied to biotech innovation), and secondary beliefs (in our case RRI practices applied to biotech innovation). In fact, as predicted, in our hierarchical regression models, deep core beliefs significantly influenced both RRI principles (Model 1) and practices (Model 2). However, only one of the four worldviews, egalitarian views, was strongly and positively

associated with stronger agreement with RRI principles (policy-core beliefs) (ß = 0.321, p = 0.006) and practices (secondary beliefs) (ß = 0.360, p = 0.001) while the other three worldviews, fatalism, individualism, and hierarchy, did not display prominent effects on RRI principles or practices. We further evaluate and discuss the role of egalitarian views vs. the other worldviews in subsequent tests below.

Professional sector-affiliation also showed significant correlation with attitudes towards RRI practices (secondary beliefs), although not with RRI principles (policy core beliefs). Participants affiliated with the biotech industry or industry-supportive trade organizations showed significantly lower agreement with the practices of RRI (secondary beliefs) (**Table 3**). Participants who work with trade organizations also held less favorable secondary beliefs and agreed less with RRI practices (ß =*−0.662, p =0.05*). However, the negative effect was even more pronounced for participants working with biotech companies (ß =*−0.798, p = 0.041*).

We also tested stakeholder group differences in RRI beliefs using ANOVA. ANOVA results confirmed the regression results, in that we did not find any significant differences among stakeholder groups regarding policy-core beliefs about RRI (RRI principles) (F = 1.64, p = 0.169), but there were significant differences among stakeholder groups with regard to secondary beliefs about RRI (RRI practices) (F = 6.39, p < 0.001). Industry and trade organizations held significantly more negative attitudes about RRI practices than government, academe, or advocacy groups according to ANOVA. The greatest magnitude difference was between advocacy and trade groups (mean difference = −1.36; p < 0.001) with the difference between advocacy and industry groups a close second (mean difference = −1.32; p < 0.0001). The lowest difference, yet still significant, was between academe and industry (mean difference = −0.83, p < 0.01). There were no significant differences between government, advocacy, and academic groups. These results are consistent with our prior results where a marked difference was found between two factions: industry + trade groups vs. government + advocacy groups, with academics affiliating with either faction depending on the specific facet of RRI (Roberts et al., 2020) (note: this previous work tested the four areas of RRI independently—i.e., inclusion, anticipation, responsivity, and reflexivity—and did not use a composite scale that combines all four like we do in this paper).

From the regression, we also found an association between years of professional experience and positive attitudes towards the principles of RRI (policy core beliefs) (ß = *+0.223, p =0.07*). However, this correlation was not significant for the practices of RRI (secondary beliefs).

In **Figure 3**, we present a visual model summarizing the regression results. In our model, the effect of sector affiliation on RRI secondary beliefs is about twice that of cultural beliefs (−0.798 for industry and −0.662 for trade, vs. +0.369 for egalitarian) (**Figure 3**). We then set out to examine the potential synergies between affiliation with biotech industry and deep core beliefs. Within industry-dominated sectors (industry or industry-supportive trade orgs), we wanted to investigate whether certain deep-core beliefs (i.e., non-egalitarian) could amplify negative RRI attitudes to explain these results. This would indicate both sectoral and cultural factors working together (i.e., not only what you belief, but also where you reside).

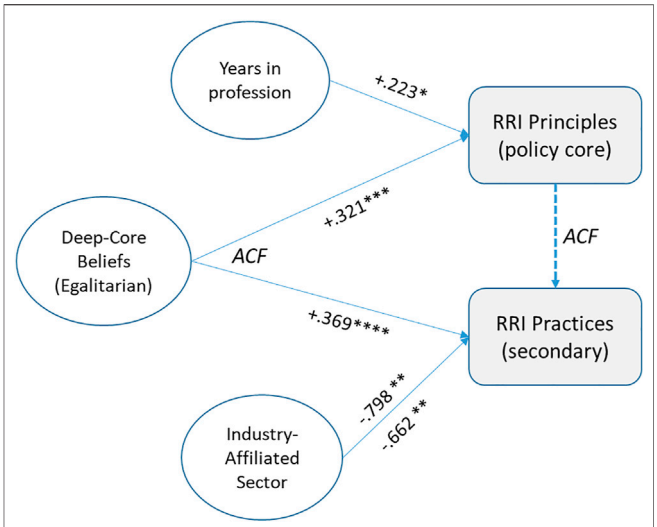

FIGURE 3 | Regression Model for Influencers on Stakeholder Beliefs about RRI in Biotech Innovation. Regression Beta coefficients shown (see also **Table 3**) (p < 0.1*, p < 0.05**, p < 0.01***, p < 0.001****). Industry (company) =−0.798; Trade organization =−0.662. ACF predicts that deep core beliefs influence policy core and secondary beliefs, and that policy core beliefs influence secondary beliefs.

