Making Meat

Science, Technology, and American Poultry Production

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In his 1948 classic, *Mechanization Takes Command*, Siegfried Giedion posed the following question: "What happens when mechanization encounters organic substance?"[1] Well aware of the application of mass-production techniques to agriculture and of the role of genetics in facilitating "the structural alteration of plants and animals," Giedion nevertheless held to a basic distinction between "living substance" and mechanization. The idea of nature as technics, of biophysical systems as technological systems, would have seemed inappropriate in his framework. For Giedion, interventions in the organic growth process were qualitatively different from efforts to subject other aspects of modern life to the dictates of the machine.

In the half century since Giedion posed this question, numerous scholars have explored the relationship between nature and technology in a variety of areas, emphasizing the difficulty of making hard and fast distinctions. Environmental historians such as Donald Worster, William Cronon, and Richard White have interrogated some of the ways in which nature is incorporated into technological and political-economic systems.[2] Historians of science such as Robert Kohler have explored how experi-

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1. Siegfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History* (New York, 1948), 6.

2. See, for example, Donald Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West* (New York, 1985); William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York, 1991); and Richard White, *The Organic Machine* (New York, 1995). See also Jeffrey K. Stine and Joel Tarr, "At the Intersection of Histories: Technology and the Environment," *Technology and Culture* 39 (1998): 601–40.

mental creatures (drosophila in his case) are constructed as research instruments and technologies.[3] And several historians and social scientists have investigated the role of science and technology in the industrialization of agricultural systems. Jack Kloppenburg and Deborah Fitzgerald, for example, have both demonstrated how a particular biological organism (hybrid corn) has been refashioned as an agricultural commodity and a vehicle for capital accumulation.[4]

Following these leads, this article focuses on another organism, the broiler or young meat-type chicken, asking how science and technology have subordinated its biology to the dictates of industrial production. By looking explicitly at those technoscientific practices involved in making the industrial chicken, it offers a perspective on the course of technological change in agriculture that further blurs the distinction between nature and technology.[5]

A product of key innovations in the areas of environmental control, genetics, nutrition, and disease management, the industrial broiler emerged during the middle decades of the twentieth century as a very efficient vehicle for transforming feed grains into higher-value meat products. By the 1960s the broiler had become one of the most intensively researched commodities in U.S. agriculture, while complementary changes in the structure, financing, and organization of leading firms created an institutional framework for rapidly translating research into commercial gain. The resulting increases in productivity and efficiency led to falling real prices, despite

3. Robert E. Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago, 1994).

4. Jack Ralph Kloppenburg Jr., *First the Seed: The Political Economy of Plant Biotechnology, 1492–2000* (New York, 1988); Deborah Fitzgerald, *The Business of Breeding: Hybrid Corn in Illinois, 1890–1940* (Ithaca, N.Y., 1990), and "Beyond Tractors: The History of Technology in American Agriculture," *Technology and Culture* 32 (1991): 114–26. As Fitzgerald notes, the agricultural sciences have been neglected by historians, left in something of a no-man's-land between agricultural history and the history of science and technology. In *The Business of Breeding* she offers a corrective, an exemplary study of how the development of a particular agricultural commodity can be used to explore the production of scientific knowledge and the transformation of that knowledge into commercial practice. On the historical development of agricultural science and the U.S. agricultural research system, see Margaret Rossiter, "The Organization of the Agricultural Sciences," in *The Organization of Knowledge in Modern America, 1860–1920*, ed. A. Oleson and J. Voss (Baltimore, 1979), and Charles E. Rosenberg, *No Other Gods: On Science and American Social Thought* (Baltimore, 1997), chaps. 8–12.

5. On the history of breeding and intellectual property in the American chicken industry, see Glenn E. Bugos, "Intellectual Property Protection in the American Chicken-Breeding Industry," *Business History Review* 66 (1992): 127–68. For a nuanced discussion of the relation between the "science of genetics" and the "art of breeding" in Raymond Pearl's research on egg production, see Kathy J. Cooke, "From Science to Practice, or Practice to Science? Chickens and Eggs in Raymond Pearl's Agricultural Breeding Research, 1907–1916," *Isis* 88 (1997): 62–86.

growing demand, and successfully brought chicken to the center of the plate for many Americans.[6]

Like hybrid corn, the story of the industrial chicken must be seen as part of a larger process of agro-industrialization, which has not only transformed the social practices of agriculture, food production, and diet in twentieth-century America but also facilitated a profound restructuring of the relationship between nature and technology. This article explores the various and ongoing efforts to intensify and accelerate the biological productivity of the chicken—asking how nature has been made to act as a force of production. Like Jack Kloppenburg's analysis of how capital intervenes in and circulates through nature in the case of plant breeding and biotechnology, the following story focuses quite specifically on the role of science and technology in incorporating biological systems into the circuits of industrial capital.[7]

Yet where Kloppenburg offers an institutional analysis of how the "commodification of the seed" serves as an accumulation strategy, this essay focuses more broadly on a variety of technologies involved in accelerating biological productivity. While breeding and genetic improvement were clearly central vectors of technological change in making the industrial chicken, they were by no means the only ones. Intensive confinement, improved nutrition and feeding practices, and the widespread use of antibiotics and other drugs also represented important aspects of a larger technology platform aimed at subordinating avian biology to the dictates of industrial production.

Given the unpredictable nature and emergent properties of biological systems, however, any program aimed at the systematic intensification of biological productivity will almost inevitably be confronted with new

6. The role of science and technology in creating the industrial chicken is only one part of a much larger story that includes, among other elements, the evolution of vertically integrated agribusiness firms, the changing structure of American agriculture, the development of low-wage rural labor markets, and changes in consumer diets. Aside from a few brief observations, this article does not attempt to tell that larger story.

7. Kloppenburg. For an earlier discussion of the idea of nature as productive force, particularly in the context of the new biotechnologies, see Edward Yoxen, "Life as a Productive Force: Capitalizing the Science and Technology of Molecular Biology," in *Science, Technology, and the Labour Process*, vol. 1, ed. Les Ledivow and Bob Young (London, 1981). More recently, David Goodman and Michael Redclift have written about agricultural biotechnology in similar terms: "Modern biotechnologies immeasurably enhance the scope, precision, and speed of selective genetic intervention for plant and animal breeding. As the boundaries to industrial appropriation of plant and animal genomes recede, the potential for using genetically manipulated organisms as instruments of production is correspondingly extended. These enormous recent strides in transforming nature into a productive force under industrial control have built upon advances in the understanding of the molecular structure of biological systems made in the early 1950s." David Goodman and Michael Redclift, *Refashioning Nature: Food, Ecology and Culture* (London, 1991), 169.

sources of risk and vulnerability. Efforts to accelerate biological productivity must confront the vagaries of nature and the unintended consequences of attempts to simplify and incorporate biological processes into industrial systems. New vulnerabilities associated with genetic monocultures, the emergence of new pathogens, the spread of antibiotic-resistant bacteria, and related problems of food safety are just a few of the unintended consequences of the industrialization of broiler biology. Although some of these new risks and vulnerabilities create new business opportunities (in the animal health industry, for example), they also pose considerable threats to the continued viability of the industry. As Rachel Carson put it almost forty years ago: "Nature fights back."[8]

A Chicken in Every Pot

By any economic standard, the success of the U.S. broiler industry during the post–World War II period has been remarkable. Between 1950 and 1999 U.S. production increased at an average rate of 7 percent per year to over forty billion pounds, while real prices declined by almost a third.[9] Today the average American consumes over eighty pounds of chicken a year, more than beef, pork, or any other animal flesh protein. Annual revenues for the industry exceed fifteen billion dollars, and many of the largest firms are moving aggressively into the export market.[10] Industry giant Tyson Foods now produces roughly 140 million pounds of chicken per week, almost three times as much as its nearest competitor and more than any other entity outside of the United States except China and Brazil. Tyson, which has led the industry into fast food, further processing, and, more recently, the export market, now refers to chicken as "a global protein" around which the company "speaks many languages."[11]

At the heart of the postwar success of the U.S. broiler industry have been systematic innovation, massive increases in productivity, and a relentless development of new products and new markets, all facilitated by an institutional transformation that has made the industry one of the most advanced systems of food production in the world—the very definition of agribusi-

8. Rachel Carson, *Silent Spring* (New York, 1962), chap. 15.

9. Price trends are since 1960. See U.S. Department of Agriculture, *Poultry Yearbook* (Washington, D.C., 1995) and *Poultry—Production and Value, 1999 Summary* (Washington, D.C., 2000).

10. Department of Agriculture, *Poultry—Production and Value, 1999 Summary*. Exports grew from less than 5 percent of total production in 1990 to more than 17 percent of total production in 1997; see Gary Thornton, "Nation's Broiler Industry," *Broiler Industry* 61 (1998).

11. Tyson Foods Inc., *Fact Book* (February 2000) and *1997 Annual Report*, available at www.tyson.com/investorrel/publications.

ness.[12] Since the early 1960s, integrated firms have controlled as much as 90 percent of broiler production in the U.S. These firms, known as integrators, own their own hatcheries, feed mills, and processing operations while contracting out live production, or "grow-out" operations, to small farmers.[13]

Paralleling vertical integration has been an equally pronounced process of geographic concentration in the American South. Since the 1960s, more than four-fifths of all broilers produced in the United States have come from the South, despite the fact that it remains a feed deficit region. The modern integrated broiler industry, in short, has possessed a distinctive southern accent since its inception. The reasons for this are many and varied, but include most prominently the changing structure of southern agriculture, deeply embedded merchant-farmer relationships, and the availability of surplus rural labor to service the processing plants. Though a full discussion of these factors is obviously well beyond the scope of this essay, it should be emphasized that the emergence of the modern broiler industry, with its extensive reliance on contract farming and low-wage labor markets, was very much a product of the South's distinctive post–New Deal agrarian transition.[14]

For the purposes of this article, the critical point regarding the institutional sophistication of the broiler industry has been its ability to capture the gains associated with rapid technical advance—a fact that clearly presupposes the existence of a system of research and development capable of generating innovations in the first place. This system of innovation emerged out of a complex mix of public research, private science, and business enterprise during the first half of the twentieth century. As they did with other agricultural commodities, publicly supported scientists affiliated with the land-grant university complex performed much of the early basic research on the principles of poultry genetics, nutrition, and health, while private

12. J. H. Davis and R. A. Goldberg, *A Concept of Agribusiness* (Boston, 1957); B. W. Marion and H. B. Arthur, *Dynamic Factors in Vertical Commodity Systems: A Case Study of the Broiler System* (Wooster, Ohio, 1973).

13. "Integrators" is a term of art used in the industry to refer to large poultry firms, such as Tyson Foods, that have successfully integrated poultry production and processing into a single coordinated industrial system. Grow-out operations, which involve raising chicks to market weight, are contracted out to small independent farmers. The integrator will deliver a fresh batch of day-old chicks every seven or eight weeks, along with medication and feed. The farmer is responsible for housing, labor, and energy costs. Farmers are compensated based on their relative feed-conversion efficiencies—the ratio of live pounds of chicken produced to feed consumed. Thus, while the integrator takes on the market risk for the chickens, the farmer takes on the biological or production risks.

