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ARTICLES

The Ethics of Innovations in Genomic Selection: On How to Broaden the Scope of Discussion

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Abstract
The use of genomic selection in agricultural animal breeding is in academic literature generally considered an ethically unproblematic development, but some critical views have been offered. Our paper shows that an important preliminary question for any ethical evaluation of (innovations in) genomic selection is how the scope of discussion should be set, that is, which ethical issues and perspectives ought to be considered. This scope is determined by three partly overlapping choices. The first choice is which ethical concepts to include: an ethical discussion of genomic selection approaches may draw on concepts central to (Anglo-Saxon) applied ethics, but some critical views have been based on concepts from critical animal studies and continental philosophy. A related choice is to what extent discussion should focus on new ethical issues raised or on existing ethical issues that will be ameliorated, perpetuated or aggravated by an innovation in genomic selection. The third choice is to treat an innovation in genomic selection either as a technique on itself or as a part of specific practices. We argue that ethical discussion should not limit attention to new issues or ignore the implications of particular ways of applying genomic selection in practice, and this has some consequences for which ethical concepts ought to be included. Limiting the scope of discussion may be defensible in some contexts, but broader ethical discussion remains necessary.

Keywords Livestock breeding · Genomic selection · Ethics · Philosophy of technology

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Introduction

Biotechnological innovations often have potential applications in the breeding of nonhuman animals for agricultural purposes (henceforth ‘agricultural animal breeding’ or simply ‘breeding’). For example, reproduction techniques such as superovulation, oocyte collection, in vitro fertilization, embryo selection, and surrogate pregnancy can be used to generate more offspring with advantageous genetic profiles from top breeding animals, thus making more ‘genetic progress’ in a breeding programme (Niemann & Wrenzycki, 2018). Some breeding applications of biotechnological innovations—notably cloning, genetic modification, and genome editing—are ethically controversial, but others get embedded in breeding practice without much ethical discussion. Genomic selection, which basically consist in mapping an animal’s genome and predicting the phenotypic features of its offspring on the basis of known genotype–phenotype correlations, fits the latter category. The widespread adoption of this class of selective breeding approaches has not been debated extensively by lay publics[1] and generally appears to be considered an ethically unproblematic development in academic literature (with some notable exceptions, e.g., Mark & Sandøe, 2010).

This paper shows, however, that the ethical significance of (innovations in) genomic selection depends partly on how the scope of discussion is set. This scope is determined by three interrelated choices. The first choice is which ethical concepts to include. Publications on genomic selection and ethics (although they are few and far between) have drawn on diverging ethical concepts, including concepts central to (Anglo-Saxon) applied ethics on the one hand and concepts based on critical animal studies and continental philosophy on the other. A related choice is to what extent discussion should focus on *new ethical issues* raised or on *existing ethical issues* possibly ameliorated, perpetuated or aggravated by a new selection approach. The third choice is whether genomic selection should be evaluated as a *technique on itself* or as a *part of specific practices*. Recognizing that different scoping choices affect which concerns are relevant—and may hence affect normative evaluations of (innovations in) genomic selection—raises the question how an ethical discussion *should* be scoped. We will put the question on which particular concepts ethical discussion should be based to one side in this paper, but argue that ethical discussion should not limit attention to new issues or ignore the implications of particular ways of applying genomic selection in practice.

After explaining genomic breeding and its recent and ongoing developments in the next section, the subsequent three sections discuss the three scoping choices introduced in the previous paragraph. The final section summarizes the preceding sections and argues that although there may be contexts in which having a narrow ethical discussion can be justified, there should also be discussion about broader

[1] There has been ethical discussion on genomic selection among breeders and farmers, for example on the risk of inbreeding and on the young ages at which breeding animals are first included and then replaced in genomic breeding programmes. Such discussions are reflected in farmer’s magazines to some extent but barely seem have made it into academic publications.

ethical issues raised by genomic selection innovations, such as those addressed in the course of this paper.

Developments in Genomic Selection

Although its introduction has been called a "quantum leap" or "revolution" for breeding (e.g., Seidel et al., 2020), genomic selection can be considered continuous with traditional selective breeding in significant respects. Genomic breeding still relies on selecting parent animals, based on predictions of how their offspring will 'perform' with respect to phenotypic traits of interest; the main difference with traditional selective breeding is that such predictions are made on the basis of different information. It does not follow however that genomic selection is without ethical problems. Rather, or so we argue, the continuity between breeding approaches has implications for how an ethical discussion about (innovations in) genomic selection should be scoped. The current section sets the stage for our argument by briefly explaining genomic selection as well as some of its recent and foreseen developments.