Relationship Between Stakeholder Groups and Cultural Beliefs

An association between a professional sector and certain cultural beliefs (deep core) could help to explain the strong effect on beliefs about RRI practices. If different stakeholder groups hold divergent deep-core beliefs, the ACF predicts that it would be more difficult to form stable policy coalitions transcending stakeholder groups (Jenkins-Smith et al., 2014; Ripberger et al., 2014). In the context of our work, coalitions of stakeholders from different sectors would be more difficult to form and maintain in order to implement RRI if those stakeholders held different cultural world views. To evaluate if different stakeholder groups hold distinct cultural beliefs, we first did descriptive statistics on deep core beliefs (cultural beliefs) by sector (**Table 4**; **Figure 4**). We added up survey responses for each participant from the three 1-7 Likert Scale questions for each cultural archetype (**Table 1**; Methods)—Hierarchical (H), Individualistic (I), Egalitarian (E), Fatalist (F). We then averaged the results for each stakeholder group. The highest possible score would be 21 for each group average (all 7's for the three questions), with the lowest as 3 (all 1s for the three questions). Results are shown in **Table 4**; **Figure 4**. This enables us to evaluate the relationship between these independent variables and also answer if sector affiliation and deep-core beliefs work together to influence attitudes about RRI practices (secondary beliefs). Given the significant positive

TABLE 4 | Deep Core Values by Stakeholder Group--average score.

	Hierarchical	*Egalitarian*	*Fatalistic*	*Individualistic*
Industry	8.3 (3.8)	11.7 (4.0)	9.3 (4.0)	9.7 (3.3)
Academe	9.5 (2.6)	13.2 (3.3)	9.8 (2.9)	9.4 (2.6)
Government	9.1 (4.0)	14.1 (4.5)	9.2 (4.0)	10.0 (3.6)
Advocacy	9.3 (3.2)	13.8 (4.3)	10.8 (3.8)	10.8 (4.3)
Trade	10.2 (3.7)	11.7 (4.2)	8.6 (3.6)	12.1 (2.8)

*Average (std dev) reported. Minimum possible score = 3 and Maximum = 21 given scale of 1–7 for each of three questions in each cultural group (see **Table 1** and Methods).*

relationship between RRI attitudes and egalitarian beliefs and the significant negative relationship between RRI attitudes and industry or trade stakeholder-group affiliation, we wanted to see whether participants from industry and trade organizations scored lower in the egalitarian belief scale.

Although all stakeholder groups scored relatively high on the egalitarian scale (all over 11 points), industry and trade organizations had the two lowest scores (M = 11.7 and M = 11.7). The highest score for trade organizations was in the individualistic category of deep core beliefs (M = 12.1). Individualists tend to hold free-market world views consistent with support of private industry and individual competition in innovation systems (Jenkins-Smith et al., 2014; Ripberger et al., 2014), and the trade representatives came from groups supportive of biotech industry innovation. In contrast, advocacy and government groups held the strongest egalitarian views (**Table 4**; **Figure 4**) (M = 13.8 and M = 14.1 respectively). Thus, according to descriptive statistics, there appeared to be an association between stakeholder group and deep core beliefs that could explain the strong effect on RRI secondary beliefs (**Figure 3**).

We then set out to see if these group differences in cultural world views (deep core beliefs) were statistically significant using Chi-squared analysis. However, we found no statistical differences among stakeholder groups despite the differences we observed in the descriptive statistics (**Figure 4**; **Table 4**). This could likely be due to inadequate statistical power given the low cell size within the cross-tabulated grouping (e.g., n = 16–30) (**Figure 2**). Future work could be done with a higher number of participants in each stakeholder group to see if the lower egalitarianism scores we saw among our trade and industry groups is applicable in the wider United States biotech innovation system.

