



Social and Economic Opportunities and Challenges of Plant-Based and Cultured Meat for Rural Producers in the US

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Animal agriculture presents major sustainability challenges. Alternative meat (alt-meat) products (e.g., plant-based and cultured meat) are substitutes for animal meat products, made using innovative food technologies. The potential environmental impacts of plant-based and cultured meat have been well-explored but the social and economic impacts of alt-meat have received less attention, particularly as they relate to rural communities. This paper addresses the research question: What are social and economic opportunities and challenges of cultured and plant-based meat for rural producers in the US? We conducted semi-structured interviews with 37 expert informants, including representatives of cultured meat companies, plant-based meat companies, non-profit organizations, funding agencies, governmental agencies, and the beef, soy, and pea sectors, as well as researchers and farmers. Our interviews revealed a range of ways in which alt-meat sectors might present opportunities or threats for rural producers in the US. Opportunities included growing crops as ingredients for plant-based meat or feedstock for cultured meat; raising animals for genetic material for cultured meat; producing cultured meat in bioreactors at the farm level; transitioning into new sectors; new market opportunities for blended and hybrid animal- and alt-meat products; and new value around regenerative or high-animal welfare farming. Threats included loss of livelihood or income for ranchers and livestock producers and for farmers growing crops for animal feed; barriers to transitioning into emerging alt-meat sectors; and the possibility of exclusion from those sectors. Interviewees also identified a range of roles for universities and research organizations, government agencies, and non-profit organizations that could help to maximize the benefits and minimize the risks from emerging alt-meat sectors. Finally, most interviewees thought it likely that alt-meat would form an additional form of protein that captured some or all of the anticipated growing demand for protein rather than one that displaced animal meat entirely. As such, the emergence of alt-meat sectors alongside animal agriculture may offer more choices for rural producers in terms of which markets they sell to and what forms of production they adopt or pursue. This paper identifies numerous research gaps, to which natural and social scientists could usefully apply their attention.

Keywords: agriculture, alt-meat, farmers, livelihoods, ranchers, transitions

INTRODUCTION

Animal agriculture presents major sustainability challenges. Livestock production is associated with extensive greenhouse gas (GHG) emissions, land use change, freshwater consumption, and biodiversity loss (Machovina et al., 2015; Poore and Nemecek, 2018). High rates of consumption of some animal products is associated with elevated human health risks (Ekmekcioglu et al., 2018). At the same time, the animal agriculture sector is a significant contributor to many economies, and animal production and consumption in many places is grounded in strong cultural and social traditions (Herrero et al., 2009). Global demand for animal products is expected to increase dramatically in coming decades, as a function of both population growth and increased per capita consumption as individuals grow wealthier (Godfray et al., 2018).

Alternative meat (alt-meat) products are substitutes for animal meat products, made using innovative food technologies. *Plant-based meat* products mimic the taste, texture, and gustatory experience of conventional meat, and can function as a direct replacement for meat but contain no animal products (Cameron and O'Neill, 2019). The Impossible Burger and Beyond Burger are two of the brands to have first come to market, but a multitude of other products and companies are becoming commercially available (Cameron and O'Neill, 2019). *Cultured meat* products are produced through a process of *cellular agriculture*, which grows products (variously referred to as “clean,” “cell-based,” “cultivated,” or “lab-grown” meat) that are molecularly identical to conventional meat but produced through bioprocesses from animal cells extracted through biopsies (Specht et al., 2018; Post et al., 2020) rather than through raising and killing livestock. Multiple companies have developed cellular agriculture products at pilot stages (Post, 2012). Commercialized production is anticipated in the near-term, at least at a small scale.

If cultured and/or plant-based meat production reach a scale and price at which they are widely available and consumed, they could have significant environmental, social, and economic implications, presenting both opportunities and challenges. First, alt-meat products could have a much smaller environmental footprint than many conventional animal meat products. Life cycle analyses suggest that GHG emissions, land use, and water use could be lower than some animal meats for both plant-based (Goldstein et al., 2017; Heller and Keoleian, 2018) and cultured meat (Tuomisto and Teixeira de Mattos, 2011; Tuomisto et al., 2014; Tuomisto, 2019), and that plant-based meat is likely to have a lower aggregate footprint than cultured meat (Santo et al., 2020). However, some LCAs suggest that energy demands could be much higher for cultured meat than animal meat (Mattick et al., 2015b; Tuomisto, 2019). Second, cultured and plant-based meat products could substantially reduce concerns about animal welfare in the meat production process. Third, cultured and plant-based meat products could confer public and individual health benefits, by reducing antibiotic use and lessening the likelihood of foodborne illness (Mayhall, 2019; Espinosa et al., 2020; Santo et al., 2020).

Finally, cultured and/or plant based meat production could have socio-economic implications for jurisdictions (i.e.,

countries, states, and provinces) with strong rural economies that depend on animal agriculture (Santo et al., 2020). On the one hand, they could alter the livelihoods, culture, and traditions of rural producers and communities. At the same time, some jurisdictions may be able to create jobs and income by harnessing new economic opportunities associated with an emerging cultured and/or plant-based meat sector and their supply chains. These potential social and economic impacts of cultured and plant-based meat have received less attention particularly as they relate to rural communities (Stephens et al., 2018; Broad, 2020). Ranchers, farmers, and others involved both in animal agriculture and crop agriculture supply chains may experience threats and also new opportunities from the emergence of cultured and plant-based meat sectors at scale (van der Weele and Tramper, 2014; Stephens et al., 2018; Broad, 2020).

