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An Economic Analysis of Gene Marker Assisted Seedstock Selection

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The Issue

Beef cattle breeding has historically utilized statistical procedures for seedstock selection. DNA-based gene marker selection techniques, which are now being developed and commercialized, have a potential to significantly improve the efficiency of beef cattle seedstock selection. The first commercial marker tests, which were released about five years ago under the labels GeneSTAR Marbling and GeneSTAR Tenderness, target beef marbling and tenderness attributes. There is considerable marketing hype associated with these emerging technologies, with predictions by the patent holders that gene marker selection techniques will soon entirely replace conventional breeding methods. Beef producers are skeptical of this hype, yet worry that life science companies, seed stock suppliers, and others within the beef supply chain will be the primary beneficiaries of future economic rents generated by this technology. Scientists and industry experts are concerned that a rapid substitution of gene marker selection for conventional breeding will result in unanticipated efficiency losses.

The purpose of this research is to describe the science of gene marker selection and the commercialization of this technology; to obtain opinions about the technology's degree of effectiveness from various industry experts; and to model the beef supply chain in order to identify where rents will be generated within the beef supply chain and which economic factors will limit gains to beef producers.

Policy Implications and Conclusions

Economically important traits in beef, such as tenderness and marbling, are influenced both by a combination of genes and management factors. That only a handful of the more than 30,000 genes in cattle have been marked suggests that DNA-based seed stock selection, which relies on the small number of available markers, is unlikely to produce sizeable efficiency gains in the near future. Such efficiency gains will depend on the rate of scientific advancement in gene marking. Policy makers should actively promote gene marker selection in beef cattle as a technology that is used in conjunction with conventional breeding techniques. They should also fund research that examines the usefulness of gene marker technology for beef cattle producers, find ways to educate producers about this new technology, and report to producers all third-party analysis of specific test claims. Finally, policy makers should promote the efficient commercialization of this emerging technology.

It is important for policy makers to understand that gene marker-assisted selection for improved tenderness must compete with alternative technologies that address meat tenderness. Technologies such as large-scale calcium-activated tenderization (CAT), hydrodyne, blade tenderization (needling), and marination can be quite effective in converting relatively non-tender beef into relatively tender beef. The gene marker technology should also be viewed in a dynamic context. If seed stock decision

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makers routinely replace animals with non-conforming genes with those having conforming genes, then both the gains and level of biodiversity will diminish over time. Livestock breeding contains many public good attributes, and it is important for policy makers to properly understand these attributes before determining whether policy intervention is warranted.

Discussion

When selecting animals for breeding stock, beef producers are typically more concerned with an animal's genetic value rather than its phenotypic value of a particular trait. The difference is that while the phenotypic value refers to the presence or absence of particular traits, the genetic value indicates the potential (or probability) that this animal, if bred, will give birth to calves with certain desired traits. The phenotypic expression of a trait (e.g., tenderness) is controlled by genes, which may or may not be transferred to offspring. The genetic value of a trait indicates the likelihood that the genes responsible for that trait will be transferred to any offspring. The challenge of the beef cattle breeder is to determine which cows and bulls to breed in order to obtain progeny with high quality tenderness and marbling traits, as well as any other desirable attributes.

Today's beef industry uses large amounts of quantitative data and various sophisticated statistical procedures to calculate a measure of the genetic worth of an animal. This is referred to as the Expected Progeny Difference (EPD). These values, which are based on data pertaining to the animal, as well as its siblings and half-siblings, are calculated with respect to a particular trait (e.g., marbling or carcass weight), and reflect economic conditions to the best possible extent. Recent enhancements to EPD imply that systems of simultaneous statistical equations are now used to account for the quality of an animal's relatives, including cousins and grand siblings, the relationships between these relatives, and the genetic correlations between different traits. Differences in age, management, and environmental conditions among the animals are also considered. In general, older bulls (sires) have more accurate EPD estimates than younger bulls. Because the industry must constantly replace older, high-accuracy bulls with younger, low-accuracy bulls, this replacement process limits the

EPD method's overall effectiveness. Furthermore, due to the impossibility of obtaining potential tenderness data from live animals, it has historically been impossible to apply the EPD technique in selecting seedstocks for tenderness.

