The Diffusion of Livestock Breeding Technology in the U.S.: Observations on the Relationship Between Technical Change and Industry Structure

Nancy L. Johnson and Vernon W. Ruttan

Abstract: *The goal of this paper is to better understand how technological change has contributed to structural change in the U.S. livestock industry. The paper presents a cross-sector analysis of the diffusion of improved breeding technologies and industry structure in poultry, swine, dairy and beef cattle. Patterns of technological change are reviewed and compared to the predictions of a standard model of technology diffusion. The results suggest the need for a more dynamic view of technology diffusion. The paper offers several specific observations about technological and structural change in this industry that have relevance for public policy.*

Key Words and Phrases: *Breeding technologies, U.S. livestock industry, Diffusion research, Cross-sector analysis, Structural change.*

This paper presents a cross-sector analysis of the relationship between the diffusion of improved breeding technologies and the structure of the U.S. livestock industry. Understanding the causes and consequences of structural change in the U.S. livestock industry is currently a challenge for farmers, policy makers and researchers. In many cases, new technology is seen as a critical element in the process of change. Comparing the impact of technological change in one aspect of production across time and across industries highlights several interesting features of the relationship between technological changes and industry structure. The insights offered in this paper could be useful in the design of policies to address the complex economic and social issues associated with structural change in the livestock industry.

There are several reasons for analyzing breeding technology. Since the 1940s new breeding technologies have contributed to significant increases in farm-level productivity in most sectors. Genetic improvement, including genetic engineering and biotechnology, is also expected to be an important source of improved productivity in the future. However, the degree to which commercial producers have adopted the new breeding technologies varies across the sectors. In the poultry sector, these technologies have been adopted by almost 100 percent of the commercial producers, while only a small percent of beef producers use improved breeding technologies.

The pork and dairy sectors fall somewhere in between. This variation in levels and patterns of technology diffusion makes the cross-sector analysis particularly useful for examining factors that affect technological and structural evolution.

This paper discusses a descriptive model of the diffusion of innovations and provides a brief review of research on the diffusion of technology. Next it briefly describes the breeding technology and structure of production in each of the four main livestock sectors: poultry, pork, dairy and beef. Finally, it evaluates the diffusion of breeding technologies according to the model, offers several additional observations on the relationship between technical change and industry structure that could be useful for extending the traditional model, and offers a summary and conclusions.

Review of Diffusion Research

Diffusion is defined as "the process by which an innovation is communicated through certain channels over time among members of a social system" (Rogers, p. 5). Unlike adoption theory, which focuses on the decisions of individual users, diffusion theory attempts to explain the spread of an idea, product or innovation at the aggregate level. It begins with the existence of an innovation and examines its pattern and rate of spread through a target population (Thirtle and Ruttan).

The variables that influence diffusion can be grouped into three main categories (Rogers). The first is communication variables, those that affect how agents become aware of innovations. Communication variables include the source of the innovation, the channels through which agents are exposed to it, and the people or organizations that promote its adoption. The second category contains characteristics of the innovation —relative profitability, compatibility with the existing system, complexity, lumpiness in adoption, and ability to be tested and evaluated. Variables in the third category describe the nature of the production system, such as the size, number and type of firms. Rogers' model explains how different sociological variables would be expected to affect the diffusion process.[1]

Griliches proposed an alternative model based on economic variables. He described the process of adoption and diffusion of hybrid corn through the three parameters of a logistic function, the initial level of use, the rate of increase of use, and the final ceiling or saturation level. He then attempted to explain these parameters in terms of economic variables, primarily profitability. Griliches' work, and the studies that followed, helped clarify the economic forces that drive the diffusion of new technologies. In retrospect it is clear that both sociological and economic factors have been involved in adoption and diffusion.

Diffusion studies have provided many insights into the process of technological change; however, shortcomings of the traditional diffusion model limit its usefulness in many situations. Several of these would appear to be significant with regard to the

analysis of animal agriculture, which has been neglected relative to crop agriculture in the diffusion literature. First, traditional diffusion studies have tended to focus on the spread of one particular innovation. However, an innovation is often embodied in an input that has a complementary relationship to other inputs. In such a case, it is difficult to describe the diffusion process in terms of just one input. Technical complementarity is a stronger concept than "compatibility," which traditional diffusion studies consider. This issue was raised by researchers studying the diffusion of "green revolution" technologies, which consisted of a package of fertilizers, high-yielding varieties and farming practices (Feder et al.).

Further, diffusion studies in agriculture often focus on competitive environments in which there are a large number of potential adopters making independent decisions. In many cases this accurately characterizes the market of interest, however some markets depart from this assumption in ways that may significantly affect diffusion of innovations. Of particular interest in the livestock industry is the relationship between vertical and horizontal integration and technology diffusion.

Finally, many traditional diffusion models are static. The underlying assumption is that the innovation represents the only change in an otherwise stable system. In reality, a new technology may substantially change the structure of an industry. This suggests the need for a dynamic model to take into account the interrelationships between technology, agent behavior and the economic environment (Ruttan).