This paper addresses the research question: What are social and economic opportunities and challenges of cultured and plant-based meat for rural producers in the US? The paper focuses on the US: while these are potentially global transitions, the early plant-based meat products launched first in the US and the US may be among the first places that cultured meat products are commercially produced and sold.

METHODS

Data Collection

We conducted semi-structured interviews with 37 expert informants. Interviewees included representatives of cultured meat companies, plant-based meat companies, non-profit organizations, funding agencies, governmental agencies, and the beef, soy, and pea sectors, as well as researchers and farmers (**Table 1**). We aimed to get representation from a wide variety of perspectives, and identified interviewees in three ways: through our own networks of relevant contacts; by soliciting suggestions from two colleagues working in the plant-based and cultured meat sectors; and through snowball sampling whereby each interviewee was asked whether they had suggestions of other experts with whom it might be useful to talk. In addition to the 37 interviewees, we reached out to a further 27 people who for various reasons (e.g., declined, did not respond, were unavailable) we were unable to interview. We do not have sufficient information to determine whether there were any significant differences between those people that we interviewed and those that we reached out to but did not interview. Among our interviewees, there were a larger number of individuals whose experience was in alternative protein sectors than in conventional agriculture. This skew may have been indicative of the types of people who had spent time thinking about these topics and who were thus recommended to us by other interviewees.

Interviews were structured around a common set of questions (**Supplementary Table 1**). The principal aim of the interviews was to understand the perspectives of different stakeholders as to (a) the opportunities and/or threats that plant-based and/or cultured meat represent to rural producers in the US, including any evidence of these opportunities and/or risks or threats manifesting, and (b) the pathways or mechanisms that might optimize these outcomes for rural producers. Interviews were

TABLE 1 | Interviewees and their relevant expertise.

Sector	Job title	Thematic expertise
Funding agency: federal	Program Director	Crops
Funding agency: private	Research Director	Plant-based and cultured meat
Funding agency: private	Program Strategist	Climate, food, and agriculture
Funding agency: private	CEO	Venture capital in alt-meat
Government	Agriculture Marketing Specialist	Agricultural marketing
Government	Agricultural Economist	Animal and plant health
Non-profit	Associate Director of Science and Technology	Plant-based and cultured meat
Non-profit	President	Animal welfare; farmer transitions
Non-profit	Economist	Animal welfare
Non-profit	Co-Founder and Executive Director	Cultured meat
Non-profit	Cellular agriculture specialist	Cultured meat
Non-profit	Program Director	Extension, public policy
Non-profit	Regional Manager	Farmer transitions
Non-profit: communications	Founder and Editor	Cultured meat
Non-profit: museum	Director of Collections, Exhibits and Research	Cattle ranching
Non-profit; private sector	Consultant	Cultured meat
Philanthropy	Program Officer	Farm animal welfare
Private sector	Technical Consultant in Sustainability	Cattle ranching
Private sector	Senior Manager in Corporate Development	Soy sector
Private sector	Agriculture Consultant	Plant-based meat industry
Private sector	Senior Manager of Communications	Cellular agr industry
Private sector	Founder	Plant-based meat
Private sector	Farmer	Crops
Private sector	Senior Advisor	Investor network
Private sector	Founder	Cultured meat
Private sector	Director of Policy and Strategic Partnership	Cultured seafood
Private sector	Farmer; CEO and Co-Founder	Animal agriculture; cultured meat
Private sector	Co-Founder and Product Lead	Cultured meat
Private sector	Co-Founder and CEO	Cultured meat
Private sector	Vice President of Communications	Plant-based meat industry
Private sector	Co-Founder and CEO	Cultured dairy
Research	Professor	Agricultural economics
Research	Assistant Professor	Food justice
Research	Research Fellow	Cultured meat
Research	Professor	Ethics; cultured meat
Trade association	Vice President of Marketing	Pea and lentil sector
Trade association	Executive Director of Producer Education	Beef sector

conducted by Zoom and were recorded, with the consent of the interviewees, to facilitate note taking. Interviews were conducted between April 8 and June 18, 2020. Interviews lasted between 30 and 95 minutes (mean = 40 minutes).

Data Analysis

The qualitative interview data were transcribed in OneNote (Fernando and Barbeiro, 2014). We used these transcribed interviews to identify a suite of social and economic opportunities and threats that might conceivably result from a scaled-up cultured and/or plant-based meat sector. We report our findings in aggregate and anonymously, not attributing any specific idea or perspective to any individual interviewee. The entire content of the Results section that follows is drawn directly from our interviews. In the Discussion section that follows that, we add our own interpretation of our findings and relate those findings to the broader literature.

RESULTS

Our interviews revealed a range of ways in which a plant-based and/or cultured meat (*alt-meat*, from hereon) sector might present opportunities or threats for rural producers in the US. Here, we outline these potential impact pathways in detail, organized by the constituencies of people that might be principally affected by each. These constituencies include ranchers and farmers currently working in the animal agriculture sector (e.g., raising animals or producing animal feed), as well as farmers that might produce the crops needed for emerging alt-meat sectors, and rural communities in ranching and farming regions.

Although we did not ask our interviewees about their opinions on the likelihood of alt-meat scaling up, our questions did ask them to assume a scenario in which this occurred. As such, many respondents did offer an opinion on the feasibility, timescale, and/or likely magnitude of these scaling up processes as a precursor to, or caveat of, their responses. Interviewees held a range of views on the degree to which they thought alt-meat will scale up, and what “to scale up” might mean. These views related both to the likelihood of alt-meat gaining significant market traction, and to the extent of the impact of alt-meat on animal agriculture. On the first point, a minority of respondents (principally from the animal agriculture sector) did not believe that it was likely or possible that alt-meat would scale to any meaningful degree. However, most respondents thought that alt-meat would gain significant market traction. On the second point, some respondents believed that alt-meat would principally meet a growing demand for protein, as a result of total protein demand growing as fast or faster than alt-meat production. Other respondents thought alt-meat would scale to such a degree that it would reduce animal meat production from its current level. Again, opinions varied widely on the likely magnitude of that reduction and the proportion of the protein market that alt-meat might eventually account for, but none thought it likely that animal agriculture would be completely displaced in the foreseeable future.