In an attempt to increase the success rate of producing beef with increased tenderness and marbling, the beef cattle industry is beginning to utilize a genomic innovation referred to as gene markers. These techniques can directly confirm the potential parent-to-offspring transfer of those genes associated with a desired trait. This direct observation approach is in contrast with the EPD technique, which indirectly infers the potential transfer of desirable and undesirable genes through measurement of various phenotypic attributes in the individual animal and its relatives. Information regarding an animal's endowment of a particular trait is coded in the gene that controls that trait. A gene may not directly control the presence or absence of a trait. Rather, it may influence the production of an enzyme (a biological catalyst), which in turn influences development or suppression of the trait in question. For example, the thyroglobulin gene controls the secretion of the thyroglobulin enzyme, which facilitates marbling within the animal.

The same gene can vary across animals in the same breed and herd because genes themselves are comprised of individual protein molecules. In practice, the gene marker test for marbling and other traits of interest involves isolating particular genes from the animal and analyzing their marker location to determine if the form of the gene possessed by the animal is associated with the favourable trait of interest. Because every animal possesses paternal and maternal copies of each gene, the gene marker test on a randomly selected animal would designate the animal as belonging to one of four possible categories, depending on whether the paternal and maternal copies are favourable or non-favourable. A seed stock manager relying solely on the gene marker test would therefore select animals that fall into category 4 (or at least those in categories 2, 3, and 4).

Research leading to the first successful commercialization of a gene marker test for beef tenderness (in 2002) was carried out by an Australian

consortium, which included the Cattle and Beef Quality Cooperative Research Centre, CSIRO Livestock Industries, and Genetic Solutions, a Brisbane-based company. Based on the calpastatin gene, this tenderness test (GeneSTAR Tenderness) followed the successful commercialization in 2000 of GeneSTAR Marbling, which is especially important for producers of Japanese Wagyu beef cattle. Genetic Solutions commercially launched GeneSTAR Tenderness 2 in 2003 after integrating a marker for the calpain-1 tenderness gene, which had been newly discovered by the United States Department of Agriculture (USDA) Animal Research Centre. In 2004, Genetic Solutions announced that U.S.-based Bovigen Solutions would initially manufacture and market the GeneSTAR tests for marbling and tenderness in North America and eventually in South America. There are now more than a half-dozen gene marker tests for marbling and tenderness being marketed by Genetics Solutions.

While development and commercialization of the GeneSTAR tests was taking place in Australia, Frontier Beef Systems in the U.S. was actively developing and commercializing the TenderGene test, which was initially based on the calpain-1 gene and was eventually based on a combination of the calpastatin gene and the calpain-1 gene. By 2004, Frontier Beef Systems had been purchased by the multi-national Merial, which started marketing the TenderGene test through its Igenity division. Igenity had an existing L test for beef quality, and today continues to market both the TenderGene test and the L test (the latter being associated with various functions such as milk production, marbling scores, energy balance, and regulation of feed intake). The types of tests and the number of countries that have access to testing services are growing quickly. In North America, for example, Biogenetic Services, Genaissance Pharmaceuticals, and Quantum Genetics (the latter is based in Saskatoon) are currently utilizing technologies similar to GeneStar, TenderGene, and Igenity L. Test fees have dropped rapidly over the past few years due to improvements in testing technology and added competition.

To fully appreciate the beef industry's reaction to the rapid emergence of gene-marker technology, it is important to understand that the conventional EPD

approach to trait selection has evolved slowly and carefully over time. EPD is very well entrenched at the individual producer, breed association, and scientific community levels. Unlike other types of livestock, breed associations, working in conjunction with public and private scientists, have historically played an important role in genetic improvements in North America's beef cattle industry. Beef producers thus have good reason to be cautious about shifting from the relatively effective EPD approach to the still largely unproven gene marker approach. Many genes contribute toward complex traits such as meat marbling, and most of these genes remained unmarked. The current set of marked genes explains only a relatively small percentage of the total variation of trait expression across animals. Thus, EPDs should continue to be used because this technique estimates the missing information associated with the various unmarked genes.