14. For more on this, see William Boyd and Michael Watts, "Agro-Industrial Just-in-Time: The Chicken Industry and Postwar American Capitalism," in *Globalising Food: Agrarian Questions and Global Restructuring*, ed. David Goodman and Michael Watts (New York, 1997), 192–225. See also Jack Temple Kirby, *Rural Worlds Lost: The American South, 1920–1960* (Baton Rouge, La., 1987), 355–60.

actors effectively assimilated this research and applied it for commercial gain. Indeed, by the time the commercial broiler industry emerged in the 1930s, one of the most important elements of this innovation system—the field of applied poultry science—was already well established.

Unlike most other animal sciences, which did not emerge as well-defined fields of research until the 1940s, poultry science flourished during the 1910s and 1920s.[15] Emerging from the relatively ill-defined field of poultry husbandry in the agricultural experiment stations and agricultural colleges, poultry science quickly became the focus of a "cluster of subsciences" that included bacteriology, biochemistry, and the economics of egg and meat production.[16] This transformation of "husbandry" into "science" was largely a response to the new problems associated with the growing demand for healthy poultry products stimulated by the growth of urban markets, the changing American diet, and the rise of refrigeration.[17] It also reflected the fact that chickens were far more versatile as laboratory animals than other commercial livestock species and were regularly used for early research in nutrition, genetics, and health. Given the shorter biological time lags involved in chicken reproduction and growth, for example, breeding experiments and genetic improvement could proceed much faster in chickens than in other farm animals. Equally significant, the autonomy of chicken embryogenesis (that is, the fact that chicken embryos develop in eggs outside the hen rather than in the womb) combined with the early use of artificial incubation facilitated the rapid multiplication of chickens for both experimental and commercial purposes. Consequently, knowledge of chicken genetics, nutrition, and physiology accumulated rapidly during the first half of the twentieth century, putting poultry in the vanguard of animal improvement efforts.

Beginning in the interwar years and accelerating rapidly after the Second World War, advances in nutrition, health, and genetics translated into massive increases in the biological productivity of broilers. Such gains facilitated and were in turn reinforced by the subsequent integration of the industry. By accentuating the problems of coordination between different segments of the industry, rapid advances in productivity and throughput added to the incentive to integrate.[18] At the same time, the incorporation of

15. Dairy science had also been established by this time; see Rossiter (n. 4 above).

16. The organization of professional associations both grew out of and facilitated these developments. The American Poultry Science Association was formed at Cornell University in Ithaca, New York, in 1908, and launched its own journal in 1914; Rossiter, 228–30. See also Rosenberg (n. 4 above), chaps. 8–12; Lawrence Busch and William B. Lacy, *Science, Agriculture, and the Politics of Research* (Boulder, Colo., 1983); and W. E. Huffman and R. E. Evenson, *Science for Agriculture: A Long-Term Perspective* (Ames, Iowa, 1993).

17. Rossiter, 229–30.

18. This was by no means sufficient to drive integration, but it seems doubtful that in the absence of such productivity gains and the resulting coordination problems integra-

TABLE 1
BROILER PRODUCTIVITY, 1935–95

	1935	*1945*	*1955*	*1965*	*1975*	*1985*	*1995*
Average market weight	2.8	3.0	3.1	3.5	3.8	4.2	4.7
Days required to reach market weight	112	95	73	N/A	56	N/A	47
Feed conversion ratio (lbs. feed/lbs. broiler)	4.4	3.8	2.9	2.5	2.1	2.0	1.9

Source—Based on data compiled by the author from the Extension Poultry Science Department, University of Georgia, Athens, and the National Chicken Council, Washington, D.C.

hatcheries, feed mills, contract grow-out operations, and processing plants within a single firm provided an institutional vehicle for further rationalizing the production system in order to capture productivity gains. As the industry grew in size and sophistication, moreover, there was a clear shift in the locus of research and innovation from the public to the private sphere.[19] By the early 1960s, integrated firms, primary breeders, and animal health companies had become the drivers of innovation in the industry, transforming the lowly chicken into one of the more thoroughly industrialized commodities in American agriculture.[20]

The overall trend, as illustrated in table 1, has been a phenomenal increase in biological productivity. Between 1935 and 1995 the average market weight of commercial broilers increased by roughly 65 percent while the time required to reach market weight declined by more than 60

tion would have occurred. On this broad question, see Alfred D. Chandler Jr., *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass., 1977).

19. By the 1960s, university poultry science departments were relegated to an adjunct role in the overall system of innovation, primarily coordinating large-scale research efforts critical to the industry (particularly in the area of disease), providing a forum for information exchange, and training many of the industry's employees. As a result, the number of poultry science departments declined precipitously in the postwar period, with the major public poultry science research centers concentrating in the land grant universities of leading broiler-producing states (Arkansas, Georgia, North Carolina, Texas, and California). See Busch and Lacy, 33, and S. L. Pardue, "Educational Opportunities and Challenges in Poultry Science: Impact of Resource Allocation and Industry Needs," *Poultry Science* 76 (1997): 938–43.

20. Primary breeders provide the breeding stock to the integrated companies. The breeding stock is then used to produce the baby chicks that are delivered to farmers for grow-out. It should be noted, moreover, that a number of external factors facilitated the industrialization of the chicken during this period—wartime price support programs, the rise of retail supermarkets, changing consumer tastes, etc.

percent and the amount of feed required to produce a pound of broiler meat declined by 57 percent. In short, a commercial broiler from the 1990s grew to almost twice the weight in less than half the time and on less than half the feed than a broiler from the 1930s.

As in other agro-food sectors, this process of biological intensification depended upon a cluster of innovations, with advances in one area often calling forth or even requiring advances in other areas. Through technologies of confinement and continuous flow, nutrition and growth promotion, and breeding and genetic improvement, the barnyard chicken was made over into a highly efficient machine for converting feed grains into cheap animal-flesh protein.

Confinement and Continuous Flow

Intensive confinement was a critical first step in the process of industrialization. The ability to raise broilers in a confined environment provided for a kind of biological time-space compression, creating a platform upon which intensification efforts in nutrition and breeding could proceed. Yet attempts to fully adapt chickens to laboratory conditions and, more important, to confine them for commercial purposes met with only limited success during the early twentieth century. Due to a nutritional deficiency among chickens known as "leg weakness," which occurred in the absence of ultraviolet light, chickens could only be confined for relatively short periods of time. Until this problem could be solved, industrial broiler production remained a distant prospect.

Working at the University of Wisconsin in the early 1920s, researchers discovered that vitamin D, when added to a chicken's diet, prevented leg weakness.[21] Cod-liver oil, which was rich in the vitamin, quickly became a universally applied supplement in poultry feed.[22] Hens could now be kept inside year round, and chicks could be "carried to maturity under strict confinement."[23] This was of tremendous importance to the poultry indus-

21. At the time, researchers referred to the vitamin as the "antirachitic vitamin." This discovery was presented in a series of papers submitted to the *Journal of Biological Chemistry* between 1920 and 1923: see E. B. Hart, J. G. Halpin, and H. Steenbock, "Use of Synthetic Diets in the Growth of Baby Chicks: A Study of Leg Weakness in Chickens," *Journal of Biological Chemistry* no. 43 (1920): 421–41; E. B. Hart, J. G. Halpin, and H. Steenbock, "The Nutritional Requirements of Baby Chicks II: Further Study of Leg Weakness in Chickens," no. 52 (1922): 379–86; E. B. Hart, H. Steenbock, S. Lepkovsky, and J. G. Halpin, "The Nutritional Requirements of Baby Chicks III: The Relation of Light to the Growth of the Chicken," no. 58 (1923): 33–40. Hart, Steenbock, and Lepkovsky were all associated with the Department of Agricultural Chemistry at the University of Wisconsin, while Halpin was affiliated with the Department of Poultry Husbandry there.

22. Thomas H. Jukes, "Review: Recent Studies of Vitamins Required by Chicks," *Journal of Nutrition* 13 (1937): 376–82.

23. Hart et al, "Nutritional Requirements III," 34.

try, in that it overcame one of the first major biological obstacles to industrial, continuous-flow production. As one researcher from the Ohio Agricultural Experiment Station noted in 1928: "No specialist could fully succeed in raising the large numbers of chicks required for quantity production . . . without brooding them in confinement, where temperature, ventilation and sanitation can be kept under positive control."[24] Thirty years later, a leading poultry nutritionist reflected that "Without it [the discovery and use of vitamin D] the present day poultry industry would not have developed."[25]

Confinement also received a substantial technological boost from the growing availability of electric power. Completed in the 1940s and 1950s, rural electrification proved instrumental in the proliferation of chicken houses, particularly in the up-country South. Electric brooders, feeders, and other devices allowed for more precisely controlled growing environments and huge increases in labor productivity. In 1940 an average of two hundred and fifty man-hours were required to raise one thousand birds to maturity; by 1955 the required time had dropped to forty-eight hours. Electrification thus allowed for significant increases in the scale of poultry farming. What had once been a small-scale operation, with a single family producing several hundred chickens per year, became a mass-production affair, with single families producing several thousand chickens per year.[26]

Successful confinement operations, however, required a continuous supply of high-quality chicks, a technical challenge met in part by the widespread adoption of artificial incubation and improved environmental control in hatcheries during the 1920s and 1930s. Given the autonomy of chicken embryogenesis and the increased availability of reliable energy in the form of electricity, thermostatically regulated incubators substituted for

24. D. C. Kennard, "The Trend toward Confinement in Poultry Management," *Poultry Science* 8 (1928): 23. Kennard noted further that "The poultry industry is in the midst of phenomenal developments. There must be some primary factor largely responsible for this. What is it? A variety of answers could be given but the consensus of opinion would surely be that the progress and developments attracting most attention today are those which center around the intensification, specialization and the application of factory methods and sound business principles made possible by confinement."

25. L. C. Norris, "The Significant Advances of the Past Fifty Years in Poultry Nutrition," *Poultry Science* 37 (1958): 259.

26. The U.S. Rural Electrification Administration, along with the Tennessee Valley Authority and the Electric Farm and Home Authority, were quite vigorous in their efforts to push electric poultry farming among small farmers. See, for example, U.S. Rural Electrification Administration, *More Power to Your Poultry Raising* (Washington, D.C., 1945). For a discussion of the impacts of electrification on poultry farming (and agriculture more generally) in the South, see D. Clayton Brown, "Rural Electrification in the South, 1920–1955" (Ph.D. diss., University of California at Los Angeles, 1971), 280–90. Labor productivity figures are taken from Department of Agriculture, Packers and Stockyards Administration, *The Broiler Industry: An Economic Study of Structure, Practices and Problems* (Washington, D.C., 1967), 15.

the brooding hen, allowing large numbers of newly hatched chicks to be produced on demand. American commercial hatchery operations expanded dramatically, growing in number from two hundred and fifty in 1918 to more than ten thousand in 1927. By 1934, roughly half of all chickens raised in the United States were hatched in artificial incubators, with state-of-the-art hatcheries operating as "veritable chick factories" capable of producing more than one million chicks per year.[27]

Yet intensive confinement still faced considerable obstacles during the 1920s and 1930s. Most significantly, contagious diseases threatened to wipe out early broiler operations. Pullorum disease, for example, destroyed as much as half of the flock on the Delmarva Peninsula between the Chesapeake and Delaware Bays during this period and was endemic in many commercial hatchery operations.[28] Because the disease spread vertically from infected hens to chicks, halting it necessitated the removal of infected birds from the population—an undertaking that required an unprecedented degree of cooperation between commercial hatcheries, growers, and government agencies.

Without effective disease control, confinement operations were doomed. In the absence of uniform quality standards, moreover, growers hesitated to purchase baby chicks, unable to determine that they were buying birds of a specific breed that had been inspected and certified as disease free. Although several states attempted to institute programs to deal with such concerns, only a coordinated national program would effectively meet the challenge.