Opportunities

The growth of alt-meat sectors could generate several opportunities for people who work in agriculture, with crops or livestock. Such opportunities could accrue to new and beginning farmers who might be attracted to agriculture by new opportunities, as well as to those currently working in agriculture, whose products might gain additional value in these new sectors and/or who might diversify or transition their livelihoods. A cross-cutting observation that many interviewees made is that the emergence of alt-meat sectors alongside traditional animal agriculture would, broadly speaking, offer more choices for rural producers in terms of which markets they sell to and what forms of production they adopt or pursue. To the extent that some rural producers currently have limited options, additional sectors and supply chains could offer more alternatives. Many interviewees also noted that the emergence of new sectors could represent an opportunity for transitions to systems that are more equitable and fair for farmers and rural workers than the status quo.

Opportunities for Crop-Growing Farmers

Growing Ingredients for Plant-Based Meat

Growth in the plant-based meat sector is likely to create additional demand for various crops as sources of plant proteins, in turn creating a suite of opportunities for farmers that currently grow those crops or who could adopt them into their rotations. Demand for commodity crops from plant-based meat companies may create additional market opportunities for some farmers. For example, since soy is the main plant protein in Impossible Foods' products, soy farmers now have the possibility of selling to plant-based meat companies as well as to traditional commodity markets. While the first plant-based meat companies are to some degree constrained in their ingredient choice by the availability of existing commodity crop supply chains, as the sector expands there is likely to be opportunities for a greater diversity of specialist and higher-value plant protein crops, such as peas, lentils, mung beans, and other legumes. Exemplifying this opportunity, interviewees noted that pea demand in the US has increased dramatically in recent years, in part in response to demand from Beyond Meat, a plant-based meat company that uses pea protein as its main plant ingredient. As the plant-based meat sector grows, and other companies achieve the scale of Impossible Foods and Beyond Meat, many of our interviewees expected that demand for plant proteins would continue to increase.

Growth in demand for US-grown soy, peas, lentils, and other legumes for plant-based meat could result from a greater emphasis on domestic sourcing and on traceability. Currently, a majority of plant proteins are sourced from outside the US and there is little traceability of crops. But growing demand among companies and their consumers for domestically-sourced inputs could expand opportunities for US growers.

There may be several economic opportunities for farmers who are willing and able to adapt their production and to sell to some of these emerging supply chains. First, some of these crops could be more profitable. Second, production could represent a chance for farmers to diversify their income sources, in turn offering

greater resilience. Third, because many leguminous crops can be incorporated into rotations with double-cropping, they could represent an additional rather than alternative source of income.

Finally, adoption of plant protein crops could bring environmental as well as economic benefits. Leguminous crops could enhance soil health, reduce the need for fertilizer application, stabilize soils, increase water holding capacity and infiltration, and reduce runoff.

Growing Feedstock for Cultured Meat

The demand for feedstock as an input for the cultured meat sector (e.g., to produce cell culture medium, growth factors, and scaffolding), and the associated opportunities and challenges for rural producers, are much less certain. Largely, this is because cultured meat is currently being produced only at R&D scale, using inputs developed primarily for the pharmaceutical industry. There was broad agreement among our interviewees that when cultured meat scales up, it will need alternative non-pharmaceutical grade sources of cell culture medium and growth factors (including amino acids, sugars, and an alternative to fetal bovine serum). But there was divergence of opinion about the likely source of these products.

Some interviewees considered it likely that traditional agricultural crops would be the source of those inputs. If crops (e.g., barley, beets, corn, peas, soy, sugarcane, wheat) are demanded, that may create additional market opportunities for farmers growing those crops. For example, a company in Europe is using barley as a key ingredient for producing growth factors for cultured meat production, and soy has been demonstrated as a viable basis of scaffolding.

In contrast, some interviewees, including those working directly on developing cell culture medium for cellular agriculture, thought it more likely that sources other than traditional crops would be more important. Algae, fungi, seaweed, yeast, and fermentation processes were all mentioned as possible sources. Such alternatives could still provide opportunities for rural producers. But some of these alternatives may not be optimally produced on the same land as traditional agricultural crops, and the transition for a crop farmer to produce some of these alternatives might not straightforward. Some interviewees noted that some of these options could present greater flexibility than traditional crops in terms of where and how they are grown. For example, cell culture fermentation could use feedstocks and inputs that could be grown in places that are not currently suitable for arable crops, though this would not necessarily result in environmental benefits.

Opportunities for Ranchers and Livestock Farmers

Genetic Material for Cultured Meat

Cultured meat production requires a small number of cells that are originally sourced from a living animal. Many interviewees identified an opportunity within the cultured meat sector for livestock producers who might maintain a small herd of animals as a source of cells. Particularly of interest might be heritage breeds and other high-value animals, including those that thrive in specific geographies. Such herds might be maintained in perpetuity, since one model of cellular agriculture would demand

frequent input of new animal cells. A specific example is that of the company JUST collaborating with cattle ranchers in Japan to provide cells from specialty Wagyu cows. We did not gain any insights as to how financially lucrative such a venture might be. But it is likely that only a tiny fraction of all livestock producers could benefit from this business model, since the amount of cultured meat that can be produced from one cow is much greater than the amount of animal meat that can be produced from the same cow. This is both because the same animal could be used as a source of cells for many years, and because one small biopsy could generate a large amount of cultured meat. A final constraint on this possible opportunity is that at least one prominent cellular agriculture company expressed an ambition to eventually achieve indefinite self-renewal of animal cells (i.e., immortal cell lines), which would eliminate any reliance on new animal cell inputs into the system.