This paper will first evaluate the diffusion of breeding technology according to the Rogers model. In some ways, this model accurately explains what has occurred in livestock. However several aspects of the experience of technological change in one or more of the sectors of the livestock industry appear to contradict what the Rogers' model would predict, suggesting a more complex and dynamic relationship between technology, the economic environment and demand for innovation.

Changes in the Structure of U.S. Livestock Industry

Poultry. During the early post-war period, poultry production in the United States developed from a household activity into a highly mechanized and concentrated industry. Poultry breeding transformed itself from a hobby into an applied science capable of responding to the demands of commercial production and the marketplace. Today, poultry breeding is carried out on an international level by a handful of companies that produce hybrid chicks which are the product of intensive genetic selection and testing geared to meet consumers' and producers' demands in terms of quality and price.[2] Hybrid chicks, whose pedigrees are protected by patents and trade secrets, are generally sold under contract to the large integrators that constitute the poultry production and processing sector. The technology of hybrid chicks dominates commercial production. All major producers use it.

The emergence of the modern poultry industry, particularly the modern broiler industry, in the mid-twentieth century was linked to an enormous growth in productivity. Poultry research between 1915 and 1960 had an estimated annual rate of return of between 20 and 30 percent (Peterson). In 1934, broiler production in the United States was 34 million birds annually. In 1987, 5 billion broilers were produced. In 1920, the average feed conversion ratio was 13 pounds of feed to one pound of broiler. By 1940, the ratio had dropped to 4 to 1, and by 1990 it was 1.9 to 1 (Bishop and Christensen; Bugos). The grow-out period was also halved between 1940 and 1987, from 14 weeks to under 7 weeks. Improvements in egg production rose similarly. In 1930 hens averaged 93 eggs per year; in 1983 the average was 246 (Bishop and Christensen). Improvements in breeding and genetics, nutrition, mechanical technology, and transportation and storage facilities all contributed to the increased productivity of the sector.

Throughout the 1960s, the rapid growth in productivity led to overproduction and prices below cost. Growth in output exceeded growth in demand, despite falling prices (Bishop and Christensen). There was a frequent turnover among firms in the industry, with surviving firms buying up failing competitors (Bugos). Broiler production became more and more concentrated both geographically—in the southeastern states of Georgia, Alabama and Arkansas—and in terms of market structure. In 1961, six organizations—Ralston-Purina, the Cotton Producers Association, the Arkansas Valley Industries, Central Soya, Pillsbury, and Swift and Co.—accounted for 20 percent of production (Western). By 1988, the top four companies—Tyson, Holly Farms (ConAgra), Gold Kist and Perdue—accounted for 43 percent (Bugos). Stability was finally found through the introduction of brand names. By promoting "marigold-colored birds," Perdue was able to differentiate its product from the others and gain product recognition and market share (Bugos). Other companies followed, trying to build customer loyalty on a regional and, later, a national level (Reimund et al.).

Pork. Unlike the U.S. poultry industry, in which there is essentially one production structure and one type of breeding technology, the U.S. swine industry is currently characterized by competing production structures and approaches to breeding. However, significant structural changes are occurring in hog production, and it remains to be seen whether the industry will follow the pattern of poultry or continue to support different forms of production.

The technical and structural changes in the hog industry are increasing the number, size and market share of the large farms. Diversified farm operators began to specialize in hog production during the 1950s, due in large part to the availability of new mechanical technologies that facilitated the substitution of capital for labor both in hog and grain production (Degraff). In Iowa, the premier hog producing state, the number of hog farms declined by 28,000 between 1950 and 1964, while the number of hogs increased by 3.3 million (Degraff). According to Rhodes and Grimes, the

farms that grew during this period were those with 200 head or more. For the period 1979-1987, the size break-even point between growth and decline rose to 1,000 head. Current minimum average cost has been estimated to occur at a size of between 5,000 and 16,000 head annually (Rhodes and Grimes).

Behind these statistics is an even more dramatic change—the emergence during the 1980s of the so-called mega-farms. These are producers who sell more than 50,000 hogs per year. These super-producers were only 0.1 percent of hog farmers in 1991, but they accounted for almost 13 percent of total production (Rhodes and Grimes). They are also the fastest growing segment of the industry (Lazarus and Buhr). One-third of the mega-producers are located in North Carolina, making this state number three in the nation in hog production (Gillespie and Eidman).

The swine breeding stock industry is also undergoing structural change. There are essentially two main sources of improved breeding stock in the U.S. swine industry: purebred breeders and breeding companies. Purebred breeders, as their name implies, sell purebred animals. Purebred breeders are generally small producers who serve local or regional markets. Swine breeding companies, on the other hand, are similar to poultry breeding companies in that they are large, international corporations. The breeding companies produce hybrid pigs.

In 1989, the most recent year for which estimates are available, the breeding companies sold 28 percent of commercial boars and 14 percent of gilts in the United States. Purebred breeders accounted for 58 percent of boars and 10 percent of gilts (McLaren, p. 40). The market share of the breeding companies has likely increased substantially since these data were collected. Large farms are more likely to purchase boars and gilts from breeding companies than are smaller farmers. The mega-producers are customers of the breeding companies.