Other Deep-Core Beliefs and RRI Attitudes

Next, we wanted to determine if other deep core beliefs (cultural beliefs) tended to be associated with attitudes towards RRI. Our regression model showed a strong correlation between egalitarian beliefs and positive attitudes towards RRI practices and principles. But what about the other cultural archetypes? They did not show significance in the regression model, but other variables could have masked their effect. To test if other archetypes of cultural or deep core beliefs relate to RRI attitudes, we split each participant into either a high or low score (relative to the mean) for each of the four cultural archetypes (H, E, I, F). We then conducted two-tailed independent Samples t-tests to determine if these groups differed in their attitudes towards policy core beliefs (RRI principles) or secondary beliefs (RRI practices). In other words, do individuals who are high or low on each cultural deep-core value scale hold distinct policy core or secondary beliefs?

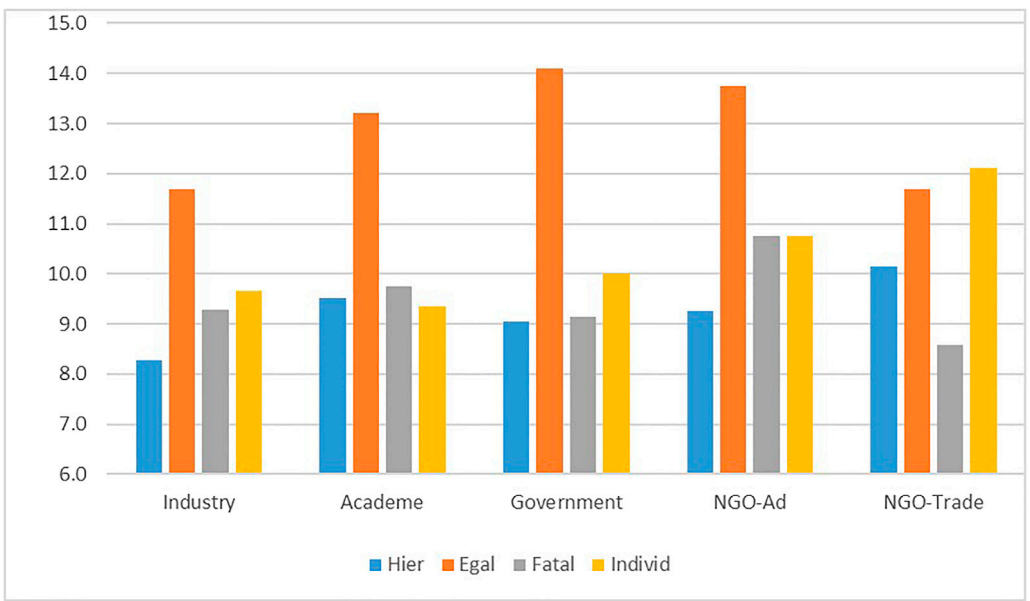

FIGURE 4 | Sectors association with certain deep core beliefs.

TABLE 5 | Deep core beliefs influencing RRI Attitudes.

	RRI principles (policy core beliefs)		RRI practices (secondary beliefs)	
	Mean difference	Sig (2 tailed)	Mean difference	Sig (2 tailed)
Egalitarian	+0.68[a]	0.000	+1.08[a]	0.000
Fatalism	+0.25	0.156	+0.48[b]	0.048
Individualism	−0.47[c]	0.007	−0.75[c]	0.002
Hierarchical	−0.31[d]	0.081	−0.50[b]	0.039

[a]p < *0.001*.
[b]p < *0.05*.
[c]p < *0.01*.
[d]p < *0.1*.