Genomic selection involves mapping (parts of) an animal's genome and statistically comparing it to a reference population, i.e. a large group of animals for which correlations between genotypic and phenotypic features have been established (Blasco & Pena, 2018). This enables predicting the phenotypic features of an animal's progeny on the basis of its genotypic features. An animal's potential for breeding can be assessed by collecting some DNA at any time before or after birth, which means that it can included in the breeding programme as soon as it reaches maturity or (at least in principle) as soon as its reproductive cells can be collected and matured in the laboratory (cf. Bols & Stout, 2018). The next generation of breeding animals can thus be produced much sooner than in breeding programmes that rely on progeny testing.[2] Because of this reduced generation interval, genomic breeding programmes can make more 'genetic gain' per year (Blasco & Pena, 2018).

Genomics allows pooling genotypic and phenotypic data from ancestrally unrelated animals, which means that stronger or new genotype–phenotype correlations can be found. This enables making faster genetic progress towards regular breeding goals, such as milk yield, udder health and fertility for dairy cows. Moreover, uncommon genotypes might be identified for which negative associations between phenotypic traits of interest do not apply, e.g. for which high milk yield is not associated with low mastitis resistance (Kadri et al., 2015); genotype–phenotype correlations could be found for traits that are not recorded routinely, e.g. for high feed

[2] In dairy cattle breeding, progeny testing typically involved begetting a hundred daughters from a bull. The phenotypic characteristics of these cows would then be recorded, and 'candidate' or 'waiting' bulls whose daughters were found to have desirable characteristics would be admitted into the actual breeding program as 'proven bulls'. According to Pryce and Daetwyler (2012), this process required at least 5 years between birth and admittance, while bulls used in genomic breeding programmes can be as young as 1.5 years.

efficiency or low methane emission (Seidel et al., 2020); and phenotypes could be predicted more accurately for rare breeds or cross-breeds (Biscarini et al., 2015).

Genomic selection is subject to ongoing innovation and development, not only because stronger or new phenotype-genotype correlations are found on which selection decisions can draw, but also because the technologies on which genomic selection relies also continue to be developed. For example, while genetic arrays previously mapped (markers for) relatively few specific DNA variations (single nucleotide polymorphisms or SNPs), newer techniques cover tens or hundreds of thousands of SNPs across the genome or even involve sequencing the full genome (Blasco & Pena, 2018). This should enable selecting for variations in so-called regulatory genomic regions, which have small phenotypic effects individually but can have substantial effects collectively. Current research programmes[3] strive to improve genomic breeding not only by identifying such regulatory genomic regions, but also by drawing on genetic science disciplines collectively known as ‘omics’ sciences, including transcriptomics, proteomics, and metabolomics (cf. Seidel et al., 2020). The aim is to find factors that affect how the genome is expressed phenotypically and to develop techniques which enable including heritable factors in breeding predictions.

Because of this continuous development, we understand genomic selection not as a particular breeding technique but as a class of such techniques, the core of which consists in mapping (parts of) an animal’s genome and statistically comparing it to a reference population for which genotype–phenotype correlations have been established. The remainder of this paper will use “genomic selection” and “genomic breeding” as umbrella terms for such techniques, and will sometimes speak of particular developments as “approaches” or “innovations” in genomic selection. An “innovation” can be either the transition from traditional breeding to a genomic selection approach or any development within genomic breeding.

In conclusion, genomic selection builds on earlier selective breeding approaches in important respects—although it draws on different information to make breeding predictions—and innovations in genomic breeding have been expanding its range of application incrementally. An important preliminary question for any ethical evaluation of these developments is how the scope of discussion should be set. We argue that ethical discussion should cover not only new concerns but also concerns that are ameliorated, perpetuated, or exacerbated by particular innovations, and should not ignore how these innovations will be applied in specific practices. In the next section, we first consider on which concepts ethical discussion should be based, which connects our work to current ethical literature on genomic selection and underscores the need to consider more fundamentally how ethical discussions of (developments in) genomic selection should be scoped.

[3] For example the BovReg project, see www.bovreg.eu

First Scoping Choice: The Range of Ethical Concepts to be Included in Discussion

The scope of discussion depends, first, on which ethical concepts are included. In this section we present normative concepts which appear in publications that discuss genomic selection from an explicitly ethical or societal perspective. The point of this section is to show that such publications have drawn on markedly different concepts and that the inclusion or exclusion of particular concepts brings different ethical dimensions of genomic selection into view, which can significantly affect the normative positions reached. We conclude that discussions of genomic selection should build on an explicit and motivated selection of ethical concepts. We will leave the question on which particular concepts an ethical discussion on genomic selection *should* be based to one side, as we cannot answer that question adequately in this paper, but will in the next sections address two more fundamental scoping choices that have some implications for this issue.

