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**THE DIFFUSION OF LIVESTOCK BREEDING TECHNOLOGY IN THE U.S.:  
OBSERVATIONS ON THE RELATIONSHIP BETWEEN TECHNICAL  
CHANGE AND INDUSTRY STRUCTURE**

by

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

## **I. Introduction**

Since the early part of the 20th century, research in animal genetics and breeding has focused on commercial applications for livestock production. Since the 1940s, new breeding technologies have contributed to significant increases in farm-level productivity. However, the degree to which commercial producers have adopted the new technologies varies widely across the sectors. Poultry has experienced almost one hundred percent adoption, while only a small percent of beef producers use improved breeding technologies. The pork and dairy industries fall somewhere in between.

The livestock industry is currently experiencing significant structural changes, many of which appear to be linked to technological change. Many studies have attempted to explain these changes within the context of a specific sector. Few attempts have been made to draw conclusions across the different sectors on how the diffusion of technology is related to industry structure. This paper examines the diffusion of the breeding technologies within the four main livestock sectors in the U.S. and attempts to identify factors that affect the differing patterns and levels of diffusion. Based on these conclusions, the paper offers some observations on the relationship between technical change and industry structure in livestock.

\*\*The author has benefitted from the guidance of Vernon Ruttan, and from the helpful comments of William Lazarus, Jerome Hammond and Gerald Shut-son.

The diffusion and impact of breeding technologies is of particular interest because the area of breeding and genetics research is expected to be an important source of innovation in the coming decades. At the same time, the potential application of biotechnology and genetic engineering to commercial livestock production raises many economic and ethical questions. By reviewing past experience with new breeding technologies, this paper reveals that many of today's concerns are not new.

Understanding how they were resolved in the past has important lessons for addressing similar issues in the context of today's livestock industry.

## **II. 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 deals with the spread of an idea, product or innovation at the aggregate level. According to Thirtle and Ruttan, diffusion doesn't include the innovation process itself. Rather it begins with the existence of a new technology and focuses on its pattern and rate of spread throughout a target population.

Rogers, in his classic book on diffusion of innovations, reviews hundreds of diffusion studies and identifies variables that may influence diffusion (p. 207). These can be grouped into three main categories. The first is communication variables, those that affect how agents become aware of innovations. These 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 includes characteristics of the innovation--relative profitability, compatibility with the existing system, complexity, lumpiness, and ability to be tested and evaluated. Variables in the third category describe the nature of the production system, such as size, number and type of firms.

Diffusion of technology is an important area of research in social sciences. In economics, a classic diffusion study is by Griliches, who characterized 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. Griliches' work, and the studies that followed, helped clarify the economic forces that drive the diffusion of new technologies. While agriculture has been the focus of many diffusion studies, animal agriculture has been neglected relative to crop agriculture.

Diffusion studies have provided insights into the process of technological change, however shortcomings of the traditional diffusion model limit its usefulness in many situations. 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 as case, it is difficult to describe the diffusion process of 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 often focus on competitive environments, where 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 ways that may significantly affect diffusion of innovations. Of particular interest in this paper is the relationship between vertical and horizontal integration and technology diffusion. Economic theory suggests that with perfect and complete markets, demand for inputs, including technology, should be identical under decentralized or

centralized market structures. If imperfect information, externalities or other market failures exist, then technology diffusion would be expected to be different in segmented versus integrated markets.

Finally, traditional diffusion models are static. The underlying assumption is that the innovation represents the only change in an otherwise stable system. Diffusion represents the process by which the innovation is incorporated into another stable equilibrium. In reality, there are often many post-innovation changes with either causal or coincidental relationships to the innovation under study. 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).

**The** next section describes the diffusion of major breeding technologies in each of the four main livestock sectors as well as the structural changes that have occurred. In order to compare diffusion across sectors and across time, the approach taken here is quite broad, focusing on qualitative descriptions of the diffusion process supported by national and regional level statistics. However, as section IV will show, several interesting observations emerge from a comparison of the different industries even at a general level.

## **II Diffusion of Breeding Technologies in the Livestock Sector**

### **A. Poultry**

During the first half of the 20th century, poultry production developed from a household activity into a highly mechanized and concentrated industry. Poultry breeding transformed itself from an art form 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, animals which are the product of intensive genetic selection and testing geared to meet the exacting demands of the processors and consumers. These chicks, whose pedigrees are protected by patents and trade secrets, are sold, often 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, and particularly the modern broiler, industry 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 U.S. was 34 million birds annually. In 1987, 5 billion broilers were produced. In 1920, average feed conversion 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 technologies were an important part of these increases.