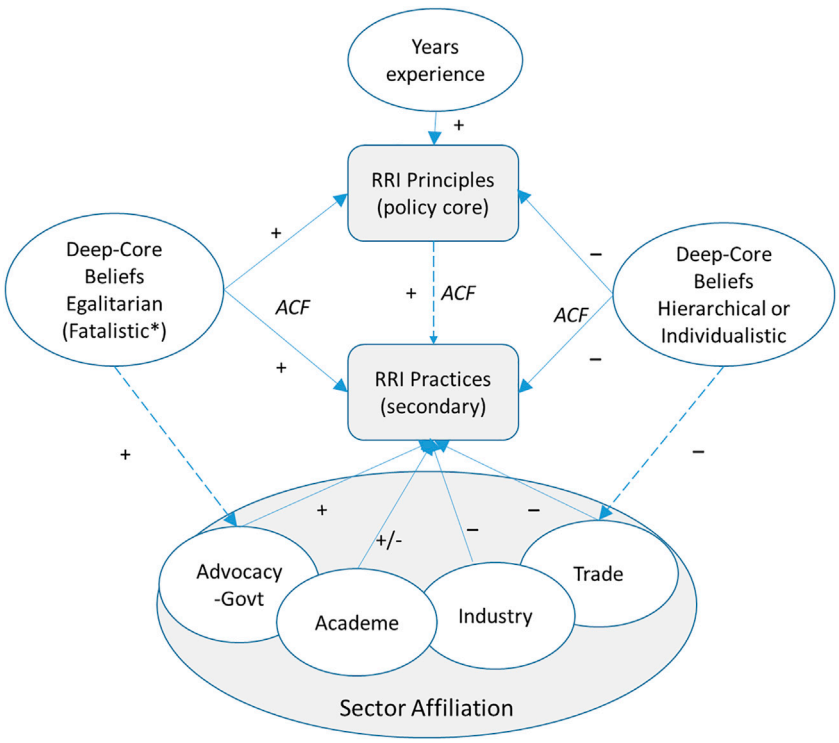

FIGURE 5 | Proposed Model for Factors Influencing RRI Beliefs in Biotechnology Stakeholders. We present this model for further testing and hypothesis building. Plus sign near arrow denotes a positive correlation, minus denotes a negative correlation. Dashed arrows indicate relationships supported by descriptive statistics (between deep-core beliefs and sector affiliation) or ACF theory (between RRI principles and practices). Note that Industry had lower egalitarian views than the sectors to the left in the diagram, but did not have higher hierarchical and individualistic world views than those sectors (see **Figure 4**). *Note also that fatalistic views were statistically significant for RRI secondary beliefs (RRI practices) at $p < 0.05$ and that the positive correlation was also found for RRI policy core beliefs (RRI principles) at $p = 0.156$ although this did not meet our significance criteria (see **Table 5**).

For the policy core beliefs (RRI principles) we found significant relationships with deep-core beliefs for all the cultural archetypes except for fatalism (**Table 5**). For RRI secondary beliefs, we found significant relationships for all of the cultural archetypes (**Table 5**). Egalitarian beliefs continued to have a strong association with positive attitudes towards RRI principles and practices, as confirmed by the regression analysis (**Table 3**; **Figure 3**) and the sample *t*-test (**Table 5**). However, we were also able to uncover through the t-tests that fatalistic beliefs positively influenced beliefs about RRI practices (secondary beliefs) albeit to a lower extent. We were also able to uncover that hierarchical and individualistic beliefs had a statistically-significant negative influence on beliefs about both RRI practices (secondary beliefs) and principles (policy core beliefs) (**Table 5**). We note that this influence is stronger for individualistic world views than for hierarchical world views.

To summarize the results, we expand on our previous model from the regression alone (**Figure 3**) to incorporate the descriptive statistics, ANOVA, and Sample *t*-test results (**Figure 5**). We present **Figure 5** as a hypothesis-generating

exercise, recognizing that our limited study does not confirm these relationships. Larger numbers of stakeholders across wider geographic regions will be needed to do so. Nevertheless, we present novel findings of these empirical relationships that can provide insights into the formulation of attitudes towards RRI policies and practices in United States biotechnology innovation systems. In closing, we now turn to a broader discussion of the model (**Figure 5**) and its potential implications for building cross-stakeholder coalitions to advocate for and implement RRI principles and practices.

DISCUSSION

Our study focused on exploring demographic, sociographic, professional, and cultural factors (deep core beliefs) factors to help explain United States biotechnology stakeholders' attitudes to RRI. In summary, no demographic or sociographic factor was found to have a significant influence on RRI attitudes. However, professional factors of years of experience and affiliation (stakeholder group), as well as cultural or deep-core beliefs, were significant predictors of biotechnology stakeholder attitudes towards RRI. It is important to note that we used study-participants comprised of biotechnology professionals from the greater Raleigh-Durham-Chapel Hill area (Research Triangle, NC). Therefore, our study conclusions are limited to the United States and this region. However, the Research Triangle provides a host of diverse biotechnology and bioscience organizations and is among the most active scientific and development regions in the United States (Rose 2015).