Bioreactors on Farms

In relation to cultured meat, many interviewees discussed the possibility of a highly distributed production system. This may be possible in principle because the bioreactor technology needed to produce cultured meat can be developed at a range of sizes, and can be located anywhere. This flexibility in scale and geography could lend itself to a model of more localized production, including on farms themselves. In such a model, an individual farmer might operate a small- or medium-scale bioreactor on their farm. Analogous models might include craft breweries, or dairy farms that produce their own yogurt. Such a model would enable small-batch production of cultured meats on individual farms. It would fit with consumer demand for small, local, micro-customized, niche products. A form of agri-tourism could develop around this. Possibilities mentioned included local variations in meat flavors and profiles; opportunities to learn about the cultured meat production process; and having the original animals from which the cell lines were sourced still living on the same farm. Indeed, this model could also be compatible with maintaining traditional animal agriculture on the same farm.

Some interviewees were skeptical of this kind of hyper-localized model, citing concerns about the affordability and cost effectiveness of small bioreactors, the investment required from farmers, and the skills required to operate the technology. Other interviewees thought that cultured meat production would likely be relatively centralized and close to more densely-populated areas, but that it is conceivable that farm-scale entrepreneurship could exist contemporaneously with industrial-scale production facilities. They again cited the brewery analogy, whereby the largest breweries are centralized but craft brewers are also successful.

Transition Into New Sectors

Alt-meat sectors could offer opportunities for animal farmers to diversify or transition completely into the production of plants, algae, mycoprotein, seaweed, or other alternative protein products. Such a diversification or transition could include repurposing some of their land and/or existing infrastructure. Some examples include former dairy farmers in the US and

elsewhere (e.g., those who have worked with the oat drink company Oatly) who have transitioned into oat production. A second example is former chicken farmers (e.g., those who have worked with Mercy for Animals' Transformation project) who have converted their poultry sheds as part of a transition into mushroom production. As a final example, Refarm'd is working with former dairy farmers to transition into animal sanctuaries and to produce plant-based milk. Some interviewees suggested that many livestock farmers, especially contract farmers in vertically integrated supply chains, might transition to alternative forms of production if they could.

Regenerative Agriculture and High-Animal Welfare Farming

Most of our interviewees believed that even in a future scenario in which alt-meat accounted for a large proportion of protein demand, and thus replaced some or even most animal meat from large-scale animal agriculture, there would likely remain a role for some forms of animal agriculture. In particular, many interviewees pointed to the possibility that lower-intensity, relatively high-animal welfare, animal agriculture could flourish under such a scenario. They speculated that alt-meat might primarily compete with animal meat on taste, price, and convenience and that it would therefore compete foremost with large-scale animal meat production. More traditional forms of animal agriculture could offer a different value proposition. For example, such farms could retain food narratives (e.g., the story of ranching in the American West), could highlight the role of small-scale, independent, and family-farmers, and could differentiate themselves with value claims such as being pasture-based, organic, and/or regenerative. Producers operating such farms might actually benefit from these greater distinctions between their products and those of alt-meat products, relative to their current competition with large-scale animal agriculture.

Co-production

Interviewees mentioned two ways in which alt-meat production might be relatively compatible with current livestock farming. First, there is already a market for hybrid or blended products that combine plant-based meat with animal meat. If cultured meat can eventually be produced at lower cost than conventional meat, it could also be used in blended products that are still primarily comprised of animal meat. This could reduce the price of the product and maintain the competitiveness of animal agriculture. It could also enable animal farmers to access new markets or to create products with a lower environmental footprint. Second, farmers could play a role in creating consumer products using cultured meat or dairy products. For example, the cellular agriculture milk company Legendairy Foods is considering supplying milk proteins to others for them to produce cheese and other dairy products. There may be an opportunity for existing artisanal dairy producers to use their product.

Opportunities for Rural Communities

Jobs in Production Facilities

Plant-based and cultured meat production facilities could create new employment opportunities in rural areas. One possible

model for a plant-based or cultured meat sector at scale could involve relatively large production facilities, which might be situated in traditionally agricultural states (e.g., Maple Leaf recently constructed a new \$310 m facility in Indiana; Beyond Meat's production is in Missouri). Similarly, bioreactors could be in rural areas rather than cities. Both forms of alt-meat production are somewhat geographically flexible. But in both cases, depending on the feedstocks demanded, locating facilities in rural communities could situate them near input crops, thus reducing transportation costs at that stage in the supply chain. Any such plant-based or cultured meat facility in a rural area could create numerous jobs, though some interviewees indicated that plant-based meat facilities tend to be more automated (and thus create fewer jobs) than animal meat processing facilities. If jobs in alt-meat production facilities are available as an alternative to jobs in animal meat production facilities, then that could represent an improvement for those laborers, since jobs in slaughterhouses are often viewed as among the most difficult and dangerous of labor roles, including low pay, exploitation, and high risk. Alt-meat production facilities could offer an improvement in safety, standards, and opportunities.