Some publications, for example Mark and Sandøe (2010), have focused on the opportunities and threats of genomic selection for animal welfare. Even when such publications do not discuss animal welfare from an explicitly ethical perspective nor argue for its prioritization in breeding programmes, an animal welfare perspective on genomic selection is clearly ethically relevant, as animal welfare is a core concept in animal ethics. It may be noted however that there is substantial disagreement on how to conceptualize animal welfare. Moreover, it should not be assumed that this is the only ethical concept that is relevant to ethical discussions of genomic selection. Recognizing animal welfare as an ethically relevant term is not the same as adopting a kind of 'welfarism' according to which ensuring welfare is all that matters in our dealings with animals.

Coles et al. (2015) offer a broader ethical analysis of genomic selection. Based on a systematic literature search for publications on biotechnologies, ethics, and animals, these authors have constructed an 'ethical matrix' (Mepham, 2000) to capture ethically relevant impacts of genomic selection on a range of stakeholders, including scientists, producers and consumers of agricultural products, animals, and the biotic environment. These stakeholders are represented as rows in a matrix, and the columns in this matrix represent ethical principles; the cells at their intersections describe impacts on stakeholders to which these principles apply. Coles and colleagues use this matrix to identify and characterize a wide variety of ethical dimensions of genomic selection.

The ethical matrix includes four ethical principles. The principle of *nonmaleficence* or *non-malfeasance* is essentially the norm to avoid causing harm to morally considerable entities, and the principle of *beneficence* the norm to act in such entities' benefit (Beauchamp & Childress, 1979). The principle of *respect for autonomy*, furthermore, requires respect for the self-determination of autonomous beings and *justice* requires fairness in the distribution of benefits as well as risks and costs (*ibid.*). These are mainstream ethical principles in applied ethics that capture our obligations not only towards other humans but supposedly also, with some modifications, our obligations to nonhuman animals and the environment (Mepham, 2000). These principles should be relatively easy to appreciate for non-ethicists, which should support ethical deliberation across disciplinary boundaries (*ibid.*). Coles et al. (2015) also recognize two ethical concepts that do not fit the ethical matrix' four principles, however. The first of these relates to the 'naturalness' or 'unnaturalness' of animals bred with genetic modification or genomic selection, the second concerns the ethical permissibility of 'disenhancing' animals by reducing their capacity for suffering under prevailing farming conditions. Based on these principles and concepts, the authors conclude that there is a stronger ethical case for genomic selection than for genetic modification, under some provisos. These provisos are that the general public does not perceive genomic selection as strongly unnatural, that adverse animal welfare effects are prevented, and that positive outcomes of genomic breeding are promoted.

Remarkably different ethical perspectives on genomic selection are offered by Twine (2010) and Holloway and colleagues (e.g., Holloway & Morris, 2008, 2012; Holloway et al., 2011), whose analyses draw mainly on the notions of 'biopower' and 'geneticization'.

The concept of *biopower* was introduced by Foucault (2018 [1976]) to characterize how human bodies and populations are being optimized according to the needs of capitalism and the modern state. According to Twine (2010) and Holloway and colleagues, this concept can be extended to characterize contemporary relationships between humans and farmed animals and, derivatively, between humans involved in breeding. They argue that the exercise of biopower in breeding is defined by three interlocking features.

First, knowledge claims are made about relevant qualities of nonhuman animals' bodies and populations, where certain authorities—for example animal scientists—are considered competent to make such knowledge claims (Holloway et al., 2011). Secondly, strategies are applied to optimize the animals' bodies and animal populations according to such knowledge claims, in particular by intervening with their reproductive processes. This typically involves ranking animals relative to certain 'performance' norms and using only high-potential animals to breed a 'better' generation of animals. Thirdly, both animals and humans involved in breeding become 'shaped' by these knowledge claims in certain ways (Holloway & Morris, 2012; Twine, 2010). Animals are bred to conform to certain ideas about what makes a good animal. This is essentially an attempt to shape animals' physical and behavioural characteristics—including temperament, maternal behaviour, and ease of handling (Twine, 2010; cf. Turner, 2010)—in ways that humans consider desirable. Authoritative claims about good breeding also put pressure on breeders to practice their vocation accordingly, even though some may resist or reject these claims (Holloway & Morris, 2012; Lonkila & Kaljonen, 2018).

The concept of *geneticization* refers to a propensity to understand and intervene in living organisms on the basis of genetics, which has increasingly replaced other ways of understanding and shaping life in the past decades (Holloway & Morris, 2008, 2012; Twine, 2010). It marks a paradigm shift in biological sciences and biotechnology generally, that has also had implications for breeding; it motivated developing approaches in which genetic knowledge could be used to improve breeding decisions.