First, we found that those with more years of experience tended to agree more with the principles of RRI. Although we do not know the underlying reasons for this correlation, one hypothesis for our observation is that early biotechnologists experienced public backlash to their work on GMOs (Kuzma 2016; Kuzma et al., 2016; Kuzma 2018), and seeing those conflicts, now want to do a better job of bringing the public into the discussion for this next generation of gene-editing (Kokotovich and Kuzma 2014; Kuzma 2016; Kuzma et al., 2016; Kuzma 2018). Thus, it makes sense that RRI principles like inclusion, anticipation, reflexivity and responsiveness seem to resonate with those who have more experience and lived through earlier biotechnology controversies.

Next, our study is the first to find through quantitative survey research that RRI attitudes, towards both principles and practices, are strongly influenced by deep-core, cultural beliefs. Cultural beliefs have been found to underpin attitudes towards other areas of technology and risk (Douglas and Wildavsky 1982; Jones and Song 2014; Johnson and Swedlow, 2020; Kiss et al., 2020), but to our knowledge, we are the first to report this association in the context of beliefs towards RRI. (**Table 5**; **Figure 5**).

In some ways, the positive association between egalitarian beliefs and favorable RRI attitudes that we discovered is not surprising, given that several concepts of RRI originate from ideas about greater democratic participation in technological decision-making and precaution or humility towards potential technological risk (Stilgoe et al., 2013). Earlier studies find that people who hold egalitarian viewpoints are generally more concerned about technological and environmental risk (e.g., Jones and Song 2014; Johnson and Swedlow, 2020; Kiss et al., 2020), and RRI embraces the principle of anticipating these risks during early phases of research and development. Egalitarian beliefs also include strong feelings of social cohesion and equality among group members, while they eschew authority and role differentiation between group members (Jenkins-Smith et al., 2014). Therefore, egalitarian views resonate with RRI principles and practices of "inclusion" and "responsivity," which strive for an opening-up of innovation systems to the voices and desires of diverse publics.

In contrast, we found that hierarchical deep-core beliefs had a negative influence on RRI attitudes (**Table 5**; **Figure 5**) and these results also make sense theoretically. For example, by definition, hierarchs favor defined roles prescribed by institutions and thus would tend to leave technological decision making to "authorities" or experts with knowledge--these beliefs seem incongruent with RRI's principles and practices related to public inclusion and responsivity in particular. We also saw a negative correlation between individualistic deep-core beliefs and RRI attitudes (**Table 5**; **Figure 5**). Individualists believe in free-marketplaces where people can compete squarely with others, without interference. Individualists may see inclusion or responsivity, and even anticipation or reflexivity, as slowing the pace of innovation or unduly influencing free-market competition. Along these lines, Van Oudheusden (2014) noted the tendency for RRI frameworks to favor social and ethical concerns above economic and free-market concerns. For example, incorporating practices of RRI, such as being responsive to public objections to a biotechnology product or stopping development of it, could prevent the advancement of societally beneficial applications. Van Oudheusden (2014) argued that RRI is not politically or culturally neutral, which is congruent with our results showing the strong association of deep-core (cultural) beliefs with attitudes towards RRI principles and practices.

Although the above findings make theoretical sense, we did not explicitly study underlying motivations as to *why* egalitarians tend to support RRI, or *why* other cultural groups tend to oppose it (hierarchs and individualists). For example, alternative explanations for the association between egalitarianism and favorable RRI attitudes could exist. Egalitarians might have motivations for supporting RRI that relate to a desire to slow innovation given their concerns about risk. For example, in our prior work, we found that biotech developers from industry and academe were concerned about RRI practices delaying innovation (e.g., through public participation or responsive practices), thus decreasing their ability to meet funder's timelines and reducing their competitiveness (Roberts et al., 2020). As egalitarians affiliate with groups often more critical of biotech products (e.g., NGO-advocacy groups), the stalling of innovation could be an underlying motivator for wanting RRI implemented. Future research could investigate the motivations of each cultural group in the context of RRI attitudes, perhaps through qualitative interviews, to better understand the relationships

between cultural-groups, stakeholder-groups, and RRI attitudes that we uncovered in this study.