In 1935, the federal government responded with the National Poultry Improvement Plan (NPIP), a unique partnership between government and

27. The manufacture of artificial incubators on a commercial scale dates from the second half of the nineteenth century in Europe. The first reference to a commercial hatchery operation based on artificial incubation in the United States is in 1873. The electrically heated incubator debuted in 1923. Thermostats were applied to incubators in the United States in 1927. See Walter Landauer, *The Hatchability of Chicken Eggs as Influenced by Environment and Heredity* (Storrs, Conn., 1961), 44; Gordon Sawyer, *The Agribusiness Poultry Industry: A History of Its Development* (New York, 1971), 28; and E. L. Warren and M. T. Wermel, *An Economic Survey of the Baby Chick Hatchery Industry* (Washington, D.C., 1935): 7, 27. This rapid growth of commercial hatcheries was reinforced by the explosion of mail order sales of baby chicks, made possible by a 1918 government decision to allow the U.S. postal service to transport live chicks and by a particular characteristic of avian biology—a just-hatched baby chick can go without food or water for up to 72 hours, making the long-distance transport of chicks possible. Aided by the newly formed International Baby Chick Association, which was established in 1916 to support artificial incubation, and vigorously promoted through heavy advertising in feed and farm journals, commercial hatcheries shipped as much as half of the annual hatch during the 1920s and 1930s to American farmers and feed dealers through the mail. See Warren and Wermel, 26–27; Sawyer, 29–32.

28. Pullorum is a rod-shaped bacterium of the genus *Salmonella*. See Richard E. Austic and Malden C. Nesheim, *Poultry Production*, 13th ed. (Philadelphia, 1990), 245–47. See also H. J. Stafseth, "Advances in the Knowledge of Poultry Diseases over the Past Fifty Years," *Poultry Science* 37 (1958): 741, and Sawyer, 57.

industry operating at both federal and state levels. In essence, the plan sought to reduce the mortality of chicks from pullorum and other diseases and to improve the production and breeding qualities of poultry through research and the development of uniform standards. The U.S. Department of Agriculture's Bureau of Animal Industry assumed responsibility for administration and coordination of individual state efforts, while designated state agencies performed selection, testing, and inspection tasks on breeding flocks and hatcheries. Based on performance records and systematic testing, breeding and disease control classifications were established to provide for uniformity and reliability in chicks and hatching eggs. In the process, an institutional infrastructure at state, regional, and national levels emerged to coordinate industry-wide responses to disease problems and to establish uniform quality standards for poultry breeders.[29] By the 1950s, poultry breeders and hatcheries throughout the country were testing for the disease on a regular basis and nearly all had adopted uniform national standards. Two decades later, pullorum had been virtually eliminated from the commercial poultry industry in the United States.[30]

Viral diseases, which tend to spread horizontally, also resulted in periodic epidemics among poultry populations, often proving quite difficult to control.[31] Marek's disease, a particularly destructive virus that causes cancer in chickens, emerged in the 1960s, leading to condemnations of as many

29. U.S. Department of Agriculture, *The National Poultry Improvement Plan* (Washington, D.C., 1938), 16, and *Improving Poultry through the National Poultry Improvement Plan* (Washington, D.C., 1938), 2; U.S. Agricultural Research Service, *Facts About the National Poultry Improvement Plan* (Washington, D.C., 1957). Under the NPIP program, poultry-producing states moved quickly to eliminate pullorum. Georgia, for example, established its first poultry diagnostic lab in 1949. A second lab was established in 1954. By 1996, six more laboratories had been established in the state and two were under construction. All diagnostic services were free to the poultry industry. The laboratory system operates on the basis of funding provided by the state legislature. See Sawyer, 60, and George Winn, "Poultry Improvement Focus of Ga. Group," *Georgia Farmers and Consumers Market Bulletin* 79 (1996).

30. By 1975 only 0.0008 percent of chickens tested contained antibodies specific to pullorum; Austic and Nesheim, 246–47. Pullorum, of course, was only one of several diseases that emerged to threaten the rapidly expanding broiler industry. Another bacterial disease, fowl typhoid, wreaked havoc in broiler flocks during the 1940s. Because it spread like pullorum the disease was targeted by the NPIP, and it was effectively eliminated from broiler flocks by the 1960s. In contrast, the protozoan disease coccidiosis, one of the most prevalent of poultry diseases, has been endemic in the industry since its inception, and the routine use of drugs to combat it is standard practice today. While it has proved to be controllable, the disease has also been one of the most expensive encountered by the poultry industry. See Austic and Nesheim.

31. Among the major viral diseases are Newcastle disease, Marek's disease, laryngotracheitis, avian leukosis, and avian influenza. Vaccines have been developed for many of these; some (against Newcastle and Marek's, for example) are administered routinely, others (laryngotracheitis) only during an outbreak. See Stafseth; Austic and Nesheim, 229–58.

as one-fifth of the broiler flocks in the United States. Another virus, Newcastle disease, pushed mortality rates as high as 90 percent in England during the 1960s and 1970s. An outbreak of avian influenza in Pennsylvania forced the destruction of millions of birds during the early 1980s. More recently, a highly pathogenic strain of avian influenza emerged in Mexico, where mortality rates in affected areas were as high as 70 percent. And, in the winter of 1997, yet another highly pathogenic strain of avian influenza emerged in Hong Kong, leading to the deaths of at least four people (this was the first case of a poultry disease jumping species to infect humans) and the destruction of more than a million chickens.[32]

Efforts to combat poultry viruses have proceeded apace, benefiting, in part, from the important role that chickens have played in virology and vaccine development. Indeed, since Pasteur first used them in experiments on inoculations against cholera in the 1870s and 1880s, chickens have remained a favorite experimental creature. During the late 1920s and early 1930s, for example, Ernest W. Goodpasture and Alice M. Woodruff developed a method of using chick embryos to cultivate live viruses and produce commercial vaccines. Although this research fed most directly into the development of vaccines to fight human diseases, it also led to the development and use of a commercial vaccine for fowl pox in poultry. Since that time, numerous other poultry vaccines have been developed. Of particular importance was the work done by researchers during the 1970s to develop a vaccine for Marek's disease—the world's first licensed vaccine for fighting a viral cancer. As with other viral diseases, however, new strains of Marek's disease have since emerged that render previously effective vaccines obsolete.[33]

Still, the challenges of managing disease within the poultry industry have hardly diminished. As soon as one problem is solved, others emerge.

32. K. Rudd, "Poultry Reality Check Needed," *Poultry Digest* 54 (1995): 12; T. Horimoto and E. Rivera, "Origin and Molecular Changes Associated with Emergence of a Highly Pathogenic H5N2 Influenza Virus in Mexico," *Virology* no. 213 (1995): 223–30; K. Subbarao and A. Klimov, "Characterization of an Avian Influenza A (H5N1) Virus Isolated from a Child with a Fatal Respiratory Illness," *Science*, 16 January 1998, 393–96; C. Beard, "Assessment of H5N1," *Broiler Industry* 61 (1998); and D. E. Swayne and J. R. Beck, "Efficacy of Recombinant Fowl Pox Virus Vaccine in Protecting Chickens against a Highly Pathogenic Mexican-origin H5N2 Avian Influenza Virus," *Avian Diseases* 41 (1997): 910–22.

33. A. M. Woodruff and E. W. Goodpasture, "The Susceptibility of the Chorio-allantoic Membrane of Chick Embryos to Infection with Fowl Pox Virus," *American Journal of Pathology* 7 (1931): 209–22; Margaret A. Liu, "Vaccine Developments," *Nature Medicine* 4 (1998): 515; Stafseth, 749; Maurice R. Hilleman, "Six Decades of Vaccine Development—A Personal History," *Nature Medicine* 4 (1998): 510. For historical context, see Greer Williams, *Virus Hunters* (New York, 1959): 135–53. To date, most of the vaccines used by the poultry industry are "biologicals," that is, killed viruses or modified live viruses. More recently, recombinant vaccines have come into use; see Rudd, 12–13. Rudd, a microbiologist, argues that lack of vigilance in the industry regarding routine vaccination has given Marek's disease enough "room to maneuver" so that new strains have developed.

Intensive confinement, geographic concentration, and the increased genetic uniformity of broiler flocks have created a fertile environment for the emergence and spread of infectious diseases. As of 1997, estimated losses from disease cost the U.S. poultry industry approximately $1.6 billion per year. Not surprisingly, much of the applied research in university poultry science departments has been devoted to understanding and dealing with the complexities of various diseases. So far mortality rates have been reduced to manageable and, more important, predictable levels.[34] In effect, disease risks have been quantified and incorporated into the economic calculus of the industry. By simplifying and standardizing the vagaries of nature, disease management and intensive confinement have provided a basis for further investments in nutrition and breeding to proceed.

At the same time, intensive confinement combined with the increasing scale and geographic concentration of the industry has created a host of new environmental problems.[35] In a number of high-production areas, the volume of poultry waste now exceeds the absorptive capacity of local and regional ecosystems, impairing the quality of surrounding waterways. On the Delmarva Peninsula, which produces more than six hundred million chickens annually, the regional environment must contend with some 1.5 billion pounds of manure every year—more than the waste load from a city of four million people.[36] Traditional waste management practices of

34. B. S. Pomeroy, "Poultry Disease Guide," *Feedstuffs Reference Issue* 70 (1998): 114–20. Special government institutions, such as the Southern Poultry Disease Research Laboratory in Athens, Georgia, and the Avian Oncology and Disease Laboratory in East Lansing, Michigan, have also been established by the USDA to coordinate research efforts and develop industry-wide strategies for dealing with outbreaks. Based on systematic use of animal drugs, the industry has been able to keep broiler mortality at around 5 percent.

35. Modern broiler farms, which typically contain four or more broiler houses, each holding up to twenty-five thousand birds, can easily produce a half million birds per year on only a few acres of land. Moreover, because of the costs and perishability constraints associated with transporting live chicks, multiple feed rations, and finished live broilers between hatcheries, feed mills, grow-out farms, and processing plants, broiler farms are typically concentrated within a 25-mile radius of processing plants and feed mills. Such production density has often been cited as more critical than plant size in achieving economies and determining competitive position in the industry. See S. T. Rice, *Interregional Competition in the Commercial Broiler Industry* (Newark, Del., 1951); W. W. Harper, *Marketing Georgia Broilers*, Georgia Experiment Station Bulletin 281 (n.p., 1953); Department of Agriculture, Packers and Stockyards Administration (n. 26 above), 13; Marion and Arthur (n. 12 above), 21; and Boyd and Watts (n. 14 above), 209.

36. Georgia and Arkansas each produce over one billion chickens per year, with production concentrated in northern Georgia and northwestern Arkansas; see Department of Agriculture, *Poultry—Production and Value* (n. 9 above). For a report on the animal waste problem in the poultry and livestock industries, see U.S. Senate Committee on Agriculture, *Nutrition, and Forestry, Animal Waste Pollution in America: An Emerging National Problem* (Washington, D.C., 1997), often called the Harkin report after Senator Tom Harkin of Iowa, who requested it. See also U.S. General Accounting Office, *Animal*

spreading poultry manure on surrounding crop and pasture lands—a practice that proved to be a great boon to efforts in some parts of the American South to restore and rejuvenate eroded crop and pasture lands—can no longer keep up with the growing volume of waste; surrounding lands simply can not absorb all of the nutrients. As a result, excess nitrogen and phosphorous are washing into local waterways, feeding algal blooms, which in turn deprive the waterways of the dissolved oxygen needed by other species. Some of the affected aquatic ecosystems are literally dying of asphyxiation. In some cases, moreover, toxic algae and microorganisms, such as the mysterious dinoflagellate *Pfiesteria piscicida*, have emerged out of the altered ecology of these streams and waterways, causing massive fish kills and threatening human health.[37] The new industrial ecology created by intensive confinement has ramifications far beyond the chicken house.