The concepts of biopower and geneticization, as interpreted by Twine and Holloway and colleagues, are meant to characterize human-animal (and human–human) relations in contemporary breeding, but at the same time frame the states of affairs thus described in normatively significant ways. Twine and Holloway and colleagues indeed draw extensively on the concepts of biopower and geneticization to raise critical normative issues. A first issue that connects to the concept of biopower is what justifies trying to optimize animal bodies and populations. Twine (2010) observes that intervening in reproductive practices to improve human bodies and populations is considered ethically problematic, whereas optimizing animal bodies and populations by similar means is widely accepted. He concludes that this asymmetry reflects the low moral status assigned to animals, which on Twine's view rests on an outdated human-animal dichotomy.

A second critical question is whether animals are being optimized towards legitimate goals. Twine and Holloway and colleagues hold that contemporary breeding follows a neoliberal logic, where market incentives are the main drivers behind breeding decisions. Twine adds that even breeding goals with no clear market value—for example reducing environmental impact and improving animal welfare—serve to further embed the current agroeconomic system. Breeding for such traits is effectively an attempt to alleviate societal concerns about animal agriculture without seriously constraining the production and consumption of animal products. Genomic would thus run counter to the deintensification of animal agriculture that according to Twine is badly needed for environmental and ethical reasons.

Thirdly, biopower and geneticization might negatively affect how animals are perceived and valued. According to Holloway et al. (2011), animals that are considered unfit for contributing to the genetic optimization of their breed are typically perceived as 'flawed'. If selection decisions are based primarily on abstract representations of animals rather than physical interactions with them, it also seems easier to perceive nonhuman animals as morally inconsiderable or even 'killable' (*ibid*.).

Lastly, geneticization is associated with shifts in authority and power among breeders and farmers, which can give rise to ethical concerns. According to Holloway and Morris (2008, 2012), breeding companies and cooperatives strived to push genomic selection onto farmers not only by offering evidence of its efficacy, but also by rhetorically framing its adoption as an economic necessity. Moreover, genomic selection is knowledge and data intensive and has thereby likely contributed to the consolidation of a few large and powerful breeding companies or cooperatives (especially in the pig and poultry sectors) and increased farmers' dependence on those companies or cooperatives (Twine, 2010).

The observation that normative discussions of genomic selection have drawn on different concepts raises the question on which concepts an ethical discussion of genomic selection *should* be based. Scholars with different disciplinary orientations may answer this question differently and may not acknowledge the legitimacy of each other's theoretical approaches. The ethical principles applied by Coles et al. (2015) are mainstream in applied ethics, while Twine (2010) and Holloway et al. draw mainly on critical animal studies and continental philosophy, notably Foucault.

According to Twine, animal ethicists have usually framed discussions on biotechnology and farmed animals narrowly, focusing on animal welfare in particular, without seriously questioning the assumption that humans may use animals for their benefit or the human-animal dichotomy that underpins this assumption. Conversely, Coles et al. (2015) do not reference the works of Twine and Holloway and colleagues—these authors' systematic literature search must either have missed these works or failed to recognize the ethical perspectives presented in them. In our experience, some ethicists even reject the concepts of biopower and geneticization as biased, as these concepts purport to describe human-animal relations in breeding but frame the issues in normatively laden ways.

Because a preliminary selection of concepts affects which ethical perspectives enter discussion and may well affect its outcome, any ethical evaluation of genomic selection should start from an explicit and motivated choice of ethical concepts. This paper could not hope to cover to all concepts and perspectives that seem important for ethical assessments of innovations in genomic selection,[4] however, nor even critique all the concepts that were mentioned in the course of this section, which only served to show that the decision which ethical concepts to include is a significant decision. Accordingly, we do not argue for the inclusion or exclusion of these or other ethical concepts in what follows. We instead discuss two more fundamental scoping choices that intersect with this first one.

Second Scoping Choice: Focusing on Novel Ethical Issues or on the Persistence or Aggravation of Pre-existing Ethical Problems

In a recent survey among conventional and organic Danish dairy farmers, 51% of the 156 respondents agreed or strongly agreed to the statement that genomic selection (combined with ovum pickup and the in vitro production of embryos) is "ethically unproblematic, because the technology is just a development from traditional breeding practices"; 37% of the respondents neither agreed nor disagreed with this statement and 13% disagreed (Lund et al., 2021). Note that the query statement presupposes that traditional breeding practices are ethically unproblematic and that if genomic selection is "just a development" from these practices, it must be ethically unproblematic, too. What it would mean for genomic selection to be "just a development" is unclear, but a reasonable interpretation is that it would raise no new ethical issues of a serious nature.