To our knowledge this is also the first inquiry that uses ACF's three tiers of beliefs (deep-core, policy-core, and secondary beliefs) for exploring the potential for coalitions to form over policies and practices for RRI. For example, ACF posits that if different groups hold divergent deep-core or policy-core beliefs, it is more difficult for them to form stable policy coalitions, as coalitions work together to translate their beliefs into policy action and implementation (which are secondary beliefs) (Jenkins-Smith et al., 2014; Ripberger et al., 2014). We designed our survey of United States biotechnology stakeholders and their RRI attitudes around the three-tier hierarchy of ACF beliefs. We also considered stakeholders' affiliations in our analysis (i.e. industry, trade orgs, academe, government, advocacy groups). Our results showed two primary coalitions that form around secondary beliefs about RRI and deep-core beliefs (more on policy-core beliefs later). One coalition consisted of two stakeholder groups---trade organizations and industry groups. This coalition viewed RRI *practices* (secondary beliefs) less positively. The other coalition consisted of government and advocacy groups and viewed RRI practices more positively (**Table 3**; **Figure 3**; **Table 5**; **Figure 5**). Academics tended to fall somewhere in between (this was also found in our previous study when we surveyed the individual practices of the four elements of RRI--Roberts et al., 2020). The coalition of trade-industry groups also tended to be slightly less egalitarian in cultural world views (deep core beliefs) than government, advocacy, or academic groups according to descriptive statistics (**Figure 4**; **Table 4**). These two major coalitions disagree on RRI implementation in particular. Differences in deep core beliefs and secondary beliefs may work against the possibility that these two coalitions (trade-industry vs. government-advocacy) would form alliances to instill RRI in United States biotechnology innovation systems.

It is important to note that the United States biotechnology innovation system has historically been polarized along stakeholder-group lines similar to the ones we found from the ACF-belief analysis. Industry and trade organizations have been fighting to convince the public and advocacy groups that there are no special risks associated with biotech products (in comparison to conventional or non-biotech products), and therefore, there is no need for people to be concerned about biotechnology risks, labeling of biotech products, or whether regulatory assessments are conducted (Kuzma 2018). In turn, advocacy groups have been fighting for better risk assessments, more transparency, and broader public inclusion in decision-making about biotech products and innovation processes, while challenging government decisions in the courts (Kokotovich and Kuzma, 2014). These two major coalitions have battled for decades for the public's minds and hearts.

On the other hand, we did not find significant differences among United States stakeholder groups with respect to policy-core beliefs, the middle tier of the ACF hierarchy (**Table 3**; **Figure 5**). That is, all stakeholder groups generally agreed on the principles of RRI (**Table 3**; **Figure 5**). The two major coalitions we found seem to differ most with regard to deep-core and secondary beliefs (industry-trade vs. advocacy-government) but not RRI principles or policy-core beliefs. Some possibilities to explain these results come to mind.

One might be that agreement with questions about RRI principles in **Table 2** arose because stakeholder groups or individuals (with potentially divergent deep-core beliefs) subscribe their own meanings to the RRI principles according to their own values or professional position. In other words, the RRI principles may be vague enough for people to interpret them to fit their own world-views. For example, the question for the RRI principle of "inclusion" ("maximizing public participation") (**Table 2**) may be translated by biotechnology developers as unidirectional "public education" or traditional "deficit model" communication (Suldovsky 2016; see also *Previous Work on Biotechnology and RRI*), while social science scholars intend it as deeper public engagement in decision making and giving voice to various publics (Stilgoe et al., 2013). So, it follows when the RRI principles (policy-core beliefs) are translated into more specific RRI practices (secondary beliefs), the industry-trade org coalition cannot sign onto them, and differences in attitudes towards RRI practices are seen between industry-trade and advocacy-government coalitions.

From a more optimistic standpoint, our results indicate that at least historically opposed coalitions can agree on the general principles of RRI applied to biotechnology innovation. Thus, there may be hope for broader coalitions to come together and implement RRI in biotechnology innovation *if suitable practices can be identified for doing so*. Stakeholder coalitions may disagree on secondary values for RRI implementation as we articulated them in this study, but it is possible that other alternatives for RRI implementation could be formulated that would be acceptable across all coalitions and still adhere to the robust version of RRI principles (Stilgoe et al., 2013).

To assess the two possibilities, future studies should bring diverse United States stakeholders together to further discuss their meanings of RRI principles (i.e., what are they reading into statements about RRI principles like the questions in **Table 2**) and articulate a broader range of potential practices for each RRI principle (i.e., what might be alternative practices to those proposed in **Table 2**). RRI practices that respect a range of cultural world views (H, I, E, F), not just egalitarian beliefs, should be considered. Translating or incentivizing RRI practices for hierarchs and individualists will be especially important given their reticence towards the socially equalizing aspects of RRI. This could be a strategy for engaging polarized coalitions in biotechnology innovation, those that may not share deep-core beliefs.