Nutrition and Growth Promotion

As confinement techniques became more effective, efforts to understand and improve the diets of chickens emerged as a key component in the effort to accelerate growth rates and increase metabolic efficiency. While such efforts have a long history, the "scientific" approach to poultry nutrition can be traced to the turn of the last century and the emergence of a more general science of nutrition. Christiaan Eijkman's pioneering research on beriberi, for example, was based on his observations of variations in the diets of fowls. Because of the chicken's utility as a laboratory animal and its commercial potential, moreover, academic researchers used chickens extensively in early nutrition studies. Thus, chickens were the first animals to be

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Agriculture: Information on Waste Management and Water Quality Issues (Washington, D.C., 1995). For a discussion of the waste problem associated with the poultry industry in the Delmarva region, see Peter S. Goodman, "An Unsavory Byproduct: Runoff and Pollution," *Washington Post*, 1 August 1999.

37. For a general discussion of the environmental impacts of industrial animal production on aquatic ecosystems, see Michael A. Mallin, "Impacts of Industrial Animal Production on Rivers and Estuaries," *American Scientist*, January–February 2000, 26–37. On nutrient loading in the Chesapeake Bay ecosystem, see Thomas C. Malone et al., "Nutrient Loadings to Surface Waters: Chesapeake Bay Case Study," in *Keeping Pace with Science and Engineering: Case Studies in Environmental Regulation*, ed. Myron F. Uman (Washington, D.C., 1993), 8–38. On *Pfiesteria*, see Robert H. Boyle, "Phantom: The Tenacious Scientist and the Elusive Fish Killer," *Natural History*, February/March 1996, 17–19; Colin Macilwain, "Scientists Close in on 'Cell from Hell' Lurking in Chesapeake Bay," *Nature*, September 1997; and Eugene Buck et al., *Pfiesteria and Related Harmful Blooms: Natural Resource and Human Health Concerns* (Washington, D.C., 1997). During the late summer and early fall of 1997, in response to severe fish kills in several Maryland rivers that feed into the Chesapeake, the state closed several rivers to fishing and recreation; John H. Cushman Jr., "Another Waterway is Closed in Maryland," *New York Times*, 15 September 1997.

used in experimental vitamin B studies and, along with other livestock species, were important subjects in elucidating the physiological functions of essential nutrients.[38]

This is hardly surprising. Scientists working at agricultural experiment stations performed some of the principal work in American nutrition research, particularly with vitamins. With general support for practical nutrition research and an institutional context fostering cooperation between biologists and chemists, the American agricultural research complex provided fertile ground for developing basic principles of nutrition and applying them to animal husbandry. In the case of poultry nutrition, knowledge accumulated rapidly and was quickly translated into commercial applications. By the beginning of World War II, the nutrient requirements of chickens were known more precisely than those of any other commercial animal species.[39]

In addition to early work on vitamins, research on carbohydrate and protein needs also proved instrumental in the industrialization of the chicken diet and the wholesale adoption of formula feeding in the industry. During the 1930s and 1940s, for example, researchers at Cornell University in Ithaca, New York, found that better growth and improved feed-conversion efficiency could be obtained by feeding chickens low-fiber, high-energy rations. Corn, which contained the highest metabolizable energy value of the cereal grains, was an obvious choice for such rations. Meanwhile, in the early 1940s, researchers at the University of California began identifying the essential amino acids needed for protein synthesis in chickens. Because amino acid deficiency translated directly into reduced growth rates, protein supplements could be used to boost performance. With wartime supplies of animal protein running short, these researchers turned their attention to the soybean—a virtual protein pill, high in crude digestible protein and low in fiber, which proved highly suitable for meeting the particular requirements of chickens.[40] Together, corn and soybean meal provided an almost ideal combination for the high-energy, high-protein commercial poultry rations that came into widespread use during the 1950s.

None of this could have happened, of course, without larger changes in U.S. agriculture. In particular, dramatic increases in corn yields proved cen-

38. Norris (n. 25 above), 256. See also Elmer Verner McCollum, *A History of Nutrition: The Sequence of Ideas in Nutrition Investigations* (Boston, 1957), 216, and Jukes (n. 22 above), 376.

39. Rosenberg (n. 4 above), 202 and chap. 12. See also Austic and Nesheim (n. 28 above), chap. 7, and Norris.

40. Norris, 266–68; G. E. Heuser, "Protein in Poultry Nutrition—A Review," *Poultry Science* 20 (1941): 362–68; and John C. Hammond and Harry W. Titus, "The Use of Soybean Meal in the Diet of Growing Chicks," *Poultry Science* 23 (1944): 49–57. See also James P. Houk, Mary E. Ryan, and Abraham Subotnik, *Soybeans and Their Products: Markets, Models, and Policy* (Minneapolis, Minn., 1972): 40.

tral to the rise of a commercial feed manufacturing industry. Between 1930 and 1965 the volume of U.S. corn production increased by 2.3 billion bushels, despite a reduction in total harvested acreage of some 30 million acres.[41] As the American corn belt was also ideal for growing soybeans, this decline in corn acreage, along with declines in the amount of farmland devoted to oats, hay, and pasture, created significant room for the expansion of soybean production.[42] With the adoption of solvent extraction methods in soybean processing during the 1950s, moreover, soybean meal could be produced much more cheaply and on a much larger scale than before.[43] These two developments, combined with the growing demand for soybean meal for livestock and poultry feed, spurred a dramatic increase in soybean production during the postwar period. Between 1941 and 1966, soybean acreage increased by more than 500 percent, while production increased almost 800 percent.[44] Taken together, these increases in the supply of corn and soybeans underwrote the growth of intensive animal agriculture, establishing some of the key economic and ecological linkages that have structured the postwar American agro-industrial complex. In effect, as the chicken was made over into a more efficient machine for converting corn and soybeans into animal flesh protein, the broiler industry became a vehicle for channeling the increased throughput of Midwestern corn and soybeans into higher-value food products for retail supermarkets.

These new poultry rations were not cheap, however. Because feed accounted for the largest overall share of live production costs, faster growth rates and precise calibration of nutrients to the metabolic requirements of the grow-out cycle became economic imperatives.[45] More rapid growth rates meant less time to market and less feed wasted on the maintenance of bodily functions. Reducing turnover time emerged as the over-

41. Kloppenburg (n. 4 above), 91.

42. Ray A. Goldberg, *Agribusiness Coordination: A Systems Approach to the Wheat, Soybean, and Florida Orange Economies* (Boston, 1986), 101–47.

43. Houk, Ryan, and Subotnik, 44–45; James Schaub et al., *The U.S. Soybean Industry* (Washington, D.C., 1989), 31.

44. Goldberg, 103. In 1966, total soybean acreage was more than 36 million acres and total production was more than 930 million bushels.

45. Because the metabolism of a broiler changes as it ages, for example, three different rations are employed during the grow-out cycle. Heuser, 363; Austic and Nesheim, 222–25. Given the huge volume of feed involved (over 6 billion pounds of broiler meat were produced in 1960), the large number of feed ingredients needed to meet specific nutrient requirements (typical poultry rations make use of more than seventy ingredients), and the changing costs of those ingredients, linear programming was widely adopted in the late 1950s and early 1960s as a method of formulating least-cost rations. This allowed feed manufacturers to respond rapidly to price changes by reformulating rations while still meeting nutritional specifications. U.S. Agricultural Research Service, *A Least-Cost Broiler Feed Formula Method of Derivation* (Washington, D.C., 1958). Park W. Waldroup, "Dietary Nutrient Allowances for Chickens and Turkeys," *Feedstuffs Reference Issue* 70 (1998): 66–77. See also Austic and Nesheim, 224–28.

riding concern for integrated firms as they sought to capture the added value associated with the transformation of feed grains into chicken meat. The critical advances in this respect were found in breeding and genetic improvement, which will be discussed in the following section, and in the widespread use of antibiotics and other antibacterials as growth promoters.

Few developments have had a more dramatic impact on animal agriculture than the use of antibiotics to promote growth. During the late 1940s and early 1950s, experiments with chicks at American Cyanamid laboratories found that antibiotics administered in feed increased the weight gain of chicks by 10 percent or more. Subsequent experiments also noted increases in feed-conversion efficiency and improved disease control. The livestock industry changed virtually overnight. By 1951, the FDA had approved the use of penicillin and chlortetracycline as feed additives. Two years later, oxytetracycline was approved. Large pharmaceutical and chemical firms quickly ramped up production capacity to mass produce antibiotics for use in animal agriculture. Penicillin and tetracycline (either as chlortetracycline or oxytetracycline) were widely deployed in poultry and livestock feeding programs.[46] Antibiotics became cheap growth enhancers for the livestock industry.

46. While debate continues as to the precise mechanisms by which antibiotics and antibacterials promote growth, the U.S. Office of Technology Assessment notes three possible modes of action: a metabolic effect, a nutrient-sparing effect, and a disease-control effect; Office of Technology Assessment, Drugs in *Livestock Feed*, vol. 1, *Technical Report* (Washington, D.C., 1979), 29. The first study to demonstrate the growth-promoting effects of antibiotics in chickens was published in 1946 by a group of researchers from the departments of biochemistry and agricultural bacteriology at the University of Wisconsin: P. R. Moore et al., "Use of Sulfasuxidine, Streptothricin, and Strepotomycin in Nutritional Studies with the Chick," *Journal of Biological Chemistry* no. 165 (1946): 437–41. For whatever reason, this research was overlooked until research at American Cyanamid demonstrated again the growth-promoting effects of antibiotics. Working at the company in the late 1940s, scientists used the spent-mash byproduct of chlortetracycline manufacture as a basis for their experiments, in which they found an "unidentified growth factor" that stimulated weight gain in chicks. Stokstad and Jukes subsequently identified this growth factor as aureomycin (chlortetracycline). This research, which was initially oriented toward determining the effect of vitamin B12 and the so-called animal protein factor on chicken growth, stimulated a wave of research on antibiotics in animal feeds. See E. L. R. Stokstad et al., "The Multiple Nature of the Animal Protein Factor," *Journal of Biological Chemistry* no. 180 (1949); 647–54; E. L. R. Stokstad and T. H. Jukes, "Further Observations on the 'Animal Protein Factor,'" *Proceedings of the Society for Experimental Biology and Medicine* 73 (1950): 523–28, and "Effects of Various Levels of Vitamin B12 upon Growth Response Produced by Aureomycin in Chicks," *Proceedings of the Society for Experimental Biology and Medicine* 76 (1951): 73–76. Later studies confirming the growth promotion effect included A. C. Groschke and R. J. Evans, "Effect of Antibiotics, Synthetic Vitamins, Vitamin B12, and an APF Supplement on Chick Growth," *Poultry Science* 29 (1950): 616–19; L. J. Machlin et al., "Effect of Dietary Antibiotic Upon Feed Efficiency and Protein Requirement of Growing Chickens," *Poultry Science* 31 (1952): 106–9; M. E. Coates et al., "A Mode of Action of Antibiotics in Chick Nutrition," *Journal of the Science of Food and Agriculture* 3 (1959): 43–48; and