Before 1920, commercial poultry producers produced eggs, with meat as a byproduct. Private breeders and those at university experiment stations maintained purebred flocks which were available to farmers interested in improved breeding. During the 1920s university researchers became active in studying the possibility of hybrid vigor among crossbred chicks<sup>1</sup> (Hanke). In spite of its economic potential, crossbreeding was

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<sup>1</sup>The term hybrid and crossbreed are often used interchangeably in the literature. A crossbreed refers to the offspring of purebred parents of different breeds. A 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

opposed by the traditional poultry breeding establishment and was unpopular with farmers. Hartmann offers two reasons: first the permanency of the benefits of hybrid vigor was questioned, and second, the principles and standards of the breeding industry were based on purebreds rather than crossbreeds. Some breeders of purebred chickens refused to sell chicks to university professors suspected of engaging in crossbreeding (Hanke).

This resistance on the part of poultry breeders left a void into which stepped the hybrid corn companies, whose experience with corn breeding convinced them of the economic value of hybrid vigor. Pioneer began a hybrid chick program in 1936 based on the technique of inbreeding.<sup>2</sup> In 1942 the “Hy-line chick” was released. In 1944 DeKalb began a poultry program, and four years later the “DeKalb Chix” came on the market. The third major producer of hybrid chicks by the 1950s was Ames In-cross, a subsidiary of Fosbilt feeds (Sauer).

Farmers were slow to accept the new chicks, but good results from hybrids in performance tests eventually increased acceptance rates (Bugos). By 1956 egg production of hybrid hens was 195 per year (Sauer). To boost sales, Hy-line sold its chicks for half price in exchange for a promise from the farmer to keep careful records of the chicks productivity. This plan provided the valuable word of mouth publicity, as well as production data, that was necessary to convince a skeptical audience. These methods paid off. “By the 1954, the Hy-line Chick had captured a 20 percent share of the very decentralized American market for layers” (Bugos, p. 142). Crossbreeds rapidly captured the market for broilers. By 1943, 97 percent of commercial broilers were

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same breed or line. Hybrid vigor, or heterosis, is a phenomenon that occurs when the offspring of a cross are larger and more vigorous than the parents (Lasley, 1978)

<sup>2</sup>Inbreeding is the crossing of related parents, such as a father and a daughter.



crossbred. However it must be remembered that the broiler market was considerably smaller than the layer market at this time.

The techniques used by the corn companies were successful in proving the productive potential of crossbreeds. However the single cross, inbreeding process they used was costly and unpredictable, and dependence on inbred lines was a major weakness of the system. Though it is no longer used commercially, Hartmann concludes that “the introduction of the hybrid chickens produced by applying the system of corn breeding provided the necessary stimulus for many established breeders to undertake crossbreeding activities which resulted in similarly. successful hybrid stocks and paved the way for the structure of the modern poultry breeding industry ” (P. 14).

Before 1950, the market for layers was much more important than the market for broilers. In 1940, the ratio of broilers to layers was 1 to 3; by 1950, it was 6 to 1 (Hartmann). During that period, a variety of forces came together to make possible a dramatic increase in scale of production. New mechanical technologies for large-scale production, processing, transportation and storage increased the size of production units and the market. Advances in nutrition, disease control and breeding--including a reliable method for sexing chicks that allowed meat and egg production to be separated--also contributed to the increase in size and the specialization into meat or egg production.

In addition, new institutional arrangements in production and marketing attracted new participants with new attitudes about poultry production (Reimund). The new broiler producers, who generally came from outside of poultry, used the available new technologies and operated on a much larger scale than existing poultry producers. Integrators, initially feed manufacturers looking to increase demand for their products, provided financial support and insurance to producers. The arrangements eventually

became formalized in the production contracts that characterize today's highly integrated poultry production and processing industry.

Competition was increasing along with scale in the industry. Throughout the 1960s, overproduction and prices below cost were an almost constant problem. 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 southeast --Georgia, Alabama and Arkansas--and in terms of market structure. In 1961, six companies accounted for 20 percent of production (Western). By 1988, the top four companies--Tyson, Conagra, Goldkist and Perdue, accounted for 43 percent (Bugos).