A related opportunity is to repurpose existing infrastructure. The company Rebellious Foods has converted animal meat processing facilities into plant-based meat processing facilities. Since the two types of food processing facilities are fulfilling similar functions, the scale of operations, and the types of jobs are somewhat similar.

Food Security

A few interviewees mentioned opportunities for greater food security, particularly if the cost of alt-meat were to be lower than the current costs of animal meat. In addition, the anticipated geographic flexibility over where cultured meat can be produced could mean better food access for rural and remote communities. For example, cultured seafood could be produced in locations far from coasts, and communities with limited accessibility to traditional animal meat supply chains could be better-positioned to produce cultured meat locally.

Health, Safety, and Quality of Life

Interviewees noted that alt-meat production could reduce some of the health risks faced by rural communities, which are associated with animal agriculture. For example, air and water pollution generated by manure would not be a concern for communities living near alt-meat facilities.

Other Uses for Land

The amount of land required to cultivate ingredients and feedstocks for plant-based and cultured meat, respectively, is projected to be far less than the amount of land required for animal agriculture. So, all else being equal, if alt-meat displaced some significant proportion of animal agriculture that could release significant areas of rangeland, pasture, and/or arable cropland from food production. In such a scenario, one potential revenue stream for landowners could be payments (e.g., from governments) for ecosystem services such as

carbon sequestration or biodiversity conservation generated by habitat restoration.

Threats

The degree to which alt-meat represents a direct risk to farmers, ranchers, and livestock producers depends not only on whether alt-meat technologies scale up, but also on whether they will scale to such a degree that they will reduce animal meat production from its current level. Our interviewees held differing opinions on that point. Most interviewees believed that it is extremely unlikely that there could be a complete transition from animal meat consumption to alt-meat consumption in the near future. Many interviewees also believed that alt-meat would principally meet a growing demand for protein and would not therefore dramatically reduce current demand for animal meat in the near future. Such interviewees therefore concluded that the fear that farmers and ranchers within traditional animal agriculture would necessarily suffer economic and livelihood loss is not well-founded. In any case, they noted, any transition would be gradual over a course of decades rather than abrupt. As such, farmers and other incumbent actors would have time to adjust, adapt, and/or transition as appropriate. Some interviewees pointed to past transitions in food systems (e.g., the Green Revolution; the growth of aquaculture; the trend toward chicken as a preferred animal meat in the US) as sources of lessons about the rate, type, and impacts of any such changes.

The scale of any threat from the emergence of alt-meat was also weighed by many interviewees against other threats to the social, economic, and cultural well-being of ranchers, farmers, and rural communities. They collectively named several concurrent trends that many of them thought might affect the animal agriculture sector more than any possible competition from alt-meat. For example, the aging farmer population and the gap that could leave in the demographics of the rural sector was frequently mentioned. A second trend was that of consolidation, whereby smaller farms and ranches tend to be subsumed by larger operations. Several interviewees cited the dairy industry as an example whereby many farms are struggling or have closed, which may in part be driven by consumer shifts toward non-dairy alternatives but is also a consequence of consolidation, falling margins, and trade wars.

A number of possible risks and threats were identified by our interviewees that, similarly to the opportunities, related to crop growing farmers, ranchers and livestock producers, and rural communities more broadly. We report on each of these in turn below, but first outline some more generic and cross-cutting risks identified in our interviews.

First, some interviewees noted that the large size of the animal agriculture industry in the US, including the feed industry, means that even a small percentage decrease in demand (including due to competition from alt-meat products) could have a large and significant absolute impact in terms of income and livelihoods. As such, some interviewees thought that many individuals and communities dependent on animal agriculture for their livelihoods or business viability did in fact view the emergence of alt-meat industries as a direct threat, even while it may not threaten the survival of the sector as a whole. For example, one

interviewee cited a projection by consultancy group AT Kearney that by 2040 less than half of meat consumed will come from animals; the report received significant media attention and so may have informed the risk perception of some producers.

Second, and in contrast, a concern raised by several interviewees who were not directly involved in the alt-meat sectors was that much of the expectation and optimism from those who advocate for, or who are working on developing, alt-meat products could be overblown or unfounded. That is, several interviewees did not share any certainty that alt-meat would scale up and account for any significant proportion of meat consumption. This scenario would represent risk for farmers if they made investments or committed to transitions in anticipation of a scaled up alt-meat sector that did not subsequently materialize.

Third, some interviewees thought that a significant risk is that in a scenario where alt-meat production and consumption did scale up significantly, a few large companies would capture the majority of the benefit. They highlighted the risks to individual farmers if a few producers monopolized the sector. This could occur if the technologies involved (e.g., bioreactors) developed in such a way that they were unaffordable or inaccessible to farmers or if there were other economies of scale. As such, interviewees thought that while farmers could benefit from the emergence of these sectors, there was no guarantee that a new system would be fairer, more equitable, or beneficial to individual farmers. Many interviewees emphasized a need to include farmers and ranchers in discussions and decisions around transitions, to represent their interests and to ensure best-possible outcomes for them.

Finally, a broader, more conceptual risk that one interviewee identified is if there were to be a rapid shift in the social narrative around food, and meat in particular. They considered it plausible that the advent and adoption of alt-meat at small scale could quickly make traditional farming methods seem out of date and inefficient, or immoral. A social sentiment might form, and spread, that animals should not be farmed at all.