Focusing on the question whether it raises serious new issues seems like a straightforward way to scope an ethical discussion about (innovations in) genomic selection. Especially if the underlying issue is whether a new technique in breeding should be adopted or not, it is important to ensure that this would raise no new ethical problems. This is not only inherently ethically relevant but also helps

[4] One further perspective that deserves consideration is that genomic selection might mediate human-animal relations in ethically significant ways, as suggested by the works of Donna Haraway. We are indebted to an anonymous reviewer for this suggestion.

to anticipate and avoid potential societal objections. Experience with cloning and genetic modification has shown that strong societal opposition can be expected against biotechnologies which do raise new ethical issues and that avoiding such a societal backlash is necessary for the successful adoption of new biotechnologies. In addition, focusing on potential new issues helps to keep the discussion targeted and manageable, and is simply sufficient if current breeding practices are indeed ethically unproblematic.

Framing the ethical discussion in this way has implications for the scoping choice discussed in the previous section, namely which normative concepts to include. The concepts of biopower and geneticization simply become irrelevant, as they are meant to characterize and critique developments in human-animal relations that have been going on for a long time. The relevance of concepts that do not refer to such wider developments, for example animal welfare and integrity, is not diminished by this way of scoping the discussion; ethical discussions on breeding innovations can legitimately consider whether welfare or integrity will be affected in significant new ways.

There are good reasons not to limit the scope of discussion in this way, however. First, if only potential problems are raised, it remains unclear why adopting a genomic selection innovation merits consideration at all. A positive ethical case for such an innovation can be constructed most plausibly on the assumption that current breeding techniques do raise ethical concerns, and this premise is indeed more plausible than its negation. Traditional selective breeding has led to some widespread welfare problems associated with the optimization of production traits—such as leg problems and mastitis susceptibility in dairy cows, fearfulness and susceptibility to bone fractures in laying hens, and health issues associated with low birth weight in piglets (Farstad, 2018; Fernyhough et al., 2020; Turner, 2010)—and there can be little doubt that these problems are ethically significant. It has been argued that genomic selection enables more 'balanced' breeding and hence facilitates breeding animals that are both productive and have high welfare (Mark & Sandøe, 2010). The premise that current breeding practices raise ethical problems thus makes clear how adopting a genomic selection innovation may be an improvement, from an ethical perspective, while its negation paradoxically undermines the possibility of constructing such a positive case. Pre-existing ethical issues that can be solved or ameliorated by adopting a genomic selection approach should thus be within the scope of discussion.

Second, whether a technology such as genomic selection raises new concerns or not can itself be a matter of controversy. Some early proponents of genetically modified (GM) foods argued that GM raised no significant new issues, as humans have been manipulating nature through selective breeding for centuries (Jasanoff, 2016); a similar argument was that GM foods were 'substantially equivalent' to their non-GM counterparts and therefore raised no real safety concerns (cf. Millstone et al., 1999). Yet their opponents rejected the appeal to 'substantial equivalence' as an economically motivated attempt to downplay the uncertainties surrounding GM foods (Millstone et al., 1999) and objected against the disregard of ethical concerns (besides safety concerns) raised by GM (Jasanoff, 2016). Whether a new technology raises new concerns depends on one's normative perspective; one cannot first settle what is new objectively and only then have an ethical discussion. This also implies that the technology cannot be adequately justified with an 'argument from precedent', which argues that a means to an end is morally acceptable if some other means to that end is widely accepted (Parens, 1998). Such an argument begs the question by *presupposing* that the technology and any new aims for which it will be used do not raise additional concerns.

Third, even supposing that (some innovation in) genomic selection does not raise any new issues, it may be relevant to consider which ethical concerns with respect to breeding will persist after its introduction. If current breeding practices do raise ethical issues, then a genomic selection innovation might inherit some of these, even if it can solve or ameliorate others. Some have for example argued that breeding interferes with animals' reproductive freedom in ethically problematic ways (e.g., Donaldson & Kymlicka, 2011), or commodifies them in ways that does not recognize their intrinsic value as individuals (e.g., Twine, 2010). The most fundamental objections cannot be appeased unless abolishing agricultural animal breeding is a realistic option, but it remains important to keep an eye open for further improvements in any case. Shutting persisting problems out of the discussion would obscure the ethical need for further (fundamental or gradual) improvement.

Finally, and more importantly for the question whether the introduction of a genomic selection innovation is indeed a favourable development, focusing on serious new issues means that gradual developments are ignored. Even if no breeding innovation is an 'ethical game changer' by itself, defending the innovation with an 'argument from precedent' is again precarious, as a series of innovations could have significant ethical implications collectively (cf. Parens, 1998; Twine, 2010). Indeed, ethical problems in breeding may typically arise from a succession of choices or events. That serious health and welfare impairments are common among dairy cows and broilers is not the outcome of any particular decision, but rather of repeated breeding decisions prioritizing productivity traits (cf. Farstad, 2018; Fernyhough et al., 2020), while the fact that animals are typically bred for (and in) very intensive settings is the result of many progressive steps towards intensification. If gradual developments become ethically significant at *some* point, evaluating breeding innovations in a piecemeal fashion and asking whether they separately introduce serious new ethical issues is inadequate. This would allow ethical problems to aggravate significantly, without critical questioning, on the basis of gradual developments in an undesirable direction. Ethical discussion should arguably avoid presupposing from the outset that such developments are *not* going on, which means that its scope should not be limited to serious ethical problems newly arising from particular innovations.