Chicks were only 3 percent of the cost of a live broiler by the 1970s, but they played a crucial role in the production process (Bugos). Uniformity in terms of growth rates and characteristics was essential to the continuous operation of highly-mechanized, automated processing lines. Given the demands of both their technology and their markets, the processors were able to specify exactly what kind of bird they wanted. They didn't wait for the Industry to provide it. In 1946, the A&P Company decided to jump start the search for the perfect bird by sponsoring the "Chicken of Tomorrow," contest.

Three years later Charles Vantress of Live Oak, California was named the winner, receiving "\$5000 and invaluable publicity" for his cross of a Comish rooster and a New Hampshire hen, two birds known for their size and muscling qualities (ibid). The runner up in the first contest was the son of the owner of a Glastonbury Connecticut farm called Arbor Acres. On the strength of its performance in the contest, Arbor Acres captured 25 percent of the female breeding market while Vantress, who also won the second contest

in 1951, held one third of the market for males (Bugos, Hanke). The winners of these contests took over the market. The only new breeding companies to enter since that time have been spin-offs from the winners (Bugos). By 1985, 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 lines (ibid).

Such extreme concentration in both the breeding and the production/processing industries has led to establishment of close, even subsidiary, relationships between producer/processors and breeding companies. In 1986, Tysons bought half ownership of Cobb-Vantress to secure unrestricted access to its chicks (ibid). This renders the concept of diffusion at the production level somewhat moot. Producers are linked, directly or indirectly, to the breeding companies that generate new technologies.

## **B. Swine**

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

There are essentially three main sources of breeding stock in the U.S swine industry: a farmer's own herd, purebred breeders and breeding companies. This paper focuses on the latter two since they are sources of improved stock. Purebred breeders, as their name implies, sell purebred animals. They 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 38 percent of commercial boars and 14 percent of gilts in the U.S. 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 since these data were collected.

Since 1990, there has been a dramatic increase in the number of breeding companies operating in the U.S. Established companies such as Pig Improvement Company (PIC), Farmer's Hybrid and DeKalb have been joined in recent years by affiliates of European breeding companies such as Seghershybrid, Newsham Hybrids, National Pig Development Co., and Danbred USA. Many of the European companies operate in the U.S. through joint ventures or marketing agreements with American breeders or producers (Marbey).

The source of seedstock is related to the type of breeding system a producer is using, and the type of breeding system is closely linked to the structure of production. There are two main breeding systems through which producers introduce improved genetics into their herds. In rotational crossbreeding programs, farmers purchase purebred boars from breeders and mate them with crossbred sows. This system became popular after experiment station studies in the 1930s and 1940s showed the potential for hybrid vigor in swine (Craft; Whatley et al, 1953). It 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. However, the retention of sows for breeding means that the maternal and paternal lines are not unrelated. The closer the relation between a boar and a gilt, the less potential for heterosis. This reduces the potential for productivity

gain because it prevents separate selection for reproductive characteristics and carcass characteristics.

The second way of incorporating improved genetics is terminal cross reeding. This program was developed in the late 1950s in Europe, where producers face high land and feed costs (Marbery). Terminal crossbreeding maximizes output per animal, “crossing distinct maternal and paternal lines to produce the end product” (ibid, 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. Estimates of the benefits of terminal cross breeding range from \$4.73 to \$13.90 per pig (Lazarus, 1991).

Rotational crossbreeding is associated with home-raised gilts and purchased purebred or crossbred boars. In terminal crossbreeding, breeding animals, especially boars, are purchased from breeding companies. In the U.S., the relatively small percent of boars and gilts that come from breeding companies reflects the dominance of rotational crossbreeding. By contrast, in Europe, nearly, 100 percent of boars and 70 percent of gilts come from breeding companies (McLaren).

This suggests a reluctance on the part of U.S. producers to adopt the new breeding technology. “While US producers began replacing labor with capital with the advent of confinement in the 1970s basic breeding systems were little changed from the 1950s. While experimenting boldly with technology--slatted floors, crates, climate control--

producers were reluctant to switch away from their reliance of rotational crossbreeding systems and fascination with breed “type” shows as the basis for their selection decisions” (Marbery, p. 18). According to Gerald Shurson of the University of Minnesota, “if you look at reproductive efficiency and growth efficiency, we in the United States haven’t been forced to achieve the performance that producers in other parts of the world have. Consequently we have been satisfied with average genetics” (Freeze, 1993, p. 35).