Threats for Crop-Growing Farmers

Many of the threats or risks to crop-growing farmers that were mentioned in the interviews related to the barriers to transitioning into alternative crops. Interviewees noted that many commodity crop-growing farmers are relatively locked into production for the animal feed sector. Much of their physical, human, social, and financial capital may be tied to corn and soy production in ways that could make it difficult to transition into alternatives or that would make transitions too costly. For example, to adopt alternative plant protein crop rotations might require different tillage and harvesting equipment, and it might be more difficult to secure crop insurance or to persuade lenders to award credit for new crops that might be considered riskier. Factors beyond the farm gate could also present barriers, including a lack of reliable well-established markets to sell into, and an absence of infrastructure (e.g., elevator facilities) to support those supply chains.

Some interviewees speculated that if alt-meat displaced animal agriculture to any degree, the projected efficiency, relative to animal meat, of conversion ratios of crop inputs to alt-meat

outputs could lead to a net reduction in the total amount of crops required. This could then reduce the total arable land area, and in turn perhaps reduce the number of farmers needed to cultivate that land.

Threats for Ranchers and Livestock Farmers

Cattle Ranchers

Fewer risks were identified by interviewees for cattle ranchers. In particular, interviewees were relatively unconcerned about risks for cow-calf ranchers. They noted that a majority of calves come from small (<200 head) operations, whose owners usually have other sources of income. Many cow-calf ranchers keep cattle on their properties as a second form of income, or for tax benefits (since farmland in many states is taxed more favorably). Others maintain herds of cattle for the pleasure, culture, or lifestyle of doing so. Even if the sector were to decline, many such ranchers are not solely financially dependent on that income.

In contrast, a small number of ranchers account for a majority of cattle feeding and fattening operations. These large cattle feeders are not hobbyists, and would be more affected by any decline in the sector. However, as we note above, many interviewees did not believe that the animal meat sector was threatened by the alt-meat sector in the near future. Even if it were to be, it is possible that the competition would be primarily with chicken and pig meat rather than with cattle.

Chicken and Pig Farmers

The risks were considered to be greatest for individuals raising chickens and pigs, many of whom are locked into consolidated, vertically-integrated systems by virtue of unfavorable contracts. Several interviewees noted that the large corporations (e.g., Cargill, Tyson) that contract with these farmers have themselves invested in alt-meat and could relatively easily shift their business model if they wanted to. However, there are fewer obvious opportunities or alternatives for these individuals, and this situation is compounded by the debt that many are in. Additionally, in many cases their land may not be viable for alternative forms of food production. There are cases where former chicken farmers had repurposed their sheds (e.g., to grow mushrooms) but such transitions have not happened at large scale. As such, a shift away from these forms of meat production for any reason could leave contract farmers behind without viable alternatives.

Threats for Rural Communities

While a localized model of alt-meat production is one possibility (section Opportunities for Rural Communities), another plausible pathway is that bioreactor facilities could be located in or near urban areas. Companies might be motivated to situate facilities in proximity to urban areas to reduce transportation costs of their products, or in rust-belt cities to stimulate job creation and economic opportunities. Additionally, it could be impractical to establish alt-meat production facilities in very rural communities, due to an absence of networks and infrastructure. As such, at least in principle, the process of meat production could be decoupled from a dependence on rural

areas and rural communities, depriving those communities of opportunities from these new sectors.

Potential Roles for Different Actors Outside the Private Sector

Interviewees referred to a number of potential roles for actors outside the private sector that could help to maximize the benefits and minimize the threats that they had identified. We discuss these briefly below, categorized into roles that could be played, respectively, by universities and research organizations, government agencies, and non-profit organizations.

Universities and Research Organizations

There are numerous opportunities for researchers to contribute knowledge and understanding in ways that might maximize the benefits and minimize the risks described above. First, if alt-meat sectors will bring opportunities, then research that accelerates the rate at which those products reach the market and scale up, for example through open-source technology and publicly-available data, could be beneficial. There are multiple common needs across the cultured meat industry, including the need for effective scaffolds and cell culture media. There is also a need for basic crop science and development of new variants optimized for alt-meat products. Second, interviewees called for research on the impacts of transitions. There is little systematic understanding of the pathways that could support just transitions for farmers from a protein system oriented around animal agriculture to one where plant-based or cultured meat play a larger role. Rigorous social science and systems thinking, including analyses of the economic costs and benefits of alt-meat for farmers in the US, could help to identify and quantify the opportunities for rural America. Finally, there may be a role for agricultural extension staff in supporting crop transitions.

Government Agencies

Various governmental agencies could play a role in facilitating and catalyzing transitions to a world in which alt-meat plays a role in meeting protein demand. First, regulatory clarity could help to provide a clear path to market for alt-meat products. Significant issues to resolve include those of labeling and of inspection processes. Second, governments could play a role in incentivizing land transitions, for example by providing tax credits for rewilding unused land. Third, public funding could help to support the types of research indicated in section Universities and Research Organizations, including the development of open source technologies that are needed across the alt-meat sector and that would be more costly and slower to develop privately. Fourth, governments could remove, reduce, or reallocate subsidies and support for animal agriculture, to create a more level playing field for alt-meat companies. Fifth, governments could create and/or support policies and programs that support just transitions for farmers and rural communities, including debt forgiveness, compensating for losses incurred, and funding (re)training initiatives. Finally, governments could promote job creation and economic benefits by incentivizing companies to establish production facilities in historically marginalized or disadvantaged communities.