Mark Thallman from the USDA's Animal Research Centre worries that breeders who face the temptation to select animals based on a single gene will misuse the gene marker technology. Single gene selection can have a far greater negative impact than the conventional problem of single-trait selection. Thallman cites the example of a bull with a very high EPD for a particular trait, but with a relatively undesirable marker test result for one of the genes affecting that trait. After release of the gene marker information, semen sales dropped significantly, apparently because breeders were using single-gene selection criteria when making their breeding decisions. Thallman states that if a bull has a high and accurate EPD, but does not have a favourable form of the marked gene, then it is likely that the unmarked genes associated with the trait are particularly effective at generating the desired trait. The unfavourable gene marker test does not necessarily lower the performance potential of the animal, but perhaps it does signify that matching the bull with a female that carries the favorable form of the gene maximizes the chances of producing a calf with the desired trait.

Other industry experts believe that widespread adoption of gene marker technology will add significant value to the beef supply chain. The problem, however, is who will adopt first, and how

will these early adopters be compensated? Premiums are paid at the retail end, but firms at the seedstock end will primarily incur the testing expense. Because the benefits may be slow to trickle down through the supply chain, it is not clear how wider investment in this technology will take place. Big packers will not utilize this technology as long as they are dealing primarily with commodity beef. Investment is most likely to occur only if packers begin to merchandise a branded product that explicitly incorporates tenderness traits.

Harry Lawson, from Lawson's Angus in Australia, is rather pessimistic about the immediate prospects of gene marker technology. He believes that the technology has a bright future, but years of continued research to develop a much larger array of tests are required before the innovation has sufficient value to warrant full-scale commercialization. He argues that the genomic companies offering the testing service and the breeders who are currently promoting animals based on marker tests are misleading potential customers because information associated with the tests is currently not especially helpful in increasing enterprise profitability. Moreover, breeders may end up funding the relatively large and on-going R&D and evaluation costs associated with gene marker technologies, but with relatively little return on their investment. If feedlots and other bull-buying customers come to expect that the breeding material be tested for genotype, then this practice may become routine in the industry, even if it is not economically viable for a particular sector.

To assess the full economic potential of gene marker technology, it is important to grasp the extent to which premortem and postmortem technologies can be used to improve beef quality within the supply chain. For example, marbling is enhanced by a variety of premortem strategies including feeding cattle high-energy diets, supplementing feed to reduce animal stress during transport in the forty-eight-hour pre-slaughter period, and castration. Postmortem quality enhancing practices and technologies generally target beef tenderness. Tenderness of a carcass depends on the chilling temperature and aging. Technologies have also been proposed for inducing tenderization of tough products, which include calcium-activated tenderization (CAT), hydrodyne, blade tenderization

(needling), and marination. These techniques have various degrees of effectiveness, application cost, and industry adoption. Their capacity to transform tough beef into tender beef will certainly impact the economic value of the gene marker assisted breeding techniques that attempt to eliminate in a preemptive manner tough beef from the supply chain.

An economic model of the beef supply chain developed by the authors of this report supports the claim that gene marker assisted selection has the potential to add sizeable value to the beef supply chain by increasing production of high quality beef. Beef industry demand for this technology is derived as a function of various industry parameters, including the difference in consumer demand for tender and non-tender beef and the extent that a gene marker test reduces producer uncertainty regarding beef tenderness outcome. Monopolist suppliers of the gene marker test infer a producer's demand for gene marker testing and then select a profit-maximizing price for the test. The model is calibrated with parameter estimates from various literatures and the opinions of industry experts. Simulated results reveal that the relatively small gains associated with the current technology will be distributed amongst all participants within the beef supply chain. The share of technology rents captured by producers range from small to moderate, and this share is quite sensitive to the key parameters that define the model.