However, national averages do not represent a uniform pattern of technology diffusion. Very large farms are much more likely to obtain seedstock from breeding companies than are smaller producers. Technical and structural changes currently occurring in the hog industry are increasing the number, size and market share of the large farms. Between 1979- 1987 the break-even point doubled to 1000 hogs per year (Rhodes and Grimes). Current minimum average cost has been estimated to be between 5000 and 16,000 head annually. 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 . 1% of hog farmers in 1991, but they accounted for almost 13% of total production (Rhodes and Grimes). They are also the fastest growing segment of the industry (Lazarus and Buhr). Predictions are that within 10 years, corporations will control between a third and a majority of the nation’s hogs (Kilman, 1994.a).

Their size, specialization and emphasis on management allow the large operations to devote considerable attention to breeding and genetics. Terminal crossbreeding, artificial insemination, a high level of mechanization, and attention to cleanliness and disease control give the large farms a cost advantage. “Some experts suggest than a mega-farm can easily make a hog for 10% less than the typical family farm” (Kilman, 1994a, p. A5).

The reasons why the largest producers are customers of the breeding companies are not undisputed. The companies promote their superior genetics, which are based on extensive genetic research and testing and supported by large quantities of performance data. While acknowledging the importance of genetic testing and data, some experts contend that the productivity of the hybrid pigs is not necessarily higher than that of the purebreds (Fee and Freeze).

One clear advantage of the breeding companies is that they can offer volume and uniformity that the large customers demand (Gunset). The increasing size of production units and the rise of horizontal integration at the production level mean that the number of animals managed by a single person has increased dramatically (Rhodes). Further, some of the mega farms are characterized by close integration with processors. Processors want to control their supply--in terms of quantity and quality--and close linkages with large producers allow them to do it economically. Pork quality, especially increased leanness, is an important issue at the retail level and this is being transmitted backwards to the breeding level.

Some breeding companies sell to both small and large producers, while other focus exclusively on the larger farm market. Several breeding companies target the large farm market by promoting their products through the makers of, for example, large confinement houses (Marbery). In other cases, a producer/processor might contract directly with a breeding company to guarantee exclusive rights to its genetics (Marbery; Gillespie and Eidman). In a market characterized by supply relationships of this sort, the small producers and the small breeders are at a disadvantage.

Purebred breeders market their product very differently from the corporate suppliers. As noted earlier, purebred breeders are predominantly private, family farmers who specialize

in the production of breeding stock. They advertise mainly in local newspapers and breed magazines. Rather than promote their individual operation, producers often promote the superiority of the breed (Hayenga et al, 1981). Rhodes points out that with only three specialized national hog magazines left, mass communication is unlikely to continue to be an effective means of product promotion for any input supplier. Some experts suggest that purebred breeders could compete better with the breeding companies for the large farm market if they organized themselves to provide the same services, in terms of volume and performance testing, that the companies do (Fee and Freese). Many progressive purebred breeders have begun to do so (Shurson, 1995).

Until recently, artificial insemination (AI) had not been widely used in hog production in the U.S. The AI technology in swine is not as well developed as in other livestock sectors. Frozen boar semen isn't as effective as fresh semen, and conception rates using AI are lower than with natural service (Freese, 1994). Therefore AI providers must rely on fresh semen, which limits the market size.

Improvements in technology and distribution are causing this to change. AI use is currently increasing among swine producers, and both purebred breeders and breeding companies are operating AI studs (Lazarus, 1995; Shurson). One of the main benefits of AI is that it reduces the number of boars required to service a herd, which in turn increases the number of sows a producer can maintain. Other benefits include increased flexibility in choice of genetics, less disease risk, and consistent breeding performance year round (Freese, 1994). AI is often considered a scale-neutral innovation, however the fact that fresh semen must be used could lead to adoption by larger farmers.



### C. Dairy

The dairy industry is generally considered to be receptive to new technologies (Joumeaux). Dairy was the first livestock sector to embrace the concept of improved breeding for commercial production. The first local herd improvement association was founded in Michigan in 1905 (Herman). When artificial insemination became available in the late 1930s breed and herd improvement associations within the dairy industry responded positively to the efforts of the extension service to promote its use. Table 2 shows the increase in cows bred by AI during the first few years it was available. By the 1970s average adoption rates in the U.S. were approaching 65 percent, where they are today (Hogeland, Hanke). However between regions the use rates vary from 50 and 80 percent (Hanke, US Congress).

#### **The Number of Cows Bred in the U.S. by Bull Associations and by AI, 1939-1942**

Year	Bull Associations <sup>a</sup>		AI Organizations	
	Bulls	Cows	Bulls	Cows
1930	1079	35,333	33	7,539
1940	1266	41,678	138	23,977
1941	1292	41,478	237	70,751
1942	1291	43,251	412	112,788
1942	1230	41,487	574	182,524

<sup>a</sup> Prior to AI, farmers belonged to bull associations, through which they jointly owned bulls.

Source: Agricultural Research Administration, USDA, January 1944 from Herman, 1981.

Several reasons are given for the relatively early and rapid adoption of AI technology by the dairy industry (Joumeaus, Herman). First, once AI was shown to be as effective as natural service, the extension service made a special effort to promote it. AI was introduced at the local level through cooperatives formed by producers, breeders and researchers and extension personnel.

The first producer-owned AI breeding cooperative in the United States began operating in New Jersey in 1938. A local extension agent convinced 102 dairy farmers in New Jersey to form a cooperative organized along the lines of the coops he had seen on a recent visit

to Denmark. The organization began with just over 1000 cows. Several months later a similar association was established in Hughesville, Missouri, including dairy farmers, the Missouri College of Agriculture and the Farm Security Administration. By 1946 there were 84 AI production facilities (bull studs) recorded by the USDA's Dairy Herd Improvement Letter. At the county level there were over 600 artificial breeding associations in 34 states (Herman, 1981). Initially, AI cooperatives offered custom service, where technicians came out to the farm to perform inseminations. Some also offered classes to educate farmers (Herman).

The role of the regional cooperatives was instrumental in the development of the AI industry (Herman). When AI was introduced in 1939, the market was not sophisticated enough for many private companies. AI organizations needed not only to perfect the techniques, but also to persuade skeptical producers that the product actually worked. Coops and other early associations, working closely with agriculture extension workers and university scientists, performed this role. They essentially created a functioning market into which other organizations later entered. During the 1950s after frozen semen became available, there was a period of rapid consolidation among the AI organizations. Today the market is supplied by 20 cooperatives and several large private firms (Hogeland). Despite their international marketing abilities, the cooperatives continue to have a regional, membership oriented focus that reflects their origins (Hogeland).

A second important factor in the rapid diffusion of AI was its compatibility with the existing production structure. Keeping bulls is a nuisance and a danger so farmers were eager to get rid of them. AI did not require a large capital investment or a major reorganization of the production process. The frequency with which dairy farmers see their animals facilitates heat detection and animal monitoring.

Third, in terms of industry characteristics, Joumeaux points out that dairy farms are usually located near each other and are relatively homogenous in terms of production processes and technology. These factors positively affect the spread of new technologies. He also suggests that the price supports in place in the dairy industry contribute to higher and more stable incomes for dairy farmers, which could also be expected to increase their willingness to adopt new technologies.

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 in 1980s put pressure on the high cost dairies (US Congress). In general, larger farms have lower production costs, and as a result production began to shift from the traditional dairy areas like the Northeast and the Midwest to the Pacific, Mountain and Southern plains regions (ibid). Average herd sizes were 50-150 cows in the Northeast and Midwest, and 500-1500 in the Southern and Western states.

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, fast-growing dairy states like California and New Mexico, the use rates are much higher (Hanke, US Congress). This willingness to innovate is reflected in the higher production levels attained by producers in these regions. Table 3 shows average production per cow for the different regions.

**Table 3. Milk Output Per Cow By Region in 1989**

<u>Region</u>	<u>Pounds/cow</u>
Lake States	13,928
Northeast	14,261
Pacific	17,527
Mountain	16,134
Southern Plains	13,173
Corn Belt	13,408
U.S. Average	14,244

Source: U.S. Congress, 1991, p. 19

According to Shumway, in 1987 current production levels could have been 33-45 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). Farmers decide how much time to invest acquiring knowledge about breeding and genetics based on their expected return. Factors such as unit size appear to increase expected return.

More and more farmers are investing in computers to help them access and analyze the large quantities of performance data that are 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).

According to the Office of Technology Assessment, successful dairies are distinguished by “progressiveness, philosophy, and quality of management. These factors directly impact technology adoption and the size of dairy farms” (US Congress, 1991, p. 7). 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, thereby increasing their productivity advantage over small, more traditional dairies.

#### **D. Beef Cattle**

Unlike dairy, the beef cattle industry is reputed to be slow to adopt new technology. Improved breeding technologies appear to be no exception. The beef improvement programs in the U.S. are only half as old as the dairy program, reflecting a much later interest in genetic improvement (Baker). About 15-20 percent of beef cattle in the U.S. are born through artificial insemination (Keeton). A Canadian study estimated that while 95 percent of Ontario dairy producers use AI, only 5-10 percent of beef producers do (Cranfield and Houfard). The apparent resistance to new technologies has led several authors to take a closer look at the adoption of breeding technology by beef producers. In many cases, they concluded that there are often good economic reasons why beef producers have not adopted new technologies (Joumeaus, Cranfield and Howard; Cartwright; Cunha et al). Institutional, structural and informational characteristics of the beef industry appear to reduce the profitability of breeding technologies in beef.

As with the other livestock sectors, breeding purebred beef cattle was popular in the U.S. by the mid 19th century. By the turn of the century, U.S. breed associations existed for all the major British breeds. At that time, a breeder’s goal was to win at regional and national stock shows. The characteristics that were rewarded in these shows were very different from those that were important in commercial production. Over time the

standards of these two sides of the beef industry have come closer together. However the showing continues to be a profitable goal, and there continue to be two distinct factions within the beef industry, one focusing on purebreds for show and the other on crossbreeds for commercial production. Use of new breeding technologies such as AI is still much more prevalent among the former group than the latter (Cranfield and Howard).

Competition from the commercial producers eventually caused the breeding establishment to accept and promote performance testing and selection for economic characteristics. By mid-century commercial cattle were more profitable, yet commercial producers benefited little from the efforts of the established breeders (Willham, 1982). Eighty percent of U.S. beef came from feedlots in the south and southwest and from crossbred cattle (ibid). What breeding improvements occurred in these areas came in the form of new breeds--Santa Gertrudis, Beefmaster--that were developed by Southern ranchers, in cooperation with experimentation stations, to withstand the harsh climate (Cunha et al).

The arrival of the large, fast-growing Charolais from Mexico in the 1930s was the impetus for breeders to begin emphasizing characteristics like size and rate of weight gain. In the 1940s and 1950s, interest in performance testing grew among researchers at state and regional testing stations and, later, among the breed associations (Willham, 1985). During the 1960s and 1970s the efforts of the Beef Improvement Federation to increase the demand for performance information coincided with the arrival in the U.S. of the so-called "exotic" breeds -- Simmental, Limousin, Maine-Anjou and other continental European breeds. Like the Charolais, these breeds had size and growth characteristics that were in demand among commercial producers.

Several changes resulted from the arrival of the exotics and the growing profitability of commercial production. First, the arrival of the exotics indirectly stimulated the use of AI in beef cattle (ibid). Customs restrictions prevented animals from being imported directly into the U.S., which meant that semen was available only through AI from bulls on Canadian quarantine stations. Prior to this time, AI was rarely used in the U.S. beef industry. When AI first became practical in the 1930s, it had been bitterly opposed by the established breed associations. They attempted to limit its use through restrictions such as requiring that both sire and dam of a registered animal be owned by the same person. Their resistance is understandable since the value of a champion bull is due to his exclusivity. AI would dramatically reduce the number of bulls demanded, which would reduce the economic value of many current breeding animals. A lawsuit during the 1960s against the American Angus Association finally stopped the breed associations from actively obstructing the AI industry.

The exotics also spurred the development of national sire evaluation programs. Producers were very interested in the new breeds, but had no data upon which to base their breeding decisions. Performance evaluations of these new breeds were eagerly awaited from the US Meat Animal Research Center (Willham, 1982). In 1971, the American Simmental Association released the first sire summary. The British breed associations, recognizing that performance programs would become their major reason for being, were quick to follow (Ibid). They developed programs, based on the theory and example of dairy improvement programs, to measure productivity across herds and increase the accuracy and intensity of selection predictors (Middleton and Gibb, 1991).

Finally, the availability of the exotic breeds increased the demand for cross breeding among commercial producers. Originally very unpopular among breeders, crossbreeding has become an accepted and important part of commercial beef production. Tests showed

that output per cow can increase as much as 25 percent per cow as a result of hybrid vigor (Herman, 1981). This hybrid vigor can be maintained through properly planned crosses, however management time increases (ibid). By 1984, approximately 50 percent of commercial producers used some crossbreeding (Willham, 1984).

Despite the efforts of researchers and industry federation officials, the level of adoption of AI and the use of available performance data by producers in selection decisions is low. Joumeaux looked specifically at failure to adopt new technologies among sheep and beef cattle producers. His paper focuses on New Zealand, but many of his arguments apply in the US as well. He begins with the assumption, which has been confirmed in an empirical study by Cranfield and Howard, that there are no significant demographic characteristics that distinguish beef producers from dairy producers, who adopted AI more readily. Joumeaux attributed the slower rate of adoption to three factors: structure, institutions and extension activities.

In terms of production structure Joumeaus suggests that there are differences between dairy and beef cattle farms that favor adoption of technology by dairy producers. There is a wide variety of production systems used by beef producers compared to the more homogenous dairy production system (Joumeaus, Cartwright). Further, beef cattle ranches are often located very far from each other, and the climatic conditions can vary widely between them. In addition, heat detection is difficult for ranchers whose animals range over large areas.

Cartwright argues that most breeding research is narrowly focused on a few characteristics. In dairy, milk production may be an appropriate variable on which to focus attention, but in cattle many factors are important in measuring overall herd performance. He promotes a more systems-oriented approach to breeding, suggesting



that, instead of a particular physical characteristic, income or return on investment should be the dependent variable of interest to researchers (Cartwright, Hohenboken).

In terms of institutional factors, Joumeaux contrasts the “cooperative” oriented nature of the dairy industry to the more individualistic nature of beef production. He suggests that there is more to this than simply the traditional stereotypes of cattle ranchers as “rugged individualists.” Dairy herd improvement programs, processing and even communication channels are often cooperative efforts, while their counterparts in the beef industry, if they exist, are not. The dairy industry is more involved in improvement programs and in research and development. There is no unified beef improvement program in the U.S. Beef genetic improvement efforts are very fragmented compared to other livestock sectors within the U.S. or to other national beef improvement programs such as in Canada, Australia, or Japan (Middleton and Gibb, 1991). Joumeaux concludes that communication channels are more “open and effective” within dairy as compared to beef. The nature of the beef industry would be expected to inhibit technology adoption.

Third, Joumeaux identifies the greater focus of extension activities on dairy farmers as an important factor in dairy farmers’ greater willingness to adopt new technologies. The ratio of agents to farmers is higher in dairy, which he hypothesized should lead to greater adoption. Other evidence, however, suggests that the causation is more complex.

Findings of Cranfield and Howard, who studied the AI use of Ontario beef producers, indicate that non-users had significantly more contact with extension agents and spent more time at farm and community organizations. Non-users also had higher incomes, used cross breeding and had a more commercial orientation than AI users. AI users tended to be purebred breeders with smaller operations who list farming as a secondary occupation. These results are consistent with a picture of AI users as people whose

primary interest in animal breeding is for personal satisfaction rather than economic gain. (Cranfield and Howard).

Middleton and Gibb argue that the structural transformation currently occurring in the beef industry is more severe than in any other segment of the livestock industry. 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 declined 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 processing industry, which experienced extremely rapid concentration during the 1980s. In 1994, sixty-nine percent of beef processing was done by four companies (Bixby et al). What the effect of this concentration in processing will be on production is unclear. It is linked to concentration among producers and breeders in swine and poultry. There is evidence that larger beef producers were the only ones able to make a profit during the 1970s and 1980s (Purcell).

Genetic improvement programs will be important to stabilizing the beef industry and regaining lost consumer demand. According to Middleton and Gibb (p. 3864)

“A recent change in the orientation of meat packers towards consumer desires is causing a change in the way slaughter cattle are priced and purchased. Packers expect fed cattle that meet their specifications; feeders expect cattle that meet both their specifications, and the packer’s cow/calf producers expect seedstock genetics that meet the specification of all segments. And, at each stage, there is a growing expectation of documentation. Again, new traits must be measured to satisfy the requirements of each segment, and delivery systems are needed that can provide understandable genetic documentation.”

The standards of processors are having a powerful impact on breeding goals. Pressure from the supply side could increase the diffusion of breeding technology within the beef industry.

#### **IV. Observations on Diffusion of Technology and Industry Structure in the Livestock Sector**

In several respects, the above sectoral case studies reinforce the general conclusions of previous diffusion studies (Rogers). First, in terms of the communication of an innovation, previous studies suggest that the awareness of innovation comes from outside the existing system and through mass media communication, while the actual adoption of an innovation is more closely associated with interpersonal communication and local information networks (Rogers). The diffusion of livestock breeding technologies provides some support for this hypothesis. In most sectors, the traditional breeding establishments initially resisted the introduction of the new technologies. Relative outsiders, such as the corn breeding companies in poultry or the European breeding companies in pork, introduced the new technologies commercially in the U.S.. While these early promoters didn't always enjoy widespread adoption of the technologies, they were nonetheless instrumental in getting the traditional establishment to take notice. 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 cooperatives and the provision of education and technical support appear to have increased the rate with which farmers accepted the new technology.

Regarding the specific characteristics of an innovation, evidence from livestock is also generally consistent with what 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 a higher rate of diffusion. Technologies which 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 these adjustments. Dairy is the best example of compatibility, while beef provides an example of incompatibility. 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.

In terms of production structure, there is some evidence that, *ceteris paribus*, homogeneity of producers is positively associated with technology adoption. Once again, dairy and beef provide support for the generalizations.

While these conclusions do 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.

First, the breeding technologies reviewed here--namely AI and hybrid animals--appear to be associated with economies of size in terms of the management input. The real cost of adoption decreases with the effective size of the production unit. This contributes to the increase in unit size and/or horizontal integration at the production level that is now prevalent throughout the industry. 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.

As information technology and genetic knowledge improve, the potential benefits of adopting improved technology become even larger. Continued adoption of breeding technologies by producers will continue to put upward pressure on farm size. There is no evidence that we are at the frontier in terms of unit size, at least from the perspective of management of breeding information.

Second, there appears to be a clear relationship between adoption of technologies and vertical integration in livestock. Breeding technologies have contributed to integration through their complementary technical relationships with other inputs such as improved feeds, medicines or building systems, and with processing systems. This 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 that this has occurred in livestock is through financing of production. The fixed costs of adopting a package of technologies are high. In the absence of integration, the risk of adopting falls on the producers, while other sectors 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. Integration appears to be a response to the fact that externalities in technology adoption cause markets--especially for credit and insurance--to fail.

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. In pork, established producers have taken a more prominent role in defining the horizontal and vertical relationships within the industry. This follows the pattern of the Danish hog industry, often considered to be “the world’s most advanced system of production” (McLaren, p. 40), where “the producers own the slaughter houses and packers collect a production levy to finance performance testing and data processing, advisory and administrative expenses” (ibid, pp. 40-41). Compared to the U.S. hog industry, the Danish hog industry has very high levels of technology adoption, including breeding technologies such as hybrid pigs and AI. This is consistent with the hypothesis that adoption is related to degree of integration.

Third, there appears to be a link between vertical integration in an industry and its responsiveness to changing consumer demand. The poultry and the mega-farm sector of pork are examples of industries which have benefited from their ability to provide products with specific characteristics demanded by consumers. Increased leanness and uniformity of the carcass have contributed to higher quality and lower prices for final products in these sectors. In both cases, breeding technologies have played an important role in facilitating the responsiveness to demand at the retail level. This suggests that where the scope for genetic change is great, the diffusion of breeding technologies is higher. As discussed above, higher adoption rates are related to more vertical integration.

The importance of demand side factors is likely to increase in the future. 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 of the livestock

industry. Past experience would suggest that such a change would be accompanied by increased vertical integration. The dairy industry presents an interesting case in this regard. 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 (US Congress). This could have implications for the structure of the dairy industry.

## **V. Conclusion**

Using a traditional approach to innovation diffusion fails to capture many of the important factors affecting the choice of breeding technology in U.S. livestock sectors. While the traditional approach offers some explanation for the differing diffusion patterns among sectors, many important questions about the longer-term relationships between technology adoption and industry structure remain unanswered in such a framework. Technology adoption in U.S. livestock is clearly related to increasing size and decreasing number of firms. It is also related to increasing integration among those that remain. As the number of 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. The impact of market integration on the generation and diffusion of technology is an important areas for further research. A complete model of technology diffusion must allow for interactions between agents, technology and industry structure that result from the introduction of an innovation (Ruttan). Such a model would be necessary to accurately describe the process of technical and structural evolution in the U.S. livestock sector.

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