Non-profit Organizations

Non-governmental organizations (NGOs) and other non-profit organizations could play various roles to facilitate and catalyze transitions. First, some NGOs could play a useful role in communication and dialogue. They could convene a diversity of stakeholders for open conversations that are amicable rather than adversarial. Avenues for collaboration and communication may be critical throughout the development of alt-meat products, including to navigate complex and potentially political discussions around labeling. Such dialogues could be important to enable farmers and ranchers to thrive both in the animal meat and alt-meat sectors. Second, there could be a role for non-profit groups in facilitating rural transitions, including through retraining, and subsidizing transition costs. Transition programs can be imperative to support farmers in gap periods as they shift between production models, although such programs could also be led by government agencies. Non-profits could also advocate for coalitions of labor groups that represent the interests of rural workers. Third, some non-profit organizations have demonstrated utility in advocating for an even playing field. A single non-profit may be able to represent the interests of a majority of alt-meat companies as they relate to policy, regulation, labeling, and research funding. The Good Food Institute is a prominent example of this role. Integral to all three of these roles is a cross-cutting theme of education and awareness. This could include alerting farmers, ranchers, and communities to forthcoming change, and giving them the information and tools they need to prepare and to capitalize on opportunities or to mitigate risks. It could also include engaging particularly with younger people, and drawing their attention to the skills and knowledge that they might need in order to engage in and benefit from jobs in these new alt-meat sectors. Finally, some interviewees cautioned that while non-profits can facilitate positive change, there is also possibility for harm. Many non-profits are mission-driven, and are variously motivated by environmental, health, or animal welfare concerns. To the extent that this leads to mixed messaging, inaccurate information, or conflict with incumbent actors there exists the possibility of hindering rather than helping outcomes for rural producers.

DISCUSSION

Summary of Results

Our research identifies and maps out different ways in which the advent of commercialized cultured meat and/or a scaled-up plant-based meat sector (collectively, *alt-meat*) could affect outcomes among different stakeholders in rural parts of the US. Our interviews revealed that if alt-meat scales up, it could create a range of opportunities and challenges. Most of our interviewees did not imagine a near-term scenario in which alt-meat completely replaces animal meat. A complete substitution has been prominently advocated by some groups (e.g., Good Food Institute), and has been stated as an objective by some companies (e.g., Impossible Foods). But among our interviewees, even most of those that envisioned rapid growth in and adoption of alt-meat thought it likely that it would form an additional form of protein that captured some or all of the anticipated

growing demand for protein rather than one that displaced animal meat entirely.

We categorized the opportunities and threats identified by interviewees as variously being relevant to crop farmers, ranchers and livestock producers, and rural communities more broadly. While much of the media coverage and narratives told about cultured meat and plant-based meat have envisioned these sectors as necessarily being at odds with animal agriculture, our interviews revealed a range of opportunities and complementarities that might also emerge. Opportunities included growing crops as ingredients for plant-based meat or feedstock for cultured meat; raising animals for genetic material for cultured meat; producing cultured meat in bioreactors at the farm level; transitioning into new sectors; new market opportunities for blended and hybrid animal- and alt-meat products; and new value around regenerative or high-animal welfare farming. Threats included loss of livelihood or income for ranchers and livestock producers and for farmers growing crops for animal feed; barriers to transitioning into emerging alt-meat sectors; and the possibility of exclusion from those sectors. Finally, interviewees identified a range of roles for universities and research organizations, government agencies, and non-profit organizations that could help to maximize the benefits and minimize the risks from emerging alt-meat sectors.

Additional Opportunities and Costs

Our interviewees represented a range of experiences and perspectives across the plant-based meat, cultured meat, and animal agriculture sectors. We do not know how close our interviews came to exhausting the list of possible opportunities and threats, although we did detect a plateauing of our exposure to new ideas as we neared the end of our interview process. That said, as authors, we can conceive of other plausible social and economic impacts that could affect rural producers. For example, opportunities might emerge if alt-meat were to cost less than animal meat, since total demand for meat could then increase. Similarly, if blending alt-meat with niche (e.g., pasture-fed or heritage) animal-meat were to reduce consumer prices then that could also increase total demand. Plausible threats that were not mentioned in our interviews include the possibility that if cropland or grazing land falls in value due to reduced demand for animal products or animal feed, producers could face greater pressure to sell it to other producers, leading to greater consolidation, or to real estate or other land use developers. Second, if cropland is increasingly used to grow ingredients for alt-meat markets, the supply of land for other markets (e.g., biofuel, animal feed) may shrink. Third, to the degree that ranchers or feedlots are affected by the emergence of alt-meat, the livelihoods of people working in other parts of the livestock supply chain (e.g., feedlot workers, veterinarians, and employees of animal feed manufacturers) could also be affected. Finally, any reduction in domestic demand for animal meat or feed crops in the US could potentially be compensated for by the expansion of exports, mitigating the impact on domestic producers but negatively impacting producers in other countries.

There are also nuances that did not arise in the interviews but that are relevant to these opportunities and risks. For example,

while some farmers may be able to produce the same crops (e.g., soy) for a plant-based meat sector as they currently do for the animal feed sector, the plant-based meat sector may demand different varieties (e.g., with higher protein content) or management practices (e.g., organic) that could complicate a transition.

Prior Research on the Socio-Economic Impacts of Alt-Meat

Relatively little research has addressed the system-wide socio-economic dimensions of alt-meat. Much more research on alt-meat focuses on the technological breakthroughs and limitations, and on the anticipated consumer acceptance of and attitudes toward alt-meat (Bryant and Barnett, 2018; Post et al., 2020). This is understandable, given the nascent nature of these technologies and the limited degree to which even plant-based meat has scaled up to date. Yet there is a need for systems-wide analyses for alt-meat, including to anticipate unintended and as yet unforeseen consequences (Mattick et al., 2015a). A few of the issues raised in this paper have received at least some attention from researchers, including discussion of potential sources of cell culture medium for cultured meat and of potential distributed production models. We briefly discuss the intersection of our findings with previous research on alt-meat here.