Their use in animal feeds skyrocketed. In 1954, 2 million pounds of antibiotics were produced in the United States, of which some 490,000 pounds were used in livestock feed. By 1960, American farmers were feeding commercial livestock and poultry 1.2 million pounds of antibiotics per year. By the late 1990s, out of the total estimated U.S. production of 50 million pounds, roughly 25 million pounds were dedicated to livestock, most mixed into feed to promote growth.[47]

Although antibiotics are used in all farm animals, the poultry industry has employed them most extensively. By the 1970s, according to the U.S. Office of Technology Assessment, 100 percent of the commercial poultry raised in the United States received antibacterial supplements in their feed.[48] By the late 1990s, poultry producers were using an estimated 10.5 million pounds of antimicrobials annually, more than the amounts used for either hogs or cattle.[49] Beneficial effects included disease prevention, more uniform growth, improved weight gain, and enhanced feed-conversion efficiency. As for quantitative gains in field performance, which have been somewhat difficult to measure, various experiments for poultry conducted in the late 1970s found weight gain and feed-conversion efficiency increases of 5 percent or more, depending on the antibiotic used. Estimates of production losses that would occur if antibiotics were banned from use in animal feeds ranged between 8 and 20 percent.[50] According to one 1981 study, this translated into a "savings" of some $3.5 billion per year in lower prices for the American consumer.[51]

In short, even though debate continues as to exactly how these drugs promote growth when administered at "subtherapeutic levels," the use of antibiotics in livestock and poultry feed has had significant implications for

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Norris (n. 25 above), 263–64. See also H. R. Bird, "Biological Basis for the Use of Antibiotics in Poultry Feeds," in *The Use of Drugs in Animal Feeds* (Washington, D.C., 1969): 31–41. On the use of specific drugs and regulatory approval, see U.S. Office of Technology Assessment, *Drugs in Livestock Feed*, 22–23, and Animal Health Institute, *Summary of the Antibiotic Resistance Issue* (n.p., 1996).

47. A recent report from the Union of Concerned Scientists estimates that livestock producers in the United States currently use 24.6 million pounds of antimicrobials for nontherapeutic (growth-promotion) purposes; Margaret Mellon, Charles Benbrook, and Karen Lutz Benbrook, *Hogging It: Estimates of Antimicrobial Abuse in Livestock* (Washington, D.C., 2001). See also Orville Schell, *Modern Meat* (New York, 1984), 23, and Stuart Levy, "The Challenge of Antibiotic Resistance," *Scientific American*, March 1998, 50–51.

48. This compared to about 90 percent of swine and veal calves and 60 percent of cattle; Office of Technology Assessment, *Drugs in Livestock Feed*, 3.

49. The figures are 10.5 million pounds in poultry, 10.3 million pounds in hogs, and 3.7 million pounds in cattle; see Mellon, Benbrook, and Benbrook, 42.

50. Office of Technology Assessment, *Drugs in Livestock Feed*, 29–36.

51. Council for Agricultural Science and Technology, *Antibiotics in Animal Feeds*, cited in Richard H. Gustafson, "Antibiotics Use in Agriculture: An Overview," in *Agricultural Uses of Antibiotics*, ed. William A. Moats (Washington, D.C., 1986), 5.

productivity growth in the industry.[52] Proponents argue that improved disease control associated with these drugs has increased the viability of confinement operations, while enhanced feed-conversion efficiency combined with greater and more uniform growth has led to increased material economies and more precise and standardized integration between live production and processing operations.[53]

Antibiotic use in industrial animal production has become increasingly controversial, however. Critics argue that such practices have exacerbated the problem of antibiotic resistance and created serious public health risks. Indeed, not long after the widespread use of antibiotics in animal feeding began, public health officials and others began raising questions about the proliferation of antibiotic-resistant bacteria and the potential long-term consequences associated with extensive use of antibacterials in animal feeds.[54]

52. Office of Technology Assessment, *Drugs in Livestock Feed* (n. 46 above), 29. See also Virgil W. Hays, "Biological Basis for the Use of Antibiotics in Livestock Production," in *The Use of Drugs in Animal Feeds* (Washington, D.C., 1969), 11–30. Some scientists argue that the effect is primarily a disease-control effect, which occurs through the control of "unidentified, weakly pathogenic bacteria in the digestive tract"; see Austic and Nesheim (n. 28 above), 192. But, as Levy puts it (51), "No one is entirely sure how the drugs support growth."

53. Such widespread recourse to antibiotics as feed additives also fueled the growth of the animal health industry during the postwar period. Many of the early animal drugs were spin-offs of human antibiotics research, and large pharmaceutical firms quickly developed animal health divisions to tap the growing market. By 1974 U.S. sales of antibacterial feed additives by animal health firms had reached $675 million, accounting for almost 70 percent of the total animal health market; Animal Health Institute, *Summary of the Antibiotic Resistance Issue* (n. 46 above).

54. The issue first gained prominence in 1959, when a team of Japanese microbiologists under the direction of Tsutomo Watanabe discovered that certain bacteria were capable of transferring their resistance traits to other bacteria via extra-chromosomal fragments of DNA called plasmids; those plasmids that coded for resistance subsequently came to be known as R-plasmids. This discovery represented a major break with the established view at the time, which held that resistance was exclusively the result of mutation. With Watanabe's work, it was suddenly clear that drug resistance was a highly transferable trait and that actions taken in the area of animal health could indeed have significant implications for human health. R-plasmids, it was determined, could move between nonpathogenic and pathogenic bacteria and between bacteria that live exclusively in animals and those that colonize humans. By selecting for those bacteria, both pathogenic and nonpathogenic, that had acquired R-plasmids, antibiotics effectively created a favorable environment for the proliferation of resistant bacteria, thereby increasing the pool of self-replicating, highly transferable R-plasmids. The obvious result is the proliferation of resistant strains, some of which rapidly acquire multiple resistance traits, far faster than would occur on the basis of mutation alone. In the words of Stuart Levy: "Resistance exemplifies *par excellence* Darwinism: surviving strains have emerged under the protection and selection of the antibiotic. Use of the same antibiotics in all parts of the world has led to the emergence of resistant bacteria that find ready havens for propagation wherever they move"; Stuart Levy, "Antibiotic Resistance: An Ecological Imbalance," in *Antibiotic Resistance: Origins, Evolution, Spread*, ed. D. J. Chadwick and J. Goode (Chichester, 1997), 2. For early discussion of antibiotic resistance, see Office of

Since the 1970s, government researchers in the United States have studied the issue extensively, and a host of private interest groups have weighed in on the pros and cons of regulating or even banning the subtherapeutic use of antibiotics in animal feed. The U.S. Food and Drug Administration and the Office of Technology Assessment looked into the issue during the 1970s, and though both voiced concern over the public health implications, neither discovered strong evidence that directly linked animal feeding practices to instances of human illness. In 1980 the National Academy of Sciences reached similar conclusions. In recent years the Food and Drug Administration has revisited the issue; hearings have been held and advisory committees assembled. The National Research Council and the Institute of Medicine have taken up the question, concluding in a 1998 report that although there are problems and legitimate public health concerns, the overall incidence of human disease that can be traced to the use of antimicrobials in animal agriculture is very low. Major policy recommendations included more study and stronger regulatory oversight of the development and use of new drugs.[55]

Critics have argued in response that even when definitive epidemiological data linking antibiotic use in animal agriculture to human health become available (and the evidence is accumulating) the key issue will still be the spread of resistant bacteria among animal and human populations and the overall potential for reducing the effectiveness of antibiotics. The primary concern, in other words, is not the incidence or prevalence of diseases resulting from pathogens in the food supply but the undeniable fact of increased resistance and what this means for the capacity to treat infectious diseases (whatever their origins) over the long term.[56]

Notwithstanding such criticism, supporters of intensive animal agriculture continue to defend antibiotics as necessary components of modern industrial food production.[57] Proponents suggest that the real issue is one

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Technology Assessment, *Drugs in Livestock Feed*, 42, and Schell (n. 47 above) 24–27. For more recent assessments of the issue, see the essays in Chadwick and Goode; National Research Council, *The Use of Drugs in Food Animals: Benefits and Risks* (Washington, D.C., 1998); Dan Ferber, "Superbugs on the Hoof?" *Science*, 5 May 2000, 792–94; and Mellon, Benbrook, and Benbrook (n. 47 above).

55. National Research Council, *The Use of Drugs in Food Animals*, 1–10.

56. Schell, 113–15; Levy, "Challenge of Antibiotic Resistance" (n. 47 above) and "Antibiotic Resistance: An Ecological Imbalance."

57. As Thomas Jukes, a pioneer in poultry nutrition research and one of the scientists from American Cyanamid who first discovered the growth promoting effects of antibiotics in animal feeds, noted in 1969: "The public is sensitive, and rightly so to the advent of new technologies in the production of food. Nevertheless, the maintenance of the supply of food at the present level is not possible without using the full resources of scientific technology, including the use of antibiotics in animal production." See T. H. Jukes, "Discussion," in *The Use of Drugs in Animal Feeds*, 60.

of food hygiene.[58] While establishing links between resistant bacteria and food-borne illness is not easy, industry arguments appear to rest on increasingly shaky foundations. A growing mass of evidence from countries all over the world is beginning to demonstrate a definitive link between food-borne illnesses and resistant bacteria of animal origin.[59] And although the dangers associated with food-borne pathogens can be mitigated to some extent by improvements in food hygiene, the proliferation of resistant bacteria will most certainly not decline until the use of antibiotics is curbed. Efforts to contain the spread of resistant bacteria are not likely to succeed either. As Stuart Levy, of the Center for Adaptation Genetics and Drug Resistance at Tufts University School of Medicine in Massachusetts, notes: "Microbes circulate everywhere, and there is a continual exchange among the human, animal and agricultural hosts." The issue, Levy contends, represents one of society's "gravest public health problems."[60]

In addition to these very serious public health concerns, the continued use of antibiotics in animal feed also has important implications for the viability of poultry and livestock populations and for those who earn their livelihoods in animal agriculture. Given the current dependency on animal drugs, substantial losses would likely result from any ban on the subtherapeutic use of antibiotics. At the same time, however, the continued use of antibiotics in animal feed might be creating the potential for even more serious vulnerabilities and losses in the future. As early as 1979, an Office of Technology Assessment report noted that "such widespread use [of antibiotics in animal feed] poses an identical threat to the health of livestock and poultry and may even occur earlier and more visibly than the threat to

58. Witness the words of Richard Carnevale, vice president for scientific, regulatory and international affairs at the Animal Health Institute (AHI), the trade association for the animal health industry: "I want to stress that AHI appreciates the issue of resistance—it is clearly a problem, but how much of it is really due to animal drugs and what is the medical impact? . . . the problem is complex and . . . the risks of using animal drugs must be put in context with the real risk factors associated with foodborne illness—failures in food hygiene." See Richard Carnevale, "Industry Viewpoint on Antimicrobial Use in Food Animals" (paper presented at the American Academy of Veterinary Pharmacology and Therapeutics Symposium, "The Role of Veterinary Therapeutics in Bacterial Resistance Development: Animal and Public Health Perspectives," College Park, Maryland, 20–22 January 1998).