In considering whether a genomic selection innovation might perpetuate or even aggravate pre-existing ethical problems, one issue that deserves attention is whether this innovation will further 'lock in' such problems. 'Lock-in' refers to the phenomenon that technological systems often shape society to such an extent that it will be very difficult and costly to change them; in a 'moral lock-in', a technological system is hardly susceptible to change even though it is inferior to alternative systems on ethical grounds (Bruijnis et al., 2015). One mechanism which can create and sustain lock-ins is that the cognitive frameworks which motivate certain technological developments become more and more entrenched as society adapts to these developments, and this dynamic arguably applies to *moral* frameworks as well. One might for example argue that breeding has come to depend on the utilitarian-like (or some would say anthropocentric) ethical outlook which has been steering innovation in this sector. Because abandoning it would be highly disruptive for ongoing practices and innovation trajectories, and hence for society, such a locked-in moral outlook will probably continue to shape future developments to an important extent. This would allow problems that are not recognized by this ethical outlook to persist or even worsen. The concept of a moral lock-in thus offers a theoretical account of how ethical problems can last or aggravate in the absence of a 'game changing' event—or indeed why the 'game' *needs to* change if such problems are to be addressed successfully. It can hence be important for an ethical discussion to consider whether genomic selection innovations might reflect and further entrench a locked-in ethical outlook.

If discussions on genomic selection should cover pre-existing ethical issues, as we have argued, the concepts of biopower and geneticization may become relevant. However, such discussions may also be based on other concepts. One could for example address how genomic selection might solve or aggravate animal welfare problems (Mark & Sandøe, 2010) or consider to what extent genomic selection innovations change the instrumentalization of breeding animals (cf. Turner, 2010). The concept of a moral lock-in offers a possible explanation for how ethical problems in breeding can persist or exacerbate under the influence of prevailing moral positions.

Bringing existing ethical issues into discussions of genomic breeding innovations does entail some dialectical challenges. In many discussion contexts, the claim that current (traditional or genomic) breeding approaches raise notable ethical problems may not garner widespread acceptance. Some interlocutors may insist that breeding approaches raise significant ethical problems only if breeding priorities are set inappropriately, for example when animal welfare is not given enough weight in selection decisions. A critique of breeding more broadly might also be rejected as unrealistic: ethical concerns that would call for major changes in (or even the abolition of) current breeding practices could according to this objection not expect to have much practical impact, given vested human interests in animal breeding. We cannot address these objections adequately here, but just note that different dialectical contexts may call for different types of discussion, some broader than others (see also the final section of this paper). It will be important to set the scope of discussion explicitly in any case.

Third Scoping Choice: Assessing a Breeding Technology in Isolation or as Embedded in Contingent Practices

It could be argued that an ethical discussion of an innovation in genomic selection should ignore ethical issues that are contingent upon particular ways of applying it in practice. Assuming that the innovation can be used in unproblematic as well as problematic ways, discussing particular applications would be irrelevant to a discussion of the innovation as such. Relatedly, it seems obvious that only the genomic breeding innovation which raises ethical discussion should be evaluated and that the ethical implications of other breeding technologies should be out of scope. The discussion might consider in what ways the innovation is or is not an improvement relative to earlier selection techniques, as discussed in the previous section, but considering the ethical implications of further technologies would be beside the point. For example, addressing ethical aspects of reproductive techniques such as artificial insemination would be irrelevant in an ethical discussion of genomic breeding innovations, as these are simply distinct techniques—ethical concerns with respect to the former would have no bearing on the latter.