Our interviewees mentioned various possible sources of ingredients for plant-based meat and feedstock for cultured meat. A recent review of the scientific, sustainability, and regulatory challenges of cultured meat similarly named inputs created through fermentation and biomass (e.g., algae) as possible sources of cell culture medium (Post et al., 2020). More traditional crops may also be used as inputs for both plant-based and cultured meat, though the impacts of alt-meat on rural landscapes will depend in part on the production systems used to grow these inputs (Broad, 2019, 2020).

Many of our interviewees mentioned the possibility of decentralized models of alt-meat production, including production of cultured meat with small-scale bioreactors on individual farms. Often likened to the micro-brewery model, the possible benefits of and limits to such a distributed system have been considered by a number of authors (Stephens et al., 2018; Jönsson, 2020). Some evidence suggests that such a model could promote societal acceptance of cultured meat and reduce concerns related to the perceived unnaturalness of cultured meat (van der Weele and Driessen, 2013; van der Weele and Tramper, 2014).

Some of the other ideas raised by our interviewees have also been discussed in the literature, though often only to a limited degree. For example, Broad (2019) discussed alt-meat from a food justice lens. Stephens et al. (2018) identified a suite of knowledge gaps about the system-wide implications of cultured meat. Mylan et al. (2019) observed crop diversification among farmers who were engaging with the emerging plant-based milk sector. And both Mylan et al. (2019) and Tziva et al. (2020) identified the challenge of farmers being locked into animal agriculture as a barrier to embracing plant-based alternatives.

Future Research

Many of the impact pathways identified in this paper have not been well-explored by researchers. As such, this paper identifies numerous research gaps, to which natural and social scientists could usefully apply their attention. First, while this study identifies possible impact pathways, the data collected here were insufficient to differentiate these possible impacts with respect to their likelihood, anticipated timeframe, magnitude, or the stakeholders affected. To the extent that these characteristics can be quantified, these refinements might help decision-makers and researchers to understand the possible impacts of these sectors and to strategically target or prioritize any response. Second, it may be useful to map the opportunities and challenges associated with alt-meat, to generate a better understanding of the spatial distribution of these impacts across geographies at a refined resolution. Third, this study restricted its focus to the US, and it may be useful to understand the degree to which the opportunities and challenges associated with plant-based and cultured meat could vary between countries. Finally, it may of course be useful to measure and monitor these social and economic impacts as alt-meat sectors scale up.

Policy-Relevance

A range of factors will determine whether and when plant-based and cultured meat are consumed at scale (Stephens et al., 2018). These factors include the technologies themselves, and the perceptions, attitudes, and preferences of consumers (Bryant and Barnett, 2018; Mancini and Antonionioli, 2020). But in addition, a suite of decisions and (in)actions by different actors could also dramatically influence the food and agricultural systems in which these technologies develop and the impacts that they have on both people and the environment. This research identifies arenas in which decision-makers may be able to secure the best possible outcomes and minimize harms for rural constituents and stakeholders to whom they are accountable. Having this information before cultured or plant-based meat scales up may enable decision-makers to act proactively and strategically rather than reactively. For example, decision-makers may be able to help rural communities to develop the infrastructure and supply chains needed to grow cultured meat products locally and to grow the crops needed as cell culture medium or as ingredients for plant-based meat.

Caveats and Limitations

Many responses to our questions are necessarily largely speculative. Undoubtedly, some of the opportunities and threats identified by our interviewees and reported above are more plausible than others. Even among our interviewees, there were notable differences between individuals in their perception of the likelihood that alt-meat products could have significant impacts on the lives of people living in rural parts of the US. Cautious skepticism may turn out to be well-founded. But there is also a case to be made for thinking through these potential impact pathways and the possible consequences for rural producers, particularly since little previous research has been conducted on these questions. By reaching out to informed experts, we believe that we have gathered thoughtful

and informed insights about conceivable impact pathways from people who have spent time thinking deeply about these issues. However, we did not ask our interviewees, nor do we make any claim here, about the likelihood, timeline, or magnitude of any of these potential impacts. Nor do we state here any opinion here on whether any of these impact pathways would be more or less desirable than others: different stakeholders may hold preferences for particular outcomes, and our role as researchers was simply to synthesize the reported possibilities. We note that the positionality of each interviewee likely shaped their perspectives, including their relative optimism about the possible impacts of these technologies. Finally, we note that our interviewees did not include many farmers or ranchers: yet as plant-based and cultured meat begin to scale, it will be important to include producers more centrally in research projects.

Conclusions

Our paper characterizes potential impact pathways that might emerge if plant-based or cultured meat were to scale up to a significant degree. Our research identified a number of opportunities and threats that could affect a multitude of stakeholders across a range of spatial scales. Characterizing these pathways before plant-based meat scales further and before cultured meat becomes commercially available may enable decision-makers to act proactively rather than reactively and to take actions to secure the best possible outcomes. Doing so also identifies knowledge gaps that researchers might usefully explore.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the dataset consists of transcripts of semi-structured interviews. Individual interviewees would be identifiable from those transcripts, and so the dataset cannot be made available. Requests to access the datasets should be directed to Peter Newton, peter.newton@colorado.edu.

ETHICS STATEMENT

This study involved human subjects and was reviewed and approved by University of Colorado Boulder Institutional Review Board. Written informed consent for participation was not required for this study in accordance with national legislation and institutional requirements.

AUTHOR CONTRIBUTIONS

PN and DB-R: conceptualization, writing—review and editing, and funding acquisition. PN: methodology, investigation, analysis, and writing—original draft. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2021.624270/full#supplementary-material>

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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