The significant institutional barriers to implementation will also need to be considered, although they are perhaps not completely separable from barriers due to cultural beliefs. Our previous work (Roberts et al., 2020) and the work of other scholars (see *Previous Work on Biotechnology and RRI*) identified barriers to RRI implementation as competition and pressures to move quickly with biotech R&D in light of funding deadlines, needs to publish first, and to gain scarce private investments. Recent work by Wittrock et al. (2021) also found "tensions between excellence criteria, premised on maximizing

grants and publications on the one hand, and making room for adherence to RRI aspects on the other." (p ix). They also theorize that "the RRI model does not fit well with the US's sociotechnical imaginary" of the United States science and technology innovation system which focuses more on governance by market mechanisms (p. 101). Other scholars note that RRI resistance among researchers and innovators is in part due to their feelings that the public does not have the requisite expertise or knowledge and may have irrational fears (Marris et al., 2015; Suldovsky 2016; Hartley et al., 2017).

These previously identified barriers have relationships to our findings about cultural world-views and RRI resistance. For example, those that hold stronger hierarchical views see governance as most-appropriate by top-down expertise and this view relates to deficit-model thinking as a barrier to RRI. Those that hold stronger individualistic cultural beliefs see governance by the free-market as most appropriate, and this view relates to competition for funding and resources as a barrier to RRI. In summation, cultural beliefs color attitudes towards RRI principles and practices, and also point to both attitudinal and institutional barriers.

In conclusion, we present the model in **Figure 5** as hypothesis testing, not confirming, and for future testing. Again, our study was limited in the numbers and geographies of participants in biotechnology innovation, and more statistical studies are needed to determine if United States stakeholder groups really do hold different deep-core beliefs which the ACF would predict to be prohibitive of stable cross-sector coalition formation around RRI. The ACF also hypothesizes that cross-coalition learning and engagement is more likely to occur where discussions focus on secondary beliefs or policy implementation rather than on differences in core beliefs (Weible et al., 2009). Although knowledge of deep-core beliefs is important for predicting long-term coalition formation, it is not as important for temporary associations of coalitions for particular short-term purposes (aka "policy flings" from Lawton and Rudd 2013). Perhaps focusing cross-sector dialogues on RRI implementation (while keeping in mind that there are differences in deep core beliefs) is a better strategy for bringing different biotechnology coalitions together to practice RRI within innovation systems. Future studies may also further the robustness of quantitative work on attitudes towards RRI practices. There is an opportunity to develop and validate a scale which measures RRI practices with greater comprehensiveness and granularity than the composite scale for RRI practices used in this study (**Table 2**; see *Study Limitations*). Surveys with a more expansive set of questions about RRI practices that are administered to a larger, and more diverse set of respondents from a variety of geographic locations, stakeholder affiliations, and science and technology arenas could replicate or expand our findings to build a more significant corpus of theoretical work in this area.

Regardless, it will be a challenge to devise suitable RRI practices that 1) remain true to social science RRI principles (ala Stilgoe et al., 2013); 2) consider institutional barriers that innovators face (Roberts et al., 2020); and 3) respect different deep-core beliefs. Yet, we remain optimistic for RRI implementation given industry desires to better include the public in dialogue about newer gene-editing methods (Kuzma et al., 2016; Center for Food Integrity, 2020), and in light of our findings that historical opponents in the biotechnology policy subsystem agree on the broad principles associated with RRI. Given that the emerging oversight system for gene-edited products in food, agriculture and the environment is lacking in public transparency and engagement in key ways (Kuzma 2018; Jaffe 2019; Kuzma and Grieger 2020), it will be important for United States biotech stakeholders to work across sectors and collaboratively construct principles and practices to be more inclusive and responsive to diverse publics and consumers in order to foster legitimacy and potentially trust. Understanding the perceptions and beliefs towards RRI across stakeholder and cultural groups is a step forward for collaborative governance, along with efforts to overcome some of the attitudinal and institutional barriers as important subsequent steps.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by NC State University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JK contributed to conception and design of the study and the collection of the data. CC contributed to the conduct of the statistical analyses. JK and CC interpreted the results. JK wrote the first draft of the manuscript. JK and CC wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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