Yet it would arguably be problematic for an ethical discussion to blind itself to the effects that a genomic breeding innovation will have in practice. It seems important to anticipate the actual effects of an innovation, even if the innovation *need* not have these effects because it *could* be used in other ways. Some applications of a technology may be more likely than others; a technology can 'invite' certain uses and 'inhibit' others (Verbeek, 2011; cf. Latour, 1992). This encouragement or discouragement of possible applications arguably flows from the technology's design features on the one hand and psychological or motivational factors on the other. For example, a speed bump invites driving slowly because of its material properties but also because drivers usually do not want to wreck their suspensions, and a seatbelt alarm encourages buckling up most effectively if it is penetrating and experienced as annoying (Latour, 1992). How a genomic breeding innovation will be used in practice will also depend partly on its technical features as well as user motivations. It has for example been observed that the introduction of genomic selection unexpectedly led to increased inbreeding among Holstein-Frisian cattle (Doekes et al., 2018), which may be due to the fact that prediction accuracy increases when animals are selected that are genetically similar to the reference population (*ibid.*), but possibly also due to incentives to breed only with the very best bulls according to accurate genomic predictions.[5] Similarly, although genomic breeding can in principle be applied for a wide range of breeding goals, including breeding goals that answer primarily to societal or ethical values, some breeding goals may be more probable than others. A technical feature that affects which breeding goals will be included is that a considerable amount of quantitative data on phenotypic traits is required to establish reliable statistical associations with genotypic traits (and to establish that they are heritable in the first place). Thus, genomic breeding programmes are not likely to prioritize phenotypic traits that are difficult to conceptualize or quantify: the difficulty of conceptualizing and operationalizing welfare for example hampers the development of breeding programmes which prioritize welfare as such. Instead, genomic breeding for welfare involves selection on some range of measurable welfare-related phenotypes, for example phenotypes with respect to damaging social behaviours (Rodenburg & Turner, 2012). Moving to motivational factors, breeders in liberal economies may be most interested in optimizing phenotypic traits that have

[5] The latter was suggested in a Dutch farmer's magazine (http://nvo-veeverbetering.nl/data/documents/Veeteelt-Genomics-debat-nov-2012.pdf).

clear market value, including typical production traits but also traits that cut farmers' production costs (e.g. increased resistance to a common animal disease). Ethical discussion could relevantly consider whether economically attractive applications of genomic selection innovations are desirable, as these applications will probably appeal to breeders. Breeding goals that are not obviously profitable to breeders but might be societally or ethically desirable—such as the reduction of methane excretion by cattle[6]—also deserve ethical discussion. Such a discussion could conclude that (more) incentives should be provided to promote the prioritization of certain breeding goals in (genomic) breeding programmes.

One can also question whether distinguishing between a technology 'as such' and particular ways of applying it in practice makes sense at all. Philosophers of technology have argued that technologies are not defined solely by their material characteristics but also by their function, which is determined by how the technology is appropriated and transformed in different contexts of use (e.g., Kroes & Meijers, 2006). For example, the telephone was originally designed as a hearing aid, but its function has been redefined and its design redeveloped in interaction with actual users (Verbeek, 2011). Technologies are *multistable*. This means, among others, that they can be assigned different functions—which may involve tailoring their design to those functions—in different contexts (Ihde, 1990; Rosenberger, 2014). Although a technology usually has a 'dominant' stability which is considered its defining function, which stability is dominant in a given society is contingent, as the example of the telephone shows; a different example is that windmills were used as 'automatic prayer wheels' in Hinduism before their function was redefined by Western preindustrial societies (Ihde, 1990). If so, there can be no such thing as evaluating the technology on itself; its evaluation must refer to its functions, which cannot be separated from its use and tailoring in actual practices.

One particularly relevant issue to consider with respect to the practical application of a genomic breeding innovation is how it will be integrated with other ethically significant technologies. A technology's possible functions in practice are shaped by its 'involvements' or cross-relations with other technologies (Ihde, 1990); for example, somatic cell nuclear transfer enables cloning only in combination with techniques to induce surrogate pregnancies (or in vitro techniques that make cloned cells to grow into full organisms). If such an auxiliary technique raises ethical concerns, these must arguably inform evaluations of technology applications that draw on this auxiliary technique. The ethical issues surrounding advanced reproductive techniques (including superovulation, oocyte collection, in vitro fertilization, embryo selection, and embryo transfer) are on this line of reasoning relevant for discussions on genomic breeding. Although these techniques need not be used within genomic breeding programmes and can be used in non-genomic breeding programmes as well, combining genomic selection and advanced reproductive techniques will be particularly attractive to breeders aiming to maximize 'genetic

[6] More environmentally friendly cows are in fact already on offer (https://ahdb.org.uk/news/breeding-cows-to-help-reach-net-zero), but whether such 'EnviroCows' will appeal widely to farmers is an open question.

progress' (cf. Lund et al., 2021). One relevant critical perspective is that submitting animals to advanced reproductive techniques is highly invasive and instrumentalizing (e.g., Turner, 2010), which suffices to show that their increased use in genomic selection programmes is ethically significant and deserves discussion.

The preceding considerations show that an ethical discussion on a genomic breeding innovation can relevantly address how that innovation will in practice be applied and cross-related with other ethically significant technologies. At the same time, however, broadening the scope of discussion in this way poses considerable challenges. These challenges relate, in particular, to the multistability of technologies. If a technology can take on different functions depending on how it is appropriated or transformed by users, then how can one anticipate how it will be used and integrated with other technologies in practices?