Dairy. As with the other livestock sectors, dairy is also experiencing structural changes. The combination of increased production, slow growth in consumption and lower support prices during the 1980s put pressure on the high-cost dairies (U.S. Congress). As a result, farms are becoming larger, and production is shifting from the traditional dairy areas like the Northeast and the Midwest, where average herd size is between 50 and 150 head, to the Pacific, Mountain and Southern Plains regions, where herd sizes average between 500 and 1,500 cows (U.S. Congress). In the western United States, the large specialized dairies that were considered "aberrant" in the 1970s contributed 30.5 percent of national milk production in 1992, a 40 percent increase from the previous decade (Knutson). In traditional dairy states such as Minnesota and Wisconsin, farms with more than 100 cows saw their numbers grow while smaller farms declined (Hammond). The nation's dairy herd had declined from 15 million cows in 1965 to 10 million in 1990 (U.S. Congress).

The dairy industry is generally considered receptive to new technologies (Journeaux 1990). Dairy was the first livestock sector to embrace the concept of improved breeding for commercial production. When artificial insemination (AI)

became available in the 1940s, breed and herd improvement associations within the dairy industry responded positively to the efforts of the extension service to promote its use. In 1990, 70 percent of the U.S. dairy herd was bred by AI (Hogeland). Improved genetics have been credited with between a quarter and a half of the 1.5 to 2.0 percent annual increase in production per cow that has been achieved over the past three decades (Herman; Shumway).

The large dairies are more likely to adopt new technologies. In the traditional dairy states, just over half of the cows are bred by AI. In the non-traditional dairy states such as California and New Mexico, the number is higher (Hanke; U.S. Congress). This willingness to innovate is reflected in the higher production levels attained by producers in these regions. Producers in the Pacific region had an average output per cow of 17,527 lbs. in 1989 compared to 14,261 lbs. in the Northeast and 13,408 lbs. in the Corn Belt (U.S. Congress, p. 19).

Concentration has occurred in the breeding industry as well. The number of artificial insemination organizations which supply breeding stock dropped from a high of more than 100 in 1950 to 22 in 1990 (Herman; Hogeland). There are close links between the remaining organizations and it is expected that the number of independent operations will decline even further in the future (Hogeland).

Beef Cattle. The transformation currently occurring in the beef industry may be more severe than in any other segment of the livestock industry (Middleton and Gibb). During the 1980s it appears that there was a structural change in consumer demand for beef. Despite declining real prices, per capita consumption of beef fell from a high of 91.4 lbs. in 1977 to 69 lbs. in 1989 (Purcell). This change in demand has had a major impact on the beef processing industry, which experienced extremely rapid concentration during the 1980s. In 1994, 69 percent of beef processing was done by four companies (Bixby et al.).

These processors have also developed closer ties with commercial feedlots, whose numbers and market share have grown dramatically (Reimund et al.). Commercial feedlots have a capacity of more than 1,000 head, with some exceeding 100,000 (Nelson). Beginning in the mid-1950s, improvements in mechanical and biological technologies combined to create a favorable market and policy environment for commercial feedlots (Reimund et al.). In 1984, 73 percent of cattle came from commercial feedlots (Nelson). While they account for the majority of cattle, commercial feedlots were the minority of feedlots; 98 percent of feedlots were farmer feedlots (Nelson).

Beef calves enter commercial feedlots when they are about one year old. Most come from small herds ranging from 50 cows on a Midwestern grain farm to 1,000 cows on the Western Plains (Nelson). Though there is a trend toward larger farms, the average size remains small (Nelson; Purcell).

The major productivity gains that have occurred in beef cattle have come in the form of improved feed, feed additives and mechanical feedlot technologies (Reimund

et al.). Very little productivity gain has occurred as a result of improved breeding. Introduction of improved genetics into a herd is a slow process not only because cows produce approximately one offspring per year— as opposed to 15 for sows or 300 for chickens—but also because few beef producers use improved breeding technologies (Nelson). Only about 15 to 20 percent of beef cattle in the United States are born through artificial insemination (Keeton). While 95 percent of Ontario dairy producers use AI, only 5 to 10 percent of beef producers do (Cranfield and Howard). More popular among producers is crossbreeding, which has been shown to increase output per cow by as much as 25 percent as a result of hybrid vigor (Herman).[3] Half of commercial producers use crossbreeding, however crossbreeding was originally opposed by the breed associations, and performance data on which to base breeding decisions is not readily available and is not widely used by producers (Willham 1982; Journeaux 1990).

One explanation for the reluctance of beef cattle producers to adopt new breeding technologies is that breeders and commercial producers do not always value the same characteristics (Cranfield and Howard; Cartwright; Cunha et al.). Many breeders of purebred cattle are guided by the standards of the breed associations and the show ring. They select for qualities that may be of little value to commercial producers who raise crossbred cattle, often in harsh environments. However, the standards of the two parts of the beef industry have come closer together. In 1971, the first breed association program that allowed sires to be evaluated on the basis of predicted performance was developed (Willham 1982). However there remain two distinct factions within the industry, and producers interested in the show ring are more likely to use improved breeding technologies than commercial producers (Cranfield and Howard).

Another reason producers did not adopt improved breeding technologies is that there were few economic incentives for doing so. Only recently have the prices paid by packers begun to reflect consumers' demand for the higher quality carcasses and leaner meat that were available through improved genetics (Middleton and Gibb). Genetic improvement programs may be important in stabilizing the beef industry and regaining lost consumer demand. Pressure from the demand side could increase the diffusion of breeding technology within the beef industry.

Breeding Technology Diffusion and Its Impact on Industry Structure

The Traditional Diffusion Model. The early diffusion models generally presumed that relations between the suppliers and users of technology were governed by competitive market relationships (Rogers, Ruttan). In the livestock sector, the market structures that link suppliers and users have often been less than fully competitive. Yet, in several respects, the diffusion patterns have been consistent with the traditional

adoption-diffusion model. First, in terms of the communication of an innovation, the model suggests that the awareness of innovation comes from outside the existing system and/or through mass media communication, while the actual adoption of an innovation is more closely associated with interpersonal communication and local information networks (Rogers). The experience of breeding technology appears to fit this general pattern. In all but the dairy sector, the traditional private breeding establishments opposed the new technologies—namely crossbred or hybrid animals and AI. In some cases, breeders actively obstructed their adoption, for example, through limits on sale of purebred chicks or ownership requirements for the registration of beef cattle (Herman; Willham 1982). Hybrid corn companies introduced hybrid chicks in the 1940s and undertook research on hybrid pigs in the 1960s. In the beef industry, the advent of imported cattle from Europe forced breeders to acknowledge the importance of performance testing and AI (Willham 1982). While these early promoters did not always enjoy widespread adoption of the technologies, they were often successful in bringing the value of improved technologies to the attention of both breeders and producers.

In dairy, the only sector to experience rapid initial diffusion, the innovation of AI was introduced at the local level, and great care was taken to incorporate the farmer into the innovation process. The formation of AI cooperatives and the provision of education and technical support appear to have increased the rate with which farmers accepted the new technology (Herman).

With regard to the specific characteristics of an innovation, evidence from livestock is also generally consistent with what the Roger's version of diffusion theory would predict. Compatibility of an innovation with the existing beliefs and systems of production does seem to be, ceteris paribus, positively associated with the higher rate of diffusion. Technologies that did not require high fixed costs or major changes in the type or sequence of tasks were initially more readily accepted than those that did require major adjustments. AI was very compatible with the existing structure of production in dairy. Dairy farmers were glad to be rid of the danger and nuisance of bulls, while the frequent contact dairy farmers have with their cows facilitates heat detection and use of AI. In beef cattle production, on the other hand, ranchers who graze cattle on the range do not have frequent contact with the animals and may have a harder time making controlled breeding decisions (Cartwright; Willham 1982).

There also seems to be a relationship between the ability to monitor and measure the impact of a technology and its rate of adoption. Daily milking facilitates monitoring of productivity in the dairy industry, as do confinement systems in poultry and pork. Animals raised in open environments are exposed to many things that could affect their productivity, potentially obscuring the impact of farmer's attempts to improve productivity.

While these conclusions provide some explanation for the differing patterns of diffusion of breeding technologies among the four sectors in the short run, they are

unsatisfying in that they do not account for the fact that a sector like poultry, which initially did not fit the profile of a rapidly-adopting industry, currently has the highest level of diffusion. Further, they give little insight into the reasons for the radical structural changes that have accompanied technological change in some livestock sectors. The following observations about the relationship between technological and structural change suggest a need to view diffusion of technology as part of an ongoing process of change that both affects, and is affected by, the structure of the production system.

Economies of Size in Management. The breeding technologies reviewed here seem to be associated with economies of size in terms of the management input. The average cost of adoption appears to decrease with the number of animals produced. Breeding technologies are highly information intensive. An understanding of principles of breeding and genetics, as well as performance data collection, management and analysis, are often necessary in order to use the new technologies effectively. Increasing knowledge can increase the effectiveness of breeding technologies, however it also favors a larger operation over which to spread the costs. This has led to a specialization in breeding within some sectors of the industry which has affected the structure of production.

Poultry provides the most extreme example. Specialization has occurred to such an extent that breeding is entirely removed from the production process. Producers no longer make breeding decisions; they obtain live chicks from breeding companies. This has allowed both the breeders and the producers to increase their size. Clearly, breeding companies respond to the demands of producer/processors. However breeding is the only phase of the poultry process that lies outside the direct control of the integrators (Bugos).

Several factors contributed to this separation of breeding from production. First, the short reproductive cycle and large number of offspring increase the potential for genetic improvement in poultry compared with other animals. Second, producing hybrid chicks requires a large financial and intellectual investment. Modern breeding is a complex and expensive process of record keeping and testing, especially selecting for quantitative traits like egg production rather than qualitative traits like feather color. According to Hartmann, "Moving from the production of pure lines to crossbreeds confronted breeders with difficult financial and organizational problems....Because the chances of success increased with the scale of testing, more facilities were required " (pp. 14-15). Bugos describes the breeding process as consisting of two major practices, inbreeding and testing: "A successful hybrid program is intricate, tedious, expensive and time consuming. It can easily take from ten to twelve years to develop and produce good results. Geneticists funded by tax dollars could not promise improved genetic potential to justify such enormous investments in hybridizing" (Bugos, p. 114).[4]

The companies that introduced hybrid chicks in the 1930s and 1940s were the hybrid corn companies, Pioneer, DeKalb and Ames In-cross, a subsidiary of Foxbilt Feeds (Sauer). Their experience with corn breeding had demonstrated the economic value of hybrid vigor. In spite of its economic potential, crossbreeding was opposed by the traditional poultry breeding establishment, which favored purebred animals. It was also initially unpopular with farmers (Hartmann; Hanke). While the breeding techniques they originally used are no longer used today, the corn companies were instrumental in promoting the popularity of hybrid chicks.

Today the breeding industry is highly concentrated. By 1985, one company, Arbor Acres, accounted for 60 percent of the female broiler breeding stock. By 1989, 90 percent of the market for parent chicks was controlled by three female lines and three males (Hanke). Extreme concentration in both the breeding and the production/processing industries has led to establishment of close relationships between producer/processors and breeding companies. In 1986, Tyson bought half ownership of Cobb-Vantress to secure unrestricted access to its chicks (Hanke).

Some parts of the pork industry are following the pattern of poultry. Specialization among integrated producer/processors means that breeding decisions are removed from production. A manager at a farrowing barn owned by Tyson, the nation's largest hog producer, describes his responsibilities as "all you're expected to do is manage. If you have a maintenance problem, you call a Tyson welder or a Tyson electrician. A Tyson truck gets you feed... A Tyson truck even comes to pick up the feeder pigs when they are ready to go" (Houghton, p. 30).

Most hog farmers are less specialized, and producers still make their own breeding decisions. There are two main breeding systems through which producers introduce improved genetics into their herds. In rotational crossbreeding programs, which are favored by small farmers, farmers purchase purebred boars from breeders and mate them with crossbred sows from their own herds. This system is popular with farmers because it permits some benefit from hybrid vigor while at the same time letting them retain sows from their own herds as replacement breeding stock.

The second way of incorporating improved genetics is terminal cross breeding. This program was developed in the late 1950s in Europe, where producers face high land and feed costs and therefore require higher productivity per animal (Marbery). Most large farms use terminal crossbreeding, which maximizes output per animal by "crossing distinct maternal and paternal lines to produce the end product" (Marbery, p. 18). All offspring from the final cross are marketed, which means that replacement stock cannot be retained from the herd. The advantage of terminal cross breeding is that maternal lines can be chosen on the basis of reproductive efficiency and paternal lines on leanness, rate of weight gain and other carcass characteristics. Maximum heterosis is achieved for sows and pigs. While terminal crossbreeding requires more management time, it also results in a faster rate of genetic improvement, meaning higher productivity (Lazarus).

Their size, specialization and emphasis on management allow the large operations to devote considerable attention to breeding and genetics. Terminal crossbreeding, artificial insemination—which is becoming more widespread in pork production—a high level of mechanization, and attention to cleanliness and disease control give the large farms a cost advantage. Some experts suggest mega-farm costs are 10 percent less than the typical family farm, though others suggest the savings are not so large (Kilman 1994a, p. A5).

The dairy industry is different from the pork and broiler industries because an output of the animal rather than the animal itself is the main product. In addition, cattle's rate of reproduction is much slower than that of poultry or hogs. For that reason, a dairy herd is replaced less frequently and the rate of introduction of improved genetics into a herd is slower. These reasons help explain why the degree of breeding specialization in dairy farming is less than in poultry or pork.

Nonetheless, the management and information intensity of improved breeding has affected the structure of dairy farming. AI is often considered to be scale neutral; however, increasing the size and specialization of an operation appears to allow more profitable exploitation of the technology. AI is an innovation which has both a hardware and a software component (Rogers). It may be scale neutral in the hardware component, but in terms of the software—the information and human capital component—there appear to be economies of size. When AI was first introduced, AI cooperatives provided many technical support services to their members. Later, especially after the advent of frozen semen in the 1950s, most dairy farmers became proficient in the use of AI. This has contributed to decline in the number of AI organizations since fewer organizations were needed to serve a larger area (Hogeland).

According to Shumway, in 1987 current production levels could have been 33 to 45 percent higher had AI been fully exploited. One explanation for the difference in adoption rates and productivity between regions and producers is that there are costs involved with using AI effectively. The quality of farmers' breeding decisions is the key factor in increasing productivity through AI. Sound breeding decisions can make AI a profitable investment, but poorly informed choices can be costly (Shumway).

More and more farmers are investing in computers to help them access and analyze the large quantities of performance data available (Bosch and Lee). However, despite the urging of researchers and industry groups to base selection decisions on the numbers, many farmers are unwilling to give up selection on the basis of type, on the appearance of the bull. On the basis of several recent surveys, Hogeland reports that farmers are aware of the importance of performance data, however information such as pedigrees and photographs do influence their choices (Hogeland). She concludes that many producers "lack an adequate understanding of sire summaries" and therefore do not use them as the sole source of information for breeding decisions (p. 7).

The large, specialized dairies are more likely to focus exclusively on performance data in making breeding decisions. If the rate of adoption of AI can be considered as

a measure of willingness to adopt new technology, this suggests that the larger dairies will also be most likely to adopt other new technologies such as Bst or superovulation (Hogeland). If the marginal cost of adopting future technologies is lower for those who are already using AI effectively, this would increase the advantage of larger, more progressive dairies relative to smaller, more traditional dairies.

Complementarity of Inputs. There appears to be a relationship between adoption of breeding technologies and integration, both vertical and horizontal, in some sectors of the livestock industry. Breeding technologies appear to have contributed to integration through their complementary technical relationships with other inputs such as improved feeds, medicines or building systems, and with processing systems. Two inputs are complements if an increase in the use of one causes the marginal product of the other to increase (Debertin). Examples include improved animals and feed. A complementary relationship could also exist between a highly mechanized processing system and animals bred for carcass uniformity.

Complementarity means that other sectors that are horizontally or vertically linked to the producers are directly affected by the producers' adoption decisions. Firms in these related sectors and stages of production have an incentive to become involved in decisions about technology adoption in the production stage. The major way this has occurred in livestock is through financing of production. The fixed cost of adopting a package of technologies is often high. In the absence of integration, the risk of adopting may fall on the producer, while other suppliers and/or processors stand to benefit. Independently, producers may not be willing or able to obtain credit for these investments. In poultry and pork, the production contract solves this problem by shifting some of the risk from producers to feed manufacturers, processors or others who would benefit from the adoption of the technology.

The form that integration takes depends on the specific situation. In the case of broilers, the current structure is highly vertically integrated with feed manufacturers and processors playing the integrator role. Feed manufacturers initially financed broiler production because banks viewed the enterprise as too risky. Feed was 70 percent of production costs of feed manufacturers who saw expanded poultry production with improved chicks as a way to increase demand for their product (Reimund et al.; Hanke; Bugos). It is easier for an integrator to deal with a few large farms rather than many small ones. Advances in mechanical and health technology during the 1940s and 1950s encouraged large-scale production (Reimund et al.).

By the 1990s, most integrators were processors. Chicks were only 3 percent of the cost of a live broiler, but they were crucial to the overall functioning of the system. The highly mechanized processing facilities depended on a constant supply of uniform birds. The live broiler market had all but disappeared due to integration at the production level. This forced processors to establish relationships with feed manufacturers or to contract directly with producers (Reimund et al.).

Input complementarity is also important in the pork sector. Several of the pig breeding companies sell their products through the manufacturers of large-scale confinement systems, a practice that reflects the complementary nature of the two inputs (Marbery). Packers and processors are also becoming more involved in the production side of the industry. The degree of integration in pork is less than in poultry; however, even the large independent producers are developing closer ties to meat packers (Gillespie and Eidman; Kilman 1994b).

Contract production is also growing in the hog industry. The reasons for contracting in pork are similar to those in poultry, in particular to obtain access to capital to adopt new technologies and to reduce risk by guaranteeing a market and price for output. Corporate-owned hogs currently account for less than 20 percent of the market, but predictions are that within ten years, corporations will control between one third and a majority of the nation's hogs (Kilman 1994a).

Responsiveness to Consumer Demand. There appears to be a link between the adoption of new breeding technology and the responsiveness of a sector to changing consumer demand. The poultry and the large-farm sector of pork are examples of industries that have benefited from their ability to provide products with specific characteristics demanded by consumers. Increased leanness and carcass uniformity have contributed to higher quality and lower prices for final products in these sectors. Transmission of the demand signals from the consumers to producers appears to be facilitated by close relationships between producers and processors (Barkema). This suggests that where the scope for genetic change is great, adoption of breeding technology may lead to more vertical integration.

In poultry, retailers conveyed their demand for a specific type of bird directly to breeders through the "Chicken of Tomorrow" contests sponsored by the A&P grocery chain in 1949 and 1951. The contests rewarded breeders who could produce birds meeting A&P's qualifications. Charles Vantress of California won the two contests. Arbor Acres was runner up in 1949. The winners of these contests became the dominant firms in the breeding stock market. The only new breeding stock companies to enter the market since that time have been spin-offs from the winners (Bugos).

In pork, and, to a lesser extent, beef, prices guide breeders through producers. The extent to which producer prices reward producers who focus on characteristics valued by consumers varies among the industries. However this is changing, and producer prices are expected to reflect more closely consumer desires in all sectors. While farm size alone does not determine whether or not a producer will meet the standards, larger producers with ties to packers may be more likely to adopt the technologies that make better quality possible. Gaining consumer recognition and loyalty through the use of brand names in poultry and, more recently, pork could also encourage closer ties between processors and producers.

The dairy industry presents an interesting case in terms of the relationship between producers and processors. Through cooperatives, dairy producers have always had

close links to the processing phase. These cooperatives encouraged adoption of new technologies in order to increase milk supply. Product differentiation at the retail level does not seem to have had much impact on production relations within the sector. This could change as a result of the introduction of new technologies which are meeting with resistance from some consumer groups. Growth hormones can increase milk output per cow and genetic manipulation may soon make it possible for milk to be produced with specific characteristics, such as low lactose levels, that are popular with consumers (U.S. Congress). If the large processing cooperatives continue to support the use of new technologies, niche markets for hormone-free and non-genetically-manipulated milk could develop. This could result in dis-integration if some non-adopting producers leave the larger organizations to form their own small processing operations. Similar local markets already exist for hormone-free meat.

Conclusions

Adoption of breeding technology in the U.S. livestock industry appears to be related to increasing size and decreasing number of firms. It is also related to increasing integration among those that remain. As the number of independent decision makers declines, and as different stages of production become more closely integrated, the process of technology diffusion will likely be very different from the pattern observed in a competitive and decentralized market.

Understanding how the structural changes are related to technological changes can help policy makers more precisely target policies to mitigate adverse impacts of structure change. For example, concentration in an industry may have both positive and negative aspects. Policies should be designed to address the negative aspects, with as little impact as possible on the positive. One example would be the formation of producer or breeder cooperatives to take advantage of economies of size with relation to information management or supplier relations, while at the same time retaining a more traditional production structure with small producers.

This paper suggests several possible relationships between technological change and industry structure that should be considered in developing such policies. Further research to clarify and quantify these relationships is warranted. Such research would be useful not only for policy analysis in the context of the U.S. livestock industry, but also for developing a more complete operational model of the process of diffusion of innovations.

Notes

Nancy Johnson is a research assistant and Vernon R. Ruttan is a Regents Professor, Department of Applied Economics, College of Agricultural, Food and

Environmental Sciences, University of Minnesota, St. Paul. The authors would like to thank Bill Lazarus for his valuable comments. This research has been supported by the Minnesota Agricultural Experiment Station, publication # 22177.

1. See Ruttan for a review of methodological issues in adoption/diffusion research.
2. The terms hybrid and crossbred are often used interchangeably in the literature. Crossbred refers to the offspring of purebred parents of different breeds. Hybrid refers to the offspring of parents of a different genotypes. This would include crossbreeds, but would also include offspring of unrelated parents of the same breed or line (Lasley).
3. Hybrid vigor, or heterosis, is a phenomenon that occurs when the offspring of a cross are larger and more vigorous than the parents (Lasley).
4. Bugos asserts that hybridization is also a means by which breeders protect their investment in the absence of patents on animals. The offspring of hybrids will not exhibit the characteristics of their parents.

References

Barkema, Alan. "Reaching Consumers in the Twenty-First Century: The Short Way Around the Barn." *Amer. J. Agr. Econ.* 75(1993):1126-1131.

Bishop, Robert V., and Lee A. Christensen. "America's Poultry Industry." *Nat'l. Food Rev.* Jan.-Mar. 1989, pp. 9-12.

Bixby, Donald E., Carolyn J. Cristman, Cynthia J. Ehrman and D. Phillips Sponenberg. *Taking Stock: The North American Livestock Census.* Blacksburg, VA: The McDonald and Woodward Publishing Company, 1994.

Bosch, Darrell J., and Katherine L. Lee. "The Farm Level Effects of Better Access to Information: The Case of DART." *South. J. Agr. Econ.* 20(1988): 109-118.

Bugos, Glenn.E. "Intellectual Property Protection in the American Chicken-Breeding Industry." *Bus. Hist. Rev.* 66(1992):127-168.

Cartwright, T.C. "A Systems View of Beef Cattle Production." *A Systems Approach to Beef Improvement and Management.* Proceedings of a Beef Improvement Federation-sponsored workshop. Morrilton, AR: Winrock International, 1984.

Christian, Lauren. "Limits for Rapidity of Genetic Improvement for Fat, Muscle, and Quantitative Traits." *The Pork Industry: Problems and Progress*, ed. D.G. Topel, pp. 154-162. Ames, IA: Iowa State University Press, 1968.

Cranfield, John, and Wayne Howard. "Ontario Beef Producers' Attitudes about Artificial Insemination." Dept. of Agr. Econ. and Bus. Working Paper WP94/1O. Guelph, Ont., Canada: University of Guelph, 1994.

Cunha, T.J., M. Koger and A.C. Warwick, eds. *Crossbreeding Beef Cattle.* Gainesville, FL: University of Florida Press, 1963.

Debertin, David L. *Agricultural Production Economics*. New York, NY: MacMillan Publishing Company, 1986.

Degraff, Herrell. "Introduction at a Crossroads." *The Pork Industry: Problems and Progress*, ed. D.G. Topel, pp. xi-xiv. Ames, IA: Iowa State University Press, 1968.

Feder, Gershon, Richard E. Just and David Zilberman. "Adoption of Agricultural Innovations in Developing Countries." *Econ. Dev. and Cult. Change* 33(1985): 255-298.

Gillespie, Jeffery M., and Vernon R. Eidman. "Structural Change and New Business Arrangements in the United States Pork Industry." Dept of Agr. Econ. Staff Pap. Saskatoon, Sask., Canada: University of Saskatchewan, 1993.

Griliches, Zvi. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* 25(1957):501-522

Hammond, Jerome. "Trends in the Size Distribution of Dairy Farms in Minnesota and Wisconsin." Dept. of Agr. and Agr. and App. Econ. Staff Pap. P94-27, St. Paul, MN: University of Minnesota, 1994.

Hanke, Oscar, John L. Skinner and James Florea. *American Poultry History 1823-1973*. Printed for the American Poultry Historical Society. Madison, WI: American Printing and Publishing Co., 1974.

Hartmann, Werner. "From Mendel to the Multi-National in Poultry Breeding." *World's Poultry Sci.*, Mar. 1989, pp. 5-25.

Herman, Harry A. *Improving Cattle by the Millions: NAAB and the Development and Worldwide Application of Artificial Insemination*. Columbia, MO: University of Missouri Press, 1981.

Hogeland, Julie A. *Cooperatives' Role in the Artificial Insemination Industry*. Washington, DC: USDA ACS Res. Rep. 90, 1990.

Journeaux, Philip. "Adoption of New Technologies: Sheep and Beef Farming Relative to Dairying." Paper presented at the Annual Conference of the Australian Agricultural Economics Society, Blenheim, New Zealand, June, 1990. Proceedings published by Centre for Agricultural Policy Studies, Massey University, Palmerston North, New Zealand, 1990.

Keeton, Laura E. "Cattle Ranching in the 1990s Is an Office Job." *Wall St. J.*, Oct. 4, 1995, pp. B1.

Kilman, Scott. "Power Pork: Corporations Begin to Turn Hog Business into an Assembly Line." *Wall St. J.*, Mar. 28, 1994a, pp. A1, A5.

Kilman, Scott. "Some Farm States Resist the Advent of Corporate Hogs." *Wall St. J.*, Mar. 28, 1994b, p. A5.

Knutson, Ronald D. "Dairy Industry Challenges in the Year 2000: A Choice Between Extremes." Dept. of Agr. Econ. AFPC Policy Pap. 91-4. College Station, TX: Texas A&M University, 1991.

Lazarus, Bill. "The Controversy Over Swine Multiplier Units." *Minn. Agr. Econ.* Fall, 1991, pp. 1, 5-8.

Lazarus, Bill, and Brian Buhr. "The Minnesota Pork Industry: Competitive Situation and Prospects," mimeo. St. Paul, MN: University of Minnesota, 1994.

Lasley, John F. *Genetics of Livestock Improvement.* Englewood Cliffs, NJ: Prentice-Hall, 1978.

Marbery, Steve. "America Is the New Hub for World Pig Business." *Feedstuffs*, Special Issue, Aug. 23, 1993, pp. 1 & 18.

McLaren, D.G. "Biotechnology Transfer: A Pig Breeding Company Perspective." *Animal Biotech.* 3(1992):37-54.

Middleton, B.K., and J.B. Gibb. "An Overview of Beef Cattle Improvement Programs in the United States." *J. Animal Sci.* 69(1991):3861-3871.

Nelson, Kenneth E. "The Cattle-Beef Subsector in the United States: A Brief Overview." Washington, DC: USDA ERS, National Economics Division, 1984.

Peterson, Willis L. "Return to Poultry Research in the United States." *J. Farm Econ.* 49(1967):656-669.

Purcell, Wayne D. "Economics of Consolidation in the Beef Sector: Research Challenges." *Amer. J. Agr. Econ.* 72(1990):1210-1218.

Reimund, Donn A., J. Rod Martin and Charles Moore. *Structural Change in Agriculture: The Experience for Broilers, Fed Cattle and Processing Vegetables.* Washington, DC: USDA ESS Tech. Bull. 1648, 1981.

Rhodes, V. James, and Glenn Grimes. "The Structure of the U.S. Pork Industry," unpublished manuscript, Columbia, MO: Department of Agricultural Economics, University of Missouri, September 2, 1993.

Rogers, Everett. *Diffusion of Innovations.* New York, NY: The Free Press, 1995.

Ruttan, Vernon W. "What Happened to Technology, Adoption/Diffusion Research." *Sociologia Ruralis* 36(1995):51-73.

Sauer, Burton P. "Hybrid Hens Hike Egg Production; Pare Costs for Poultrymen." *Wall St. J.*, May 10, 1956, p. 1.

Shumway, C. Richard. "Assessing the Comparative Economics of a Biotechnology: Artificial Insemination Dairy Sites." *Agribus.* 3(1987): 207-220.

Thirtle, Colin, and Vernon Ruttan. *The Role of Demand and Supply in the Generation and Diffusion of Technical Change.* New York, NY: Harwood Academic Publishers, 1987.

U.S. Congress. "U.S. Dairy Industry at a Crossroads: Biotechnology and Policy Choices—Special Report." Washington, DC: Office of Technology Assessment OTA-F-470, GPO, May, 1991.

Willham, R.L "Genetic Improvement of Beef Cattle in the United States: Cattle, People and Their Interaction." *J. of Animal Sci.* 54(1982) 659-666.

_____. *The Legacy of the Stockman.* Ames, IA: Iowa State University/Winrock International, 1985.