59. For a review of recent studies, see Mellon, Benbrook, and Benbrook, 1–5, and Ferber. One 1995 study estimated that the annual incidence in the United States of salmonellosis and campylobacteriosis (the two major forms of bacterial food-borne illness from poultry) is between one and four million cases each. Estimates of the annual costs of poultry-associated cases of salmonellosis in the United States range from $64 million to $114.5 million; of campylobacteriosis, from $362 million to $699 million. See F. L. Bryan and M. P. Doyle, "Health Risks and Consequences of *Salmonella* and *Campylobacter jejuni* in Raw Poultry," *Journal of Food Protection* 58 (1995): 326–44.

60. Levy, "Antibiotic Resistance: An Ecological Imbalance" (n. 54 above), 2.

human health. Present production is concentrated in high-volume, crowded, stressful environments, made possible in part by the routine use of antibacterials in feed. Thus the current dependency on low-level use of antibacterials to increase or maintain production, while of immediate benefit, also could be the Achilles' heel of present production methods."[61]

The tradeoff, of course, is between immediate economic benefit and longer-term risks. Obviously, animal monocultures are highly vulnerable to pathogenic bacteria. Antibiotics, both at therapeutic and subtherapeutic doses, have certainly provided protection from pathogens in the past. By altering the ecological balance between resistant and sensitive bacteria, however, antibiotics are creating very accommodating niches for resistant bacteria that infect but do not necessarily kill the population. In the process, the likelihood of chronic, low-level losses (as well as acute, epidemic losses) increases. The most common pathogen now affecting chickens, for example, is *E. coli*, which is also highly resistant to broad spectrum antibiotics such as the tetracyclines. To date, most of the strains affecting chickens have only been weakly pathogenic and thus have resulted primarily in low-level losses. The potential that a highly pathogenic strain might emerge and acquire resistance, however, increases in proportion to the amount of resistant bacteria in circulation. Such a strain could easily wreak havoc in poultry populations and has obvious implications for food safety. The U.S. poultry industry's widespread dependence on antibiotics is thus very much a double-edged sword. Although it has allowed for major improvements in quality control and huge expansions in productivity, the new ecological imbalances and interdependencies it has created raise the specter of serious problems down the road.

Breeding and Genetic Improvement

If confinement provided the foundation for subordinating broiler biology to the dictates of industrial production, and if advances in nutrition and growth promotion marked the first step in the process of biological intensification, breeding and genetic improvement proved to be the primary drivers in the effort to accelerate biological productivity. As with poultry nutrition, systematic research on poultry inheritance began around the turn of the century. Stimulated by the rediscovery of Gregor Mendel's work, European and American researchers used chickens extensively in early studies of heredity. William Bateson, considered by some the founder of modern genetics and a major force in the spread of Mendelism during the first decade of the twentieth century, started conducting experiments with poultry in 1898. Four years later, with support from the evolution committee of the Royal Society, Bateson published the first scien-

61. Office of Technology Assessment, *Drugs in Livestock Feed* (n. 46 above), 41.

tific paper on poultry inheritance, demonstrating Mendelian segregation in animals.[62]

While Bateson and his colleagues focused largely on the pure science of poultry genetics, early American researchers, most of whom were associated with the agricultural experiment stations of Maine, Massachusetts, Rhode Island, and Kansas, sought to use their understanding of poultry genetics and breeding to select for valuable economic traits.[63] Many of these researchers participated in the American Breeders' Association (ABA), an organization established in 1903 by members of the American Association of Agricultural Colleges and Experiment Stations. Composed of commercial breeders, scientists from agricultural colleges and experiment stations, Department of Agriculture researchers, and other groups interested in inheritance and scientific breeding, the ABA proved to be a very receptive audience for Mendel's work.[64] Members involved in plant

62. D. C. Warren, "A Half Century of Advances in the Genetics and Breeding Improvement of Poultry," *Poultry Science* 37 (1958): 5–6. Bateson coined the term *genetics* in 1906. W. E. Castle referred to Bateson as "the real founder of the science of genetics"; W. E. Castle, "The Beginnings of Mendelism in America," in *Genetics in the Twentieth Century: Essays on the Progress of Genetics During Its First Fifty Years*, ed. L. C. Dunn (New York, 1951), 60. See also Ernst Mayr, *The Growth of Biological Thought: Diversity, Evolution, and Inheritance* (Cambridge, Mass., 1982), chaps. 16–17. Between 1902 and 1909, Bateson, along with E. R. Saunders, R. C. Punnett, and C. C. Hurst, presented the results of experiments on poultry heredity in various reports to the evolution committee of the Royal Society. See, in particular, W. Bateson and E. R. Saunders, "Experiments with Poultry," in *Report to the Evolution Committee of the Royal Society*, vol. 1 (London, 1902); W. Bateson, E. R. Saunders, and R. C. Punnett, "Experimental Studies in the Physiology of Heredity," and C. C. Hurst, "Experiments with Poultry," in *Report to the Evolution Committee of the Royal Society*, vol. 2 (1905); W. Bateson, E. R. Saunders, R. C. Punnett, "Poultry," in *Report to the Evolution Committee of the Royal Society*, vol. 3 (1906); W. Bateson, E. R. Saunders, R. C. Punnett, "Experimental Studies in the Physiology of Heredity," in *Report to the Evolution Committee of the Royal Society*, vol. 4 (1908). See also William Bateson, "The Progress of Genetics Since the Rediscovery of Mendel's Papers," *Progressus Rei Botanica* 1 (1906): 378–80, and Mendel's *Principles of Heredity* (Cambridge, 1913). At almost the same time that Bateson was demonstrating Mendelian segregation with poultry, Cuernot was finding similar results with mice; see L. C. Dunn, *A Short History of Genetics* (New York, 1965), 66, and Castle, 59–76.

63. In addition to these experiment stations, the department of genetics at the University of Wisconsin and the animal breeding program at Iowa State University also provided training for a large number of early poultry geneticists in the United States. See D. C. Warren, "A Half Century of Advances," 3–4; Oscar Kempthorne, "The International Conference of Quantitative Genetics: Introduction," and A. W. Nordskog, "Introductory Statement: Poultry," both in *Proceedings of the International Conference on Quantitative Genetics*, ed. E. Pollak, O. Kempthorne, and T. B. Bailey Jr. (Ames, Iowa, 1977).

64. Founded three years after the rediscovery of Mendel's work on inheritance and two years after publication of the first volume of Hugo De Vries, *Die Mutationstheorie* (Leipzig, 1901), the ABA was the first nationally organized, membership-based institution promoting genetic and eugenic research in the United States. During its ten-year existence (1903–13), the primary focus of the ABA's research program shifted gradually from agricultural improvement to eugenics. For a historical treatment of the ABA and its relation

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and animal breeding appreciated the predictive value of Mendelian ratios and set to work on applying the "fundamental laws of breeding" to agricultural improvement. Willet M. Hays, a professor of agriculture at the University of Minnesota and the first secretary of the ABA, spoke of bringing together scientists and practical breeders "in a grand cooperative effort to improve those great staple crops and magnificent species of animals." Only on the basis of such cooperation between "the breeders and the students of heredity," Hays argued, could the "wonderful potencies" of heredity be harnessed and "placed under the control and direction of man, as are the great physical forces of nature."[65]

Papers on animal and poultry inheritance published by the ABA provided details on breeding experiments demonstrating the application of Mendel's "laws" and offered suggestions for future improvement efforts.[66] Among others, Charles B. Davenport, who would later become a major figure in American eugenics, presented a number of papers on poultry inheri-

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to genetics and eugenics in the United States, see Barbara A. Kimmelman, "The American Breeders' Association: Genetics and Eugenics in an Agricultural Context, 1903–1913," *Social Studies of Science* 13 (1983): 163–204. Rosenberg (n. 4 above), 211–24, compares the reception of Mendel's work among plant and animal breeders in the United States with its reception among biologists and members of the medical profession. See also Diane B. Paul and Barbara A. Kimmelman, "Mendel in America: Theory and Practice, 1900–1919," in *The American Development of Biology*, ed. Ronald Rainger, Keith R. Benson, and Jane Maieschein (Philadelphia, 1988), 281–310.

65. In 1904 Hays became undersecretary of agriculture, but he continued on as secretary and "guiding force" of the ABA; Willet M. Hays, "Address to the First Meeting of the American Breeders' Association," in *Proceedings of the American Breeders' Association*, vol. 1 (Washington, D.C., 1905), 9–10. Hays often compared heredity or "breeding power" to electricity and always alluded to its potential as an economic force: "As electrical energy must be harnessed, so these investigations are showing that the peculiar breeding potencies of the rare plant or animal must be singled out and given opportunity to work. Both in practical breeding and in evolutionary studies the individual with exceptional breeding power is gaining respect. . . . The world is learning to seek the 'Shakespeares' of the species with the same avidity that it seeks gold mines." Willet M. Hays, "American Work in Breeding Plants and Animals," in *Proceedings of the American Breeders' Association*, vol. 2 (Washington, D.C., 1906), 158. See also the editorial "Heredity: Creative Energy," *American Breeders Magazine* no. 1 (1910): 79 (Hays was the editor of the magazine.) For more on Hays and his role in the ABA, see Kimmelman, "The American Breeders' Association," and Paul and Kimmelman, "Mendel in America."

66. On animal breeding in general, see, for example, W. E. Castle, "Recent Discoveries in Heredity and Their Bearings on Animal Breeding," and W. J. Spillman, "Mendel's Law in Relation to Animal Breeding," both in *Proceedings of the American Breeders' Association*, vol. 1 (Washington, D.C., 1905). See also the yearly reports of the Committee on Animal Hybridizing, *Proceedings of the American Breeders' Association*, vols. 1–4 (Washington, D.C., 1905–9). On poultry breeding, see C. D. Woods, "Investigations Relating to Breeding for Increasing Egg Production in Hens," *Proceedings of the American Breeders' Association*, vol. 1 (Washington, D.C., 1905), 127–31, and the yearly reports of the Committee on Breeding Poultry, *Proceedings of the American Breeders' Association*, vols. 1–4 (Washington, D.C., 1905–9).

tance based on experimental research at his Cold Spring Harbor laboratory in New York and was directly involved with the work of the ABA's poultry committee. In a paper delivered to the third annual ABA meeting in 1907, for example, Davenport spoke of the "exceptional interest" that fowls held for the "student of heredity" because of their great variety, fecundity, and diversity of characteristics. These features, according to Davenport, provided a wealth of opportunities for those interested in hybridization as a method of improvement. Using language that anticipated his later enthusiasm for eugenics, Davenport suggested that poultry breeding efforts should focus on racial "purification" as a step toward creating "a new race which shall combine various desirable characteristics found in two or more races."[67]

For early poultry breeders, however, it soon became clear that the commercially desirable characteristics of poultry (egg and meat production, fertility, growth rate, and so forth) were complex characters that could not be reduced to sharply defined Mendelian factors. The existence of so-called continuous or quantitative variation in traits such as size and color had been noted by Mendel, Bateson, Davenport, Castle, and others. What was unclear was the implication of continuous variation for Mendelism and, by extension, for future efforts in plant and animal improvement. On this matter, the work of T. H. Morgan and his colleagues on the genetics of drosophila proved decisive in demonstrating that certain aspects of the phenotype were controlled by multiple genes at different locations on the chromosomes. This confirmation that "multiple-factor inheritance" or polygeny was responsible for continuous variation and thus consistent with Mendelian principles cleared the way for the development and application of quantitative genetics to breeding.[68]

67. C. B. Davenport, "Inheritance in Pedigree Breeding of Poultry," in *Proceedings of the American Breeders' Association*, vol. 3 (Washington, D.C., 1907), 26–33, esp. 33. See also C. B. Davenport, "Recent Advances in the Theory of Heredity," in *Proceedings of the American Breeders' Association*, vol. 4 (Washington, D.C., 1908), 355–57; "A Suggestion as to the Organization of the Committee on Breeding Poultry" and "The Factor Hypothesis in Its Relation to Plumage Color," both in *Proceedings of the American Breeders' Association*, vol. 5 (Washington, D.C., 1909), 379–80, 382–83. The following year, in the first issue of *American Breeders Magazine*, Davenport defended the place of eugenics research in the ABA: "The association of research in Eugenics with the American Breeders Association is a source of dignity and safety. It recognizes that in respect to heredity man's nature follows the laws of the rest of the organic world. It recognizes that human heredity is a subject of study for practical ends; the ends, namely, of race improvement." C. B. Davenport, "Eugenics, A Subject for Investigation Rather than Instruction," *American Breeders Magazine*, no. 1 (1910), 68. On Davenport and his relation to American eugenics, see Kimmelman, "The American Breeders' Association," and Rosenberg, 89–97.