A first point to note is that multistability does not imply that a technology has an infinite range of stabilities, i.e., that there are no constraints on how users can relate to it. To the contrary, as a technology's material features enable certain applications, they simultaneously foreclose others; a hammer can for example be used as a paperweight or door knob, but not as a flotation device. Philosophers of technology (Ihde, 1990; Keymolen, 2020; Rosenberger, 2014; Verbeek, 2016) have suggested several approaches to explore a technology's possible and plausible stabilities. Some of the more empirical approaches—such as interviewing and observing different types of users on how they relate to the technology (Keymolen, 2020)—may work best if the technology is already in use, while more speculative approaches—such as creative brainstorming about possible relations to the technology (Ihde, 1990)—also seem applicable in earlier stages of innovation. How the various uses and effects of technologies can be anticipated is in fact a main issue in ethics of technology and responsible research and innovation, which we cannot hope to solve here. We just suggest that approaches which have been developed to address the multistability of technologies might be useful for anticipating how innovations in genomic selection may be used in practice. Assessing what motivational factors affect breeding priorities as well as choices regarding the use of auxiliary techniques must arguably be an important part of this.

Choosing to consider how a genomic selection innovation may be applied in particular practices also has certain implications for which ethical concepts to discuss. The concept of biopower could help to address and evaluate how genomic selection innovations will be applied in practice. If Twine (2010) and Holloway and colleagues (e.g., Holloway et al., 2011) are correct that this concept characterizes the underlying 'logic' of breeding, then it may be expected that genomic selection innovations will be embedded in practice according to this logic, for example that it will be used in conjunction with other technologies that aim to optimize animal bodies and populations in accordance with economic demands. In addition or alternatively, concepts from the ethics of technology like those we have used in this section ('invitation' and 'inhibition', 'multistability', and 'technological involvements') could be included to conceptualize how a genomic selection innovation comes to be embedded in breeding practices. Its particular applications could then be evaluated with the help of further ethical concepts; for example, the technological involvements of genomic selection with advanced reproductive techniques could be evaluated by applying concepts like integrity and instrumentalization.

Recapitulating, there are good arguments to include specific applications of genomic selection innovations within the scope of ethical discussion. Certain applications may be likely, given certain motivational factors behind breeding practices, and conceptualizing a technology as something distinct from its applications in practice may not make sense to begin with. Concepts and approaches from the ethics of technology, and possibly the concept of biopower, can help to address how genomic selection innovations will be embedded in particular contexts.

Conclusion: On How to Broaden the Scope of Discussion, Depending on the Discussion Context

As the previous sections have shown, an ethical discussion on genomic selection innovations can be scoped in various ways. At least three scoping choices determine which ethical issues and perspectives should be included in the discussion and which should not. The first choice concerns which ethical concepts are to be applied; the second choice is whether only new ethical issues should be considered or whether pre-existing ethical issues should be addressed as well; and the third choice is whether an innovation in genomic selection should be evaluated as a technique on itself or as part of specific practices.

We have argued that an ethical discussion on innovations in genomic selection should not be scoped too narrowly. Bracketing the question on which specific concepts discussion should be based, we have argued that limiting discussion to new ethical issues fails to acknowledge not only arguments in favour of adopting genomic selection innovations, but also any ethical problems that would persist or even worsen. In addition, we have argued that evaluating an innovation on itself, as something distinct from its particular applications in practice, seems naïve (as certain applications will in a given context be more likely than others) and problematic from a theoretical perspective (as technologies are not defined only by their material properties but also by their functions, which are contingent upon how they are appropriated and transformed by users). It seems important to consider how genomic breeding innovations will be applied and integrated with other technologies in practice.

There may be contexts in which having a narrower ethical discussion is defensible. For example, when animal scientists or breeders are considering a relatively minor innovation in genomic selection, they cannot be expected to elaborate on ethical problems of breeding that will not be solved (and might even worsen somewhat) by this innovation. There may also be contexts, for example policy discussions on which breeding goals to incentivize for breeders, which should focus on realistic improvements and in which non-ideal ethical perspectives are therefore more appropriate than ideal perspectives. Our point is that such discussions will not represent all valid ethical perspectives on (innovations in) genomic selection, and should not be framed as such. There should also be ethical discussions, possibly in different contexts, in which wider ethical issues with respect to genomic selection innovations *are* addressed.

The three scoping questions raised with regard to ethical discussions on genomic selection can arguably be extended to ethical discussions on other types of breeding innovations (and perhaps even more widely). It a makes sense in many such discussions to ask which ethical concepts deserve to be considered, whether new and existing ethical issues both deserve attention, and whether ethical evaluation should focus on the innovation 'as such' or address particular practices in which it will presumably be embedded. Our paper can thus be a stepping-stone towards a wider account on how to have ethical discussions about innovations in agricultural animal breeding.

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Declarations

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