Public Acceptance of Animal Genomics and Biotechnology
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Animal **biotechnology** is the application of recombinant DNA techniques to animals. Genetic engineering and cloning are two older forms of animal biotechnology (Thompson, 2020), and genome editing is a more recent entrant. Animal **genomics** is the scientific study of structure, function and interrelationships of both individual genes and the genome in its entirety. Utilization of genomic information in breeding is often referred to as genomic selection (GS). In my view these two fields – biotechnology and genomics - face entirely different public acceptance issues. In the following paper I review the literature associated with public acceptance of these two fields, and then discuss some of my own (perhaps controversial) thoughts regarding these topics based on my experience and observations.

Genetic Engineering

Genetic engineering (GE), sometimes less precisely referred to as genetic modification, has historically involved the introduction of a novel recombinant DNA (rDNA) transgene into the genome of an organism to give it a desired characteristic such as fast growth. GE animal applications are as diverse as the species involved, and each comes with its own specific set of risks, benefits, concerns and considerations. To date the vast majority of GE animals, primarily mice, rats, rabbits and pigs, have been developed for research purposes in private or university laboratory settings. A small number of applications have been successfully commercialized including GE animals as pets (GloFish®) and GE animals that produce pharmaceutical products in their milk or eggs. Despite the fact that arguments for or against GE crops are largely applicable to GE animals, with some modifications (Figure 1), only a single GE food animal, the fast-growing AquAdvantage salmon, has ever been sold to consumers, and even then, in only two countries, Canada and USA. This has been in part due to regulatory gridlock (Van Eenennaam and Muir, 2011), but also due to the politicization of issues associated with GE food.
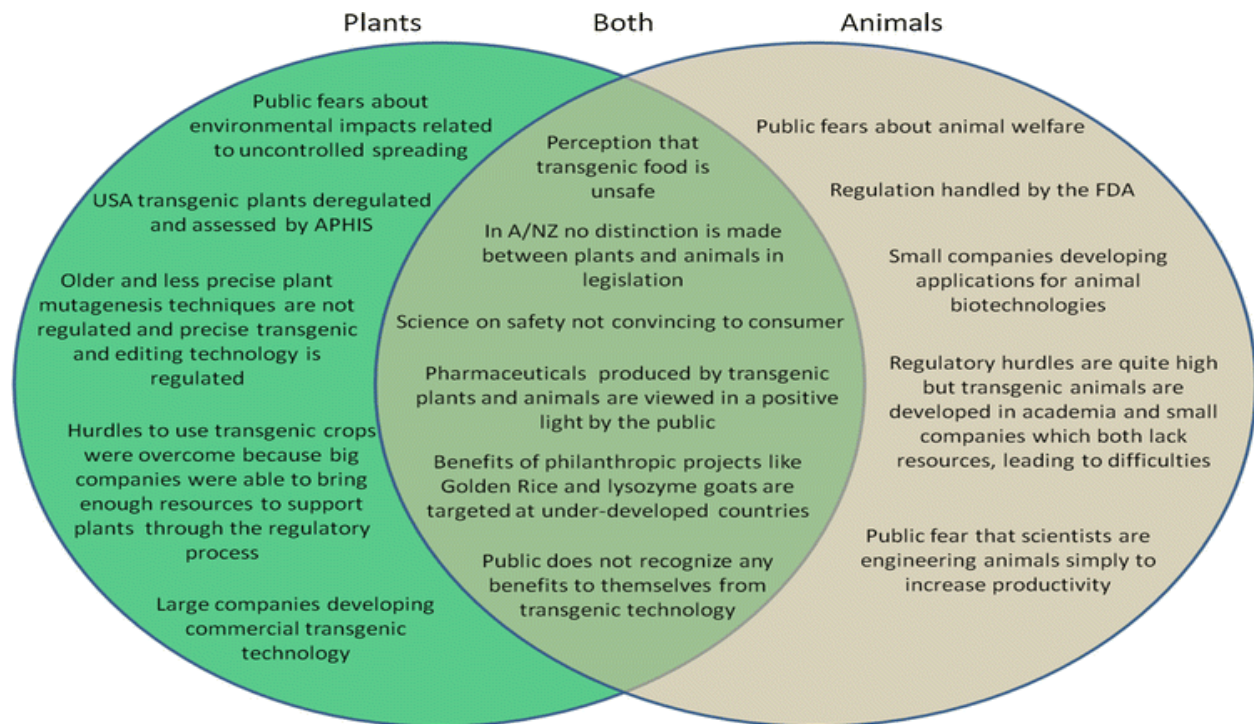

Figure 1. Public perception issues posed by plant and animal genetic engineering (Tizard et al., 2016).

Opposition to GE animals frequently goes hand in hand with opposition to research involving animals or even use of animals more generally, echoing fundamental disagreements about what our attitudes and behavior towards animals should be. Pets are considered as members of the family by many in modern society and this, coupled with the increased advocacy of animal rights and welfare groups, makes the topic of GE animals of particular interest to the mainstream public. Oftentimes, public attitudes regarding GE of animals are not specific to the use of GE per se, but rather are more generally around the production methods associated with intensive animal agriculture (Van Eenennaam and Young, 2018). Some traits generated through genetic engineering, such as faster growth, have also been spectacularly achieved through traditional selective breeding, in the absence of extensive public scrutiny or consultation. One global study reported that 62% of respondents did not approve of biotechnological applications focused on increasing farm animal productivity (Mora et al., 2012).

Activist organizations have been vocal in condeming GE animal applications starting with Jeremy Rifkin's infamous campaign against recombinant bovine somatotropin (rBST). Perhaps one of the best examples of the effect of anti-GE rallying of the public to halt a GE animal application is the case of the Enviropig. Scientists in Canada genetically engineered pigs that produced phytase in their saliva resulting in manure with reduced levels of phosphorus. This GE animal was intended to be an environmentally-friendly alternative to traditionally-bred animals as excessive phosphorus produced by swine facilities is known to contaminate groundwater and lead to algal growth, which in turn has negative effects on fish populations. Despite years of research and positive progress within the regulatory review system in the US and Canada in the late 2000s, anti-GE activists vigorously condemned the project as a "technofix" and an excuse to farm pigs more intensively. This caused the long-time funder of the project to withdraw their support. In the absence of other funding sources, the project was halted, withdrawn from regulatory review, and the animals were euthanized.

The case of the Enviropig highlights the intuitive appeal of opposition to GE. People often reject GE plants and animals based on disgust and absolute opposition to genetic engineering irrespective of any potential benefits that might be associated with the application. People who are genuinely concerned about the environment often reject GE applications that have been demonstrated to address environmental problems (Blancke et al., 2015). This outright rejection of GE is often associated with concern that it is unnatural and "violates species boundaries" or is equivocal to "playing God". It has been argued that these concerns are spurious from both scientific and ethical standpoints as species are not fixed nor unchanging, and that when we domesticated animals we effectively changed their genetics in an unnatural way as evoked by the term "artificial", as distinct from "natural", selection (Rollin, 2014).

The year 2020 marked 35 years since the first GE livestock were reported. To obtain FDA approval for the AquAdvantage salmon first reported in 1992 (Du et al., 1992), AquaBounty estimated it has spent $8.8 million on regulatory activities including $6.0 million in regulatory approval costs through approval in 2015, $1.6 million (and continuing) in legal fees in defense of the regulatory approval, $0.5 million in legal fees in defense of congressional actions, and $0.7 million in regulatory compliance costs (~$200,000/year for ongoing monitoring and reporting, including the testing of every batch of eggs), not to mention the $20 million spent on maintaining the fish while the regulatory process was ongoing from 1995 through 2015 (David Frank, AquaBounty; personal commmunication, January 2020). It is not obvious that any actual risk reduction benefit resulted from this incredibly expensive regulatory outlay. There are considerable opportunity costs associated with delaying the adoption of useful GE livestock applications in animal agriculture (Van Eenennaam et al., 2021). At this time genetic engineering is effectively absent, if not entirely verboden, from livestock genetic improvement programs globally.

Cloning

Cloning through embryo splitting has been used in livestock improvement programs since the early 1990s, however it was not until 1996 that researchers succeeded in cloning the first mammal from a mature (somatic) cell (SCNT) taken from an adult animal to produce the infamous Dolly. Many species have been cloned since then, and this technique is used by several companies that specialize in cloning farm animals (van der Berg et al., 2019). Both the FDA in 2008, and the European Food Safety Authority (EFSA) in 2012, concluded that products derived from animal clones are not different from those of non-cloned animals. In North America, South America and New Zealand, cloning for agricultural purposes is not restricted (Table 1). However, in the European Union (EU), food derived from animal clones falls under the 'Novel Foods Regulation' as food derived from animals obtained by non-traditional breeding practices. Current regulation in the EU has placed a ban on food products from animal clones, given, amongst others ethical considerations regarding animal welfare. This ban does not cover products from their progeny, which are considered to be indistinguishable from traditionally bred livestock (van der Berg et al., 2019). Currently no company in Europe is contemplating bringing products derived from animal clones, or their offspring, to market (Galli and Lazzari, 2021). A Supply Chain Management Program to identify cloned livestock in the US was set up by Viagen and Trans Ova companies in 2007. According to them, although the program was run from 2008 until 2012, no other cloning companies showed interest in participating in the program, and it was never accessed by industry. It is unclear how cloned animals produced in countries that allow cloning are kept out of products exported to the EU.

The literature around public perception of cloning is mostly from the early 2000s, in the years immediately following the arrival of Dolly. In a 2005 International Food Information Council survey of the US public regarding the cloning of animals, 74% were not in favor, 15% were in favor, with the remaining respondents unsure. In a follow-up question, respondents were asked how likely they were to buy food products from cloned animals if the Food and Drug Administration (FDA) decided that they were safe to eat. Two-thirds (64%) stated that they were unlikely to buy such products, and one-third (34%) said that they would be likely to do so. In that same year, a Eurobarometer Survey on Social Values, Science and Technology found that found 31% of respondents would never approve of cloning animals, 22% only in exceptional circumstances, 35% only if it was highly regulated and control, 8% were supportive in all circumstances, with 2% undecided.

Genome Editing

Genome editing is a relatively new player in the animal biotechnology field, having been around since the early 2000s (Bishop and Van Eenennaam, 2020). Genome editing involves the use of molecular 'scissors' to introduce changes into existing DNA, as opposed to classical GE which often involved moving genes from one species to another. Genome editing also enables a much wider-range of changes, for example, gene knock-outs, base pair substitutions, targeted insertion/deletion of larger genomic regions, and modulation of gene expression. Genome editing may produce changes that are not known to exist naturally in that species. But if these could reasonably have occurred naturally, even if they remained unrecognized by livestock breeders, it could be argued that these changes are also 'natural' (Bruce, 2017). The regulatory picture for this technology is mixed (Table 1). In the EU, New Zealand and the US, it is being treated as equivalent to GE, whereas in other jurisdictions if no foreign DNA is introduced (i.e. knockout, base pair or intraspecies allele substitution) the resulting animals are being regulated in the same way as those resulting from conventional breeding. I, and other scientists https://www.gopetition.com/petitions/harmonize-us-gene-edited-food-regulations.html, consider that the proposed US regulatory approach for animals is not fit-for purpose (Van Eenennaam et al., 2019).

Table 1. Regulation of animal cloning, transgenesis and genome editing in livestock in selected countries Modified from van der Berg et al. (2020).

Country	Animal cloning	Transgenic livestock	Gene-edited livestock
EU member states	Prohibited, until specific regulations on animal cloning are in place	Requires approval according to EU Directive 2001/18/EC and Regulation (EC) No. 1829/2003, safety assessment performed by EFSA GMO Panel	Requires approval according to EU Directive 2001/18/EC and Regulation (EC) No. 1829/2003, safety assessment performed by EFSA GMO Panel
USA	Allowed, a risk management plan and guidance for industry have been issued by the FDA	Requires approval according to Federal FD&C Act, regulations for new animal drugs as stated in 2009 FDA Guidance for industry #187 (Draft guidance) and NEPA	Requires approval according to Federal FD&C Act, regulations for new animal drugs as stated in 2017 FDA Guidance for industry #187 (Draft guidance) and NEPA
Canada	Allowed, food products of cloned animals and clone progeny are considered "novel foods" and require pre-market safety assessments according to the regulations in Division 28, Part B, of the Food and Drug Regulations (Novel Foods)	Requires approval according to the Canadian Environmental Protection Act, 1999, the New Substances Notification Regulations (Organisms) and Food and Drugs Act	No specific policy on gene editing, may be considered "novel" and require case-by-case safety assessment by Health Canada
Argentina	Allowed	Requires approval according to animal biotechnology regulation, case-by-case assessment by CONABIA	Requires approval according to animal biotechnology regulation, case-by-case assessment by CONABIA
Brazil	Allowed, commercial animal cloning mostly in partnership with EMBRAPA, registration of cloned cattle at ABCZ	Requires approval according to animal biotechnology regulation, case-by-case assessment by CTNBio	Requires approval according to animal biotechnology regulation, case-by-case assessment by CTNBio, gene-edited animals lacking recombinant DNA are regarded non-GM according to Normative Resolution #16
Australia	Allowed, generally in confined research environment	Requires approval according to Gene Technology Act 2000, by OGTR	Requires approval according to Gene Technology Act 2000, by OGTR, gene editing techniques that do not introduce new genetic material are not regulated as GMOs
Uruguay	No specific legislation on animal cloning, animal biotechnology performed in research institutes such as Institut Pasteur in Montevideo and the Animal Reproduction Institute of Uruguay	No specific legislation on animal biotechnology, environmental release of GMOs and biosecurity is subject to prior authorization by competent authorities, as stated in article 23 of law No. 17283 on the protection of the environment	No specific legislation on gene editing in animals, during a meeting of the CAS the minister of agriculture signed a declaration in favor of gene editing. Gene-edited animals may be subject to prior authorization according to law No. 17283

Note: EFSA, European Food Safety Authority; FD&C Act, Food, Drug and Cosmetic Act; NEPA, National Environmental Policy Act; FDA, Food and Drug Administration; CONABIA, National Advisory Commission on Agricultural Biotechnology; EMBRAPA, Brazilian Agriculture and Livestock Research Enterprise; ABCZ, Brazilian Zebu Cattle Association; CTNBio, National Technical Biosafety Commission; OGTR, Office of the Gene Technology Regulator; CAS, Southern Agricultural Council.

Genome editing in animals is likely to receive a range of public acceptance responses depending upon the application (Bruce, 2016). The lead application at the current time is a knockout pig that is resistant to porcine reproductive and respiratory syndrome (PRRS) virus. In general attitudes are likely to be influenced by the particular reason given for the application, how beneficial or risky it is considered to be, and specific context of application and the alternatives available. Bruce (2017) argues *"Public support for genome edited livestock is essential for the promised products to gain wide market penetration. Frivolous, or controversial applications raising public disquiet have the potential to make it very difficult for future genome edited livestock applications to be socially accepted."*

On January 18, 2017, the U.S. Food and Drug Administration released for public comment their Draft Guidance 187 on the Regulation of Intentionally Altered Genomic DNA in Animals. The draft guidance recommends that genome edited animals should be regulated in a manner similar to that used by the agency to regulate GM animals. Although this was followed by a public comment period, the FDA has yet to respond to any of these comments. This decision by the FDA to regulate genome edited animals – or more correctly the intentional alterations in the genome of animals - as new animal drugs irrespective of product risk was done in the absence of public discourse. Similarly, the decision by the European Court of Justice that these genome edited organisms were to be considered as subject to the full range of testing and regulation according to the EC Directive, as if they were transgenic, but that the early untested products of random mutagenesis were de facto considered to have been immune from such risks was made without an engagement with publics. The decision by the European Court of Justice effectively side-stepped any processes of wider societal engagement (Bruce and Bruce, 2019). These authors wrote, "*Regulation sets bounds to what can be done, who can do it and under what conditions can things be done. But if there has been no discussion with the public, this could be argued to be a case where regulation has been socially premature, and not done on behalf of the society*."

While a highly precautionary regulatory approach may be of little consequence in food-secure developed regions like North America and the EU, such an approach is likely to hinder the adoption of animal biotechnology in some developing regions that could most benefit from targeted applications such as disease-resistant livestock. In Africa, 60% of all citizens are still farmers and they are not highly productive. Yet the debates around GE crops have been dominated by a few elite scientists or largely international NGOs leading to a polarization that by-passes those most directly affected by decisions. For resource-poor Africa, responding to the promises and challenges of animal biotechnology is likely to be complex, not least because most lack the capacity for regulatory oversight. Hopefully these countries can adopt a risk-based and product-focused approach. Evidence from Mora et al. (2012) suggested that if geographic differences are considered, consumers' acceptance is higher in developing countries where the requirement for enhanced food production might be met by application of this technology.

In wealthy countries where food security is not a priority, consumer acceptance of genome edited animals is expected to be lower, especially for those applications offering economic advantages mainly to the livestock producer. Bruce and Bruce (2019) considered two examples of genome editing in livestock; hornless cattle and disease resistant pigs, from the perspective of Responsible Research and Innovation (RRI). They suggested that the knowledge gap of publics of current practices in livestock agriculture, could lead to unexpected outcomes from public consultations. For example, if an argument is made regarding genome editing to introduce the polled allele is the advantage of polled cattle, this might not be immediately obvious to those not versed in agricultural practice, and more generally "the need for dehorning may be considered shocking by some publics" (Bruce and Bruce, 2019). Applications for reduced antibiotic use, greenhouse gas emissions, and reduced possibility of transmitting zoonotic diseases were all deemed acceptable in a consultation performed by the UK Royal Society (Van Mil et al., 2017). Although it should be noted that a major pre-occupation of these participants was to ensure genome editing was used to address inequality. The participants were particularly concerned about who owns the technology, who gets rich from its use, and whether it could be used to unfairly obtain monopoly power. This raises interesting questions regarding the fit-for-purpose of the regulatory approaches that have been proposed in the US and EU which advantage large companies and incentivize intellectual property (IP) protection. Meeting the requirements of IP regimes allied to genome edited animals may prove to be disruptive to the breeding industry (Bruce, 2017).

Genomic Selection

Genomic selection was first implemented in the dairy industry in 2009, following the sequencing of the bovine genome. Based on tools to better assess the inheritance of naturally occurring genetic variation, implementation of this technology required no regulatory review or approval, and it was rapidly adopted by global dairy breeders. Other livestock industries soon followed (Van Eenennaam et al., 2014). And although its implementation has been associated with some concerns regarding increased rates of inbreeding (Misztal et al., 2021), I am unaware of a targeted campaign to prohibit or limit the use of this technology. A non-scientific google search of "opposition to genomic selection" returned only academic literature. Genomic technologies currently have no regulatory requirements for labelling or other identification or acknowledgement of use of this technology in the production of food, whether plant or animal.

Coles et al. (2015) noted that there are few studies carried out on stakeholder attitudes regarding the application of genomics that do not involve genetic modification to animal production in the human food chain. These authors considered the range of ethical issues and potential stakeholder priorities associated with the application of genomic technologies applied to animal production systems, in particular those which utilized genomic technologies in accelerated breeding. They reported that genomics, because it avoids many of the disadvantages and consumer perceptions associated with GM, is likely to prove a more publicly acceptable route than is GM for the development of healthier and more productive animals. They did caution that the use of GS should be communicated to the consumers if "*the process involved any form of disenhancement* [i.e. removing something from an animal] *or other animal welfare issue or indeed results in the use of any practices or processes that might be damaging to the environment such as increased use of pesticides, hormones, non-veterinary use of antibiotics, or other pharmaceutical products, or to the genetic diversity of domesticated animals.*"

A recent paper looked at the uncertainties associated with GS in forestry (Blue and Davidson, 2021). They interviewed a group of forest research professionals working in this field in Canada, and noted that the respondents. The wrote "*public acceptance of technology was identified as a key site of uncertainty that needs to be addressed and managed by those developing genomic technologies. Although public engagement was deemed important, we encountered repeated emphasis on the need to educate and inform the public to align with scientific views, and for most respondents, these objectives appeared to merge. Many qualified their enthusiasm for public engagement with concerns that lay publics do not know enough about GS to participate in its development and governance. Most respondents expressed concern about the capacity of lay publics to distinguish genomic selection from genetic engineering. Even those who acknowledged that public responses to emerging technologies are varied assumed that public rejection of genetic engineering is rooted in emotion and financial interests rather than reason, and thus reactions to GS would likely be the same.*" These authors criticized the forest research professionals for relying on assumptions and in some cases stereotypes to inform their understanding of public perception, saying "*that only one person referenced published research, and only a few provided actual details to substantiate claims*" regarding public perception.

These authors further argued that "*failure on the part of scientists and decision-makers to communicate uncertainties can cause problems. Notably, the prevalence of statistical, risk-based approaches to the uncertainties associated with genetically modified crops in agriculture and forestry in the 1990s provoked public alienation and fomented controversy*". They concluded with a recommendation that "*we call for acknowledgment and communication of the range of uncertainties that pervade all biotechnology research efforts, particularly those that are promoted as potential*

adaptation measures for climate change. Scientists should be upfront about the limitations of knowledge with due humility, without assuming that all uncertainties could or should be presented mathematically and statistically. In turn, scientists and decision-makers need to be cognizant that the potential responses of various publics to emerging technologies are uncertain, much in the same way that the effects of implementation of new technologies are unknown from the outset. This acknowledgment of uncertainty about existing states of public knowledge can enable a more flexible and adaptive relationship between science and its varied publics. In turn, engaging social scientists in assessing and communicating uncertainty can broaden the scope of issues and values for public discussion."

My thoughts

There exists a considerable literature castigating "scientist" (typically meaning research professionals and bench practitioners) for poor communication with the public on the topic of genetic engineering and cloning, and more recently genome editing and GS. The contention seems to be that this failure to communicate uncertainty is what historically "*provoked public alienation and fomented controversy"* around these technologies, and that this will likely cause problems for genome editing and GS. I beg to differ. Unless these later two topics become politicized, or perhaps more importantly competing business interests develop an approach to monetize fear around these technologies by inflating public perceptions of risks and arousing opposition in an attempt to trigger a spiral of silence (Scheufele, 2014), they will be integrated into livestock breeding programs largely without public scrutiny in the same way as other breeding advancements have been. Artificial insemination has not been recently communicated to the public, and yet its use is routine. However, if they become targeted, both bench and social scientists will have a hard time being heard above the drone of misinformation on social media where science and politics are inextricably linked, similar to what we observed with communications around uncertainties and relative risks associated with COVID vaccines and treatments.

I use the following evidence and observations to support these assertions. There is no money to be made opposing GS. There is no "Non-GS Project" label. There are no large multinational companies controlling its use that can be used as a proxy for evil (e.g. Monsanto). I do not foresee a targeted campaign to preclude the use of GS in genetic improvement programs, in part because it is founded on naturally-occurring genetic variations, and in part because it is hard to problematize into a clean, dichotomous framing i.e. genomic bulls are "bad", and conventionally-selected bulls are "good". And while many of the same criticisms leveled against GE and cloning can be equally associated with GS (e.g. increasing the rates of inbreeding), these concerns are likewise associated with conventional selection programs. Artificial insemination reduces genetic diversity, and conventional selection programs include traits like docility which could be considered a behavioral disenhancement. Layers are selected to not exhibit broody behavior. I am unaware of any campaigns to preclude the incorporation of temperament traits into breeding goals for ethical reasons, despite the fact this clearly alters the telos of the animal. Additionally, there are glaring disparities when it comes to the implementation of GS in the developing world, and even in small breeds; it is expensive to develop large populations of genotyped, phenotyped animals. It is not a scale-neutral technology, advantaging large breeds and genetic providers over small ones. Such inequality concerns would be problematic for a GE application, yet these concerns are rarely even discussed as it relates to GS, and they have not precluded the adoption of this technology. Genomic selection is not a perfect science, there are uncertainties and emerging issues (Misztal et al., 2021), but it is the most accurate tool we have to select the future performance of the offspring of an individual. The absence of an additional regulatory layer to the use of genomic testing has allowed the unfettered, uncontested and rapid adoption of GS in livestock breeding programs globally.

Cloning is clearly unnatural, well at least SCNT is unnatural in that it takes place in a laboratory. Cloning is actually rather common in nature, as evidenced by identical twins. Cloning elite animals has no obvious benefit to the consumer, and really is not that useful in breeding programs as it replicates the current generation rather than the next generation. It has had limited application in serving as a genetic insurance policy, and at times enabling the production of elite sires using less resources (Kasinathan et al., 2015). By these metrics it would appear cloning is destined for market failure. And it has been effectively banned in the EU. In the Netherlands, the Dutch Animal Health and Welfare Act and Animal Biotechnology Decree prohibited the application of biotechnology to animals without a specific license. Criteria for being given a license included: the goal serves a public interest, has no unacceptable impacts on health and welfare of animals and does not raise any overriding ethical objections. It is characterized as a 'No Unless' policy – no application of biotechnology to animals unless there is a very good reason for doing so. Since 2005, Denmark has required special licensing for animal biotechnology through the Act on Cloning and Genetic Modification of Animals. This legislation came about in large part due to ethical concerns surrounding the impact of biotechnological applications on animal integrity. This Act effectively limits the commercial use of animal cloning and genetic engineering to "creating and breeding animals producing substances essentially benefitting health and the environment". However, in countries where it is allowed (Table 1), opposition to cloning has slowly faded, and it is being adopted where it is cost-effective – mostly in high-value recreational animals like bucking bulls and polo ponies.

Figure 2. The Center for Food Safety depiction of cloned milk from their 2007 campaign against animal clones.

I would argue in countries where clones are not regulated differently to conventional breeding, and products from clones are not labeled as they are in fact impossible to differentiate from products from non-cloned animals – (despite the apparent green milk moustache in Figure 2!), there has been no way to effectively monetize fear around clones. The Center for Food Safety, Consumers Union, Food and Water Watch, The Humane Society of the United States, the American Anti-Vivisection Society, the Consumer Federation of America and the Organic Consumers Association tried hard in the early days of cloning, but at the end of the day it is hard to create a convincing argument that a cloned product is somehow more dangerous than its identical progenitor. And in the absence of tracking or labeling requirements, it was just not possible to create a cost-effective "absence-labeling" campaign as was done with rBST and GMOs. It is worth noting that a lucrative pet cloning industry has emerged in the absence of regulatory oversight of non-food applications of cloning. In fact, Barbara Streisand recently took on two puppies cloned from her dead dog for the fee of $50,000. If there is a direct benefit, at least in the mind of the person cloning their pet dog or bucking bull, then people are willing to overcome their hesitations regarding cloning. And as to the entry of these clones into the food supply, it is mostly a moot point. Undoubtedly products from cloned livestock – elite breeding stock at the end of their productive life, and even bucking bulls at the end of their bucking career have entered the food supply on a limited scale. And considering that the US exported 190 million dollars' worth of bovine semen in 2018, it is more than likely that there are offspring of clones running around globally.

And so we come to genome editing, the new kid on the block. And its fate is currently uncertain. Public perception is still forming around this technology, but I have a sinking feeling that genome editing will suffer the same fate as GE animals for the following reasons. Firstly, competing market forces have already started to conflate the two technologies. The Non-GMO project has come out with the following announcement "*GMOs are now being created with newer genetic engineering techniques, some of which do not involve transgenic technologies. The Non-GMO Project is committed to preventing these new GMOs from entering the non-GMO supply chain*." The National Organic Standards Board voted to exclude all genetic modification and manipulation from organic production in 2016, including genome editing. And Greenpeace in their 2021 position paper entitled "Danger Ahead. Why genome editing is not the answer to the EU's environmental challenges", *warns that the use of so-called gene (or genome) editing techniques like CRISPR-Cas could not only exacerbate the negative effects of industrial farming on nature, animals and people, but it could effectively turn both nature and ourselves (through the food we eat) into a gigantic genetic engineering experiment with unknown, potentially irrevocable outcomes.*" And so we again have a situation where activist groups and the natural and organic food industry will monetize fear and run a campaign of misinformation to suggest that genome edited animals are "unsafe", whilst animals with naturally occurring genetic variants are "pure" (and also more expensive!).

Secondly, irrespective of the nature of the genome edit, the proposed regulatory approach to genome edited animals is the same as for GE animals, in both the EU and the United States. Even SNPs and deletions are being treated as drugs in the US. The absence of one intentionally altered base pair among 3 billion in the bovine genome thus results in an unsaleable new animal drug. By capitulating to this regulatory logic and tacitly agreeing that the emperor is wearing clothes, we replicate the situation where only large companies will be able to afford the regulatory and IP costs of bringing a genome edited animal product to market. Hitherto, the IP in livestock breeding has been primarily protected by secrecy and use of cross-breeding (Bruce, 2017). Small companies and academic laboratories will be unable to make use of a technology that originally resulted from public research funds. They will again be relegated to the sidelines, unable to afford even experimental work in large animals as all milk, meat and eggs from all genome edited "investigational animals" are unsaleable, and the animals themselves have to be composted, buried, or incinerated. There is then little incentive for public sector scientists to stick their neck out doing public communication around a technology they cannot use. Especially when doing so will likely result in hostile freedom-of-information act requests, and reputational defamation by front groups financed by the natural and organic food industry such as U.S. Right To Know (Kloor, 2015).

At the end of the day, I am not convinced widespread public opposition is what is preventing the adoption of new animal biotechnologies. The prevailing narrative repeated verbatim is that the public outright rejects GMOs. But that is not observed in actual purchasing behavior when GMO products are available. For example, GloFish® (Figure 3) are marketed to aquarists in the US, where they are now sold in every state in the nation, as well as throughout Canada. Sales represent approximately 15% of US aquarium fish sales. Although some authors raised early environmental and ethical concerns about GloFish (Rao, 2005), these concerns have waned over time. GloFish is subject to enforcement discretion in the US. This is not a determination of "safety" under the Federal Food, Drug, and Cosmetic Act but is instead a determination that, based on risk, FDA does not believe it would be a good use of its limited resources to act against sponsors for the marketing and distribution of these unapproved products. Its sale is prohibited in other jurisdictions, including Europe, Australia, and Singapore. The success of this product suggests that consumers are willing to purchase GE animals, at least as aquarium pets. Alan Blake, CEO of the company marketing GloFish, wrote regarding public acceptance that consumers will

purchase a product that they desire, irrespective of the breeding method that was used to produce it. In his words, "*It is not about the process* [of genetic engineering], *it is about the product*" (Blake, 2016).

Figure 3. There is a total of four species of transgenic fluorescent GloFish® available in six colors.

Similarly, the Impossible Burger, a soy-based food product is proudly GMO with it recombinantly produced, bleeding leghemoglobin, has been a market success. Ironically the same anti-GMO groups that targeted GE in agriculture; GMO Watch, Consumer Reports, and the Center for Food Safety, went after Impossible Burger for using GMO heme and soy. They perpetuated the same fearmongering around GMO in Impossible Burgers as they had used around GMO in corn - claiming it hurt rats in a feeding study. And Impossible Food fought back, Rachel Conrad, Chief Communications officer wrote, "*Finally, we'd like to request that Consumer Reports disclose its anti-GMO agenda in full transparency, and the biases of its activist employees. For years Consumers Reports, and fellow anti-GMO ideologues have been waging a PR war against GMOs — whether in vaccines, insulin, cheese or more recently the Impossible Burger*." And likewise, the PinkGlow GE pineapple that contains lycopene, a pigment that gives some produce its red color has been success, fetching a premium of as high as $50 per pineapple.

These GE applications might be considered frivolous, after all we can live without fluorescent aquarium fish and pink pineapples. But they are market successes because 1) they were allowed to come to market, and 2) they are products that the customer wanted with at least a perceived benefit. One thing is for sure – if products are not commercially available because it is cost-prohibitive, or even impossible to get regulatory approval, then the public will not be able to indicate their acceptance by purchasing them. That has essentially been the situation for GE food animals for the past 35 years. And for GE food in Europe more generally, although there is of course a glaring incongruity there. In 2018 alone, the EU imported more than 30 million metric tons (MT) of soybean products, 10 to 15 million MT of corn products, and 2.5 to 4.5 million MT of rapeseed products, mainly for livestock feed. The EU's main suppliers are Argentina, Brazil and the United States. The share of GE products of total imports is estimated at 90-95 percent for soybean products, 20-25 percent for corn, and less than 20 percent for rapeseed (USDA Foreign Agricultural Service, 2018), suggesting GMOs are a resounding market success!

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