68. Mayr (n. 62 above), 790–94, characterizes this as a debate between biometricians and Mendelians. See also Garland Allen, *Life Science in the Twentieth Century* (New York, 1975), 56–72, esp. 70, and "The Transformation of a Science: T. H. Morgan and the Emergence of a New American Biology," in *The Organization of Knowledge in Modern*

Such findings, of course, did not make the task of the commercial poultry breeder any easier. Indeed, the realization that most economically valuable traits were controlled by multiple genes (not to mention the vagaries of environment) dashed the initial hopes of poultry breeders that simple Mendelian analysis could be used to achieve prompt improvements. As a result, most commercial poultry breeders continued their practices of selective improvement, albeit with a bit more Mendelian sensitivity. Despite the fact that two famous American geneticists could claim in 1927 that "[m]ore is known specifically about Mendelian inheritance in poultry than in any other farm animal," the practice of commercial poultry breeding during this time looked more like an art than a science.[69]

The advent of population genetics in the 1930s and 1940s offered new tools for rationalizing commercial poultry breeding. On the basis of heritability data and the mating systems analysis pioneered by Sewall Wright, poultry breeders could make more informed predictions about the potential improvements from selection and the relative gains attainable from different combinations. Given the multiple objectives of poultry breeding programs and the polygenic character of most commercial traits, quantitative genetics offered a means for developing selection indexes to identify the monetary value of particular qualities and the tradeoffs involved in particular breeding programs. Efforts to enhance valuable traits through intensive selection and inbreeding could now proceed on the basis of statistical analysis. Greater calculability, it was hoped, would bring accelerated improvement. By the 1940s, poultry breeders began applying the principles of quantitative genetics on a systematic basis.[70]

Meanwhile, the successful development and widespread adoption of hybrid corn created considerable enthusiasm among poultry breeders about the potential for heterosis, or hybrid vigor. Many saw the success of the corn breeder in developing pure inbred lines and combining them into superior hybrids as an important model for the poultry industry.[71] As in

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America, 1860–1920, ed. Alexandra Oleson and John Voss (Baltimore, 1979), 173–210, esp. 200–201. For a discussion of the implications of polygeny and Morgan's work on linkage for poultry breeding, see M. A. Jull, "The Selection of Breeding Stock in Relation to the Inheritance of Form and Function in the Domestic Fowl," *Poultry Science* 5 (1925), 1–19.

69. Ernest Brown Babcock and Roy Elwood Clausen, *Genetics in Relation to Agriculture*, 2d ed. (New York, 1927), 496–97. The book, which was quite influential in its time, was originally published in 1918. The authors go on to write that "The reasons for this are obvious: greater diversity among the breeds, lesser expense of rearing, short life cycle, ease of applying experimental methods, etc."

70. D. C. Warren, "A Half Century of Advances" (n. 62 above), 16. For an early attempt to develop a selection index for poultry, see I. M. Lerner, V. S. Asmundson, and D. M. Cruden, "The Improvement of New Hampshire Fryers," *Poultry Science* 26 (1947): 515–24. See also Jay L. Lush, "Genetics and Animal Breeding," in Dunn, *Genetics in the Twentieth Century* (n. 62 above), 493–525, and Nordskog (n. 63 above), 47.

71. D. C. Warren, "Hybrid Vigor in Poultry," *Poultry Science* 7 (1927): 1–8. For dis-

the case of hybrid corn, moreover, interest in using the techniques of hybridization with poultry shifted the locus of innovation further to the private sector. Indeed, some of the earliest efforts to develop hybrid poultry breeds were direct spin-offs of private ventures with hybrid corn.[72]

The real watershed in the push for hybridization among commercial chicken breeders, however, came with the "Chicken of Tomorrow" contests of 1948 and 1951. Sponsored by the Great Atlantic and Pacific Tea Company, these contests had the explicit aim of stimulating interest in the breeding of broad-breasted, "meat-type" chickens.[73] As early examples of retailer power in product design, they reflected the emergence of new self-service supermarkets in the United States, where chicken could be sold in various prepackaged cuts. Both contests were won by a crossbreed developed by Charles Vantress of California. With instant national publicity, Vantress and the other prize winners quickly captured large market shares for male and female birds, causing a rapid shakeout of smaller firms.[74] By the early 1950s more than two-thirds of all commercial broilers raised in the United States "carried the blood lines of Chicken of Tomorrow prize winners."[75]

With control of substantial market share, the larger commercial breeders stepped up their efforts to develop hybrids during the 1950s.[76] The Arbor Acres breeding firm, a second-place Chicken of Tomorrow winner, introduced its first hybrid female broiler in 1959 after spending the better part of the decade inbreeding and testing its purebred lines. The company

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cussion of some of the difficulties involved in applying the methods developed for hybrid corn to poultry, see D. C. Warren, "Techniques of Hybridization of Poultry," *Poultry Science* 29 (1950): 59–63; A. E. Bell et al., "Systems of Breeding Designed to Utilize Heterosis in the Domestic Fowl," *Poultry Science* 31 (1952): 11–22; and A. W. Nordskog and F. J. Ghostley, "Heterosis in Poultry," *Poultry Science* 33 (1954): 704–15.

72. In 1942, for example, the Hy-Line Poultry company, which was associated with the Pioneer Hi-Bred Corn Company, began selling hybrid chicks. In 1944 another hybrid corn company, the Dekalb Hybrid Seed Company, initiated a similar project—Dekalb Poultry Research—which concentrated on both broiler and layer stock. See D. C. Warren, "A Half Century of Advances," 14.

73. H. L. Shrader, "The Chicken-of-Tomorrow Program: Its Influence on 'Meat-Type' Poultry Production," *Poultry Science* 31 (1952): 3–10.

74. Second place in 1948 went to a purebred developed by Arbor Acres of Connecticut; in 1951 it went to another purebred developed by the Nichols Poultry Farm of New Hampshire. Shrader, 6. By 1959, Vantress controlled 60 percent of the market for male breeders. Meanwhile, Arbor Acres, which had started with a white female bird, consolidated its hold on the market for female breeders and began to experiment with hybridization. See Bugos (n. 5 above), 139–40; B. F. Tobin and H. B. Arthur, *Dynamics of Adjustment in the Broiler Industry* (Boston, 1964): 31–35.

75. Shrader, 9–10.

76. See Bell et al., 11, for a discussion of the considerable costs associated with the development and maintenance of inbred lines and the testing necessary to develop commercial hybrids in poultry.

gambled on hybridization despite the fact that it did not expect to attain the productivity gains possible from fine-tuning its purebred bird for at least five years.[77] The key advantage of hybrids lay in the so-called biological lock of hybridization. Because only the first cross of two distinct parent lines would produce the high-yielding uniform hybrids, any effort to subsequently cross these hybrids with one another would create populations that lacked uniformity and varied considerably in yield. In the case of hybrid corn, this made it economically impossible for farmers to save seed for replanting, forcing them to go back and repurchase hybrid corn seed every year.[78] Similarly, if the hybrid birds developed by Arbor Acres or other primary breeding companies were subsequently bred by hatcheries or farmers, "the pedigrees would genetically self-destruct." For these firms, "[h]ybridization secured, through the laws of nature rather than through the laws of man, an intellectual property right."[79] Thus, as in the case of hybrid corn, these new hybrid poultry breeds, with their unique, biological form of property protection, quickly became the genetic foundation of the industry. Primary breeders focused on fine-tuning their pedigrees to meet the growing demands for genetic uniformity and high performance. Their assets, their reputations, and ultimately their profits came to be embodied in these highly valued pedigrees.[80]

By the end of the 1950s, then, the era of the designer chicken had arrived. With improved nutrition, increased survivability, and better environmental control, broiler firms now had added incentive to pay a premium for chicken breeds with superior genetic potential. Surveying the field of poultry breeding in 1958, one poultry geneticist remarked that "[t]he outstanding example of the contribution of breeding work is to be found in the broiler industry since here stocks have virtually been made to order to meet the needs of the meat industry."[81]

But poultry breeding was not an easy business. Given the high-volume, mass-production nature of the broiler industry, breeders typically operated on very thin margins. In addition, long capital-intensive research cycles and the various biological risks associated with breeding translated into structural rigidities and considerable exposure to market risk. If a particular breed turned out to have a proclivity for a certain disease or did not meet the specific needs of customers, a breeder firm could lose market share very rapidly. Because of the long biological time lags involved in breeding cycles (at least five years), only the very largest firms would be able to sustain such a miscalculation. As a result of such pressures, the primary breeding industry concentrated rapidly during the 1960s and 1970s, with most primary

77. Bugos.
78. Kloppenburg (n. 4 above), 91–129.
79. Bugos, 143–44.
80. For a very interesting discussion of these issues, see Bugos.
81. D. C. Warren, "A Half Century of Advances" (n. 62 above), 16.

breeders specializing in either male or female lines.[82] By the early 1980s, fewer than fifteen primary breeders supplied the breeding stock for the 3.7 billion chickens produced annually in the United States, and two companies, Peterson and Arbor Acres, together controlled more than 60 percent of the breeding stock.[83]

Meanwhile, as the center of broiler industry shifted to the American South, primary breeders also began to establish operations in the region. In the early 1950s, Arbor Acres moved some of its grandparent flocks to Georgia and Mississippi and established a research facility in Alabama to support the southern broiler industry. In 1956, Charles Vantress moved his whole operation from California to Duluth, Georgia.[84] Such moves signified the emerging networks and alliances developing between primary breeders and the integrated broiler firms in the American South.[85]

By the early 1970s, the advent of the so-called new biotechnologies stimulated considerable interest in the broiler breeding industry. Hoping to use the new techniques of genetic engineering to develop breeds that could serve as effective vehicles for selling proprietary animal health products, several large pharmaceutical firms purchased breeder firms.[86] With the U.S. Supreme Court's *Chakrabarty* decision of 1980, poultry breeders also began

82. The decision to specialize in male or female lines reflected the fact that independent hatcheries and, later, the integrated firms preferred to buy their male and female lines from different companies, often experimenting with several different crosses or combinations at once, as a way of minimizing the risk associated with going with a single company or a single cross. In order to facilitate systematic record keeping and information exchange on the effectiveness of various crosses, the National Poultry Breeder Roundtable was established in 1952. See Bugos (n. 5 above), 145.

83. Office of Technology Assessment, *Impacts of Applied Genetics: Micro-Organisms, Plants, and Animals* (Washington, D.C., 1981), 170; Bugos, 162.

84. D. Amey, "Arbor Acres Farm, Inc.: New Products, Changing Philosophy," *Broiler Industry* 55 (1992); Bugos, 146.

85. During the 1960s the ownership structure of the primary breeding industry also began to change, and several of the major firms moved into international markets. In 1964, for example, the International Basic Economy Corporation, a conglomerate started by David Rockefeller, purchased Arbor Acres and expanded its international business. By 1968 Arbor Acres had operations in twenty-three countries, and international operations accounted for about half of the company's profits. In 1976 Arbor Acres was sold again, this time to the British agribusiness conglomerate Booker-McConnell. The Cobb Breeding Company also expanded internationally in the late 1950s and early 1960s, establishing a Common Market franchise in Europe in 1959 and a breeding program in the United Kingdom in 1961. In 1974 the rapidly expanding Tyson Foods acquired the Vantress breeding lines, integrating further upstream to control the basic genetic stock of the broiler industry. Twelve years later, Tyson and the pharmaceutical giant Upjohn, which had previously acquired the Cobb Breeding Company, formed Cobb-Vantress, which has emerged as one of the leading primary breeding firms in the world. See Bugos, 152–53, 161, and W. van der Sluis, "We Believe in One Bird for All Markets: Profile of Cobb-Vantress," *World Poultry* 10 (1994).

86. In 1974, Upjohn bought the Cobb Breeding Company, Merck Pharmaceuticals bought Hubbard, and Pfizer Chemical bought H&N Breeders; Bugos, 161.

exploring the possibility of creating transgenic chickens that would be subject to patent protection and thus provide an alternative to the conventional approach of trade secrets and hybridization.[87]

The transgenic manipulation of chickens, however, has faced certain obstacles not present with mammalian systems. In particular, specific features of the reproductive system of the hen render the earliest stages of chick-embryo development relatively inaccessible, inhibiting the direct application of methods used in the production of transgenic mammals. Still, successful techniques have been developed. In 1992, Amgen and Arbor Acres received a patent on a process for transferring nucleic acid sequences into avian germ cells. More recently, researchers at the Roslin Institute in Great Britain, home of Dolly the cloned sheep, reported on the development of a new, more efficient method of transferring DNA into the chicken germ line.[88]

Pending the isolation of desirable genes and the further development of transgenic techniques, the production of genetically engineered chickens is thus very much a technological possibility.[89] Given the current furor over genetically modified crops, however, it is not at all clear if and when it will be politically and economically feasible.

Efforts to map the chicken genome represent another area in which the new genetic technologies could have a major impact on commercial breeding ventures. As in other sectors of the emerging life sciences industry, the development of genomics holds great promise for those interested in further manipulating the chicken genetic program. Although the first linkage map for chickens was developed more than six decades ago, only in recent years has the notion of a comprehensive molecular genetic map become a

87. *Diamond v Chakrabarty*, 447 U.S. 303 (1980), in which the court held that a live, human-made microorganism is patentable subject matter under U.S. patent law. For a discussion in the context of the poultry industry, see Bugos, 162–68. For a more general discussion, see Daniel J. Kevles, "*Diamond v Chakrabarty* and Beyond: The Political Economy of Patenting Life," in *Private Science: Biotechnology and the Rise of the Molecular Sciences*, ed. Arnold Thackray (Philadelphia, 1998), 65–79. As used here, the term "transgenic" refers to an organism (plant or animal) into which genetic material from some other sexually incompatible organism has been inserted.

88. Helen Sang, "Transgenic Chickens—Methods and Potential Applications," *Trends in Biotechnology* 12 (1994): 415–20. The Amgen/Arbor Acres patent is U.S. Patent 5162215, "Method of Gene Transfer into Chickens and Other Avian Species." The Roslin Institute work is discussed in A. Sherman et al., "Transposition of the Drosophila Element Mariner into the Chicken Germ Line," *Nature Biotechnology* 16 (1998): 1050–53.

89. Most commercial breeders would likely agree with Hubbard Farms geneticist Ira Carte's recent prognosis that the industry is still "many years away from having transgenic poultry available for commercial production"; "Poultry Breeding and Genetic Engineering," *Poultry International*, October 1995, 17. Carte based his claim, it should be emphasized, exclusively on an assessment of the technical feasibility of producing transgenic chickens on a commercial basis, leaving aside the potential social, political, and environmental obstacles associated with the production of transgenic food animals.

real possibility.[90] Given the relatively small size of its genome and the fact that its DNA can be isolated from nucleated red blood cells (in contrast to mammalian species), the chicken is well suited to genetic mapping, and it has become the focus of an international collaborative mapping effort involving several foreign and American universities, the U.S. Department of Agriculture, and a number of other governmental and nongovernmental institutions.[91] By identifying, isolating, and sequencing particular genes and developing detailed linkage maps based on DNA markers, researchers hope to dissect the genetic component of the various quantitative or polygenic traits that are of commercial interest to breeders.[92] This would effectively allow selective improvement to proceed on the basis of genotype rather than phenotype, representing a very significant expansion in "breeding power."

That said, although breeding efforts have succeeded in extending the biological potential of the chicken, trade-offs between genetic susceptibilities and the performance of breeds geared to particular product mixes have become increasingly apparent.[93] Ongoing efforts to increase breast-meat yield, for example, have created a higher propensity for musculoskeletal problems, metabolic disease, immunodeficiency, and male infertility, primarily because the extra protein going to breast muscle production comes at the expense of internal organ development.[94] In recent experiments comparing breeding stock from 1957 and 1991, mortality rates for the 1991 breed were found to be up to three times higher than those of the 1957 breed.[95] To date, feed restriction programs, increased use of drugs, and improved sanitation have all been used in attempts to compensate for these increased genetic susceptibilities. Such management adjustments, however, will not solve the problem. As one poultry geneticist remarked: "We are severely changing the way these animals grow. . . I believe the time is rap-

90. The first linkage map for chickens, which utilized the techniques developed in T. H. Morgan's laboratory for drosophila, was published in 1936 by F. B. Hutt. This was also the first such map reported for any domestic farm animal species. See David W. Burt et al., "Chicken Genome Mapping: A New Era in Avian Genetics," *Trends in Genetics* 11 (1995): 190. See also M. A. M. Groenen et al., "A Comprehensive Microsatellite Linkage Map of the Chicken Genome," *Genomics* 49 (1998): 265–74.

91. Hans H. Cheng, "The Chicken Genetic Map: A Tool for the Future," *Poultry Digest*, 53 (1994): 24–28. A public database has been established at the Roslin Institute in Edinburgh to provide access to a summary of chicken genome mapping data. See Burt et al., 193.

92. Burt et al., 193–94.

93. T. J. Martin, "Industry Efficiency: A Changing Paradigm," *Broiler Industry* 59 (1996): 26.

94. Gary Thornton, "High Yielding Broiler Production: The Big Trade-Off," *Broiler Industry* 59 (1996): 18–22.

95. G. B. Havenstein et al., "Growth, Livability, and Feed Conversion of 1957 vs. 1991 Broilers When Fed 'Typical' 1957 and 1991 Broiler Diets," *Poultry Science* 73 (1994): 1785–94.

idly approaching when management alone won't be able to overcome the genetic problems because of the metabolic stresses that are being put on these birds."[96] In effect, breeding programs have attained higher breast meat yields at the expense of increased susceptibility to various diseases and increased mortality—a situation that appears even more serious when viewed in the context of increasing concentrations of broiler operations in specific geographic areas, the proliferation of antibiotic resistant bacteria, and the threat of emerging diseases.

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Intensification and the Problem of Nature

The story of the industrial chicken illustrates a number of more general tendencies manifest in the industrialization of agricultural systems. Based upon the precise coordination of a package of high-quality inputs—genetics, feed, medication—and ever more careful grow-out management, avian biology was (and continues to be) pressed into the service of industry and made to operate as a productive force.[97] But the manipulation and acceleration of biological productivity via the systematic application of science and technology was and is only part of a much larger story involving substantial changes in agrarian structure, the agricultural labor process, and the relation of farm-level production to various input and output sectors. Indeed, the story of biological intensification in the broiler industry has been intimately bound up with the rise of vertically integrated agribusiness firms, the spread of contract farming, and the concentration of production in the American South. To adequately treat these aspects of the larger history of the American broiler industry would require far more space than is available here. Instead, by focusing exclusively on the technologies of intensification, this article has sought to develop a perspective on technological change in agriculture that tries to capture the varied and variable ways in which nature is incorporated into agro-industrial systems.

Such a perspective points unambiguously to the sobering conclusion that any program of biological intensification will generate its own set of unintended consequences. If pushed too far, efforts to subordinate biological systems to the dictates of industrial production have a tendency to undermine their own biological foundations and facilitate various forms of ecological disruption. Of course, there is nothing novel in (and no lack of supporting evidence for) the claim that technological change carries with it all sorts of risks and produces all sorts of unintended consequences. The

96. Quoted in Thornton, 22.

97. On the question of the relative contribution of genetic improvement to broiler performance (versus nutrition, disease control, etc.), see Havenstein et al. In trials comparing the performance of a 1957 breed with a 1991 breed, controlling for nutrition, housing, etc., they determined that genetics account for nearly 80 percent of broiler performance increases between 1957 and 1991.

history of industrial agriculture contains numerous examples of the unforeseen and often disruptive effects of technological development—the failures of monocropping, the spread of pest resistance, genetic erosion, and soil degradation, to name a few. As James Scott notes, "Cultivation is simplification," and simplification implies loss of resiliency and increased vulnerability.[98] By ramping up technological change, the industrialization of agriculture can increase the scale and scope of simplification and, as a result, the associated disruptions and vulnerabilities.

The broiler industry is paradigmatic in this regard. Indeed, virtually every effort to further industrialize broiler biology has resulted in the emergence of new risks and vulnerabilities. Intensive confinement combined with increased genetic uniformity has created new opportunities for the spread of pathogens. Increased breast-meat yield has come at the expense of increased immunodeficiency. And, of course, widespread recourse to antibiotics has created a niche for the proliferation of resistant bacteria. Since most of these risks affect the live production sector most directly, it is hardly surprising that integrated firms prefer to outsource grow-out operations to small contract farmers.[99]

Many of these problems also have ramifications further down the food chain. In particular, concerns over food safety have achieved a very high level of national and international prominence in recent years, raising serious questions about the sustainability of the prevailing model of industrial livestock production in the United States and other industrialized countries. Growing numbers of food-borne illnesses, the spread of antibiotic-resistant bacteria in chicken, beef, pork, and other foods, and the growing animal waste problem associated with intensive confinement have led some to suggest that the inherent contradictions of industrial livestock production are beginning to manifest themselves—the proverbial chickens come home to roost. "Modern meat," to borrow the title of Orville Schell's 1978

98. James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven, Conn., 1998), 264.

99. The standard production contract currently used in the industry is a feed-conversion contract that ties compensation to performance. The integrated companies provide the inputs (chicks, feed, and medication), to which they hold title throughout the process, while the contract growers provide housing (according to company specifications), energy, and labor. Contracts are offered on a take-it-or-leave-it basis, and almost all are only valid for a single grow-out period (six to seven weeks), but are generally renewed if performance is consistently acceptable. The average cost of a chicken house exceeds $120,000. The typical broiler grower has as many four houses, which translates into an initial fixed capital investment of roughly $500,000. In effect, the contract grow-out arrangement allows the integrated firms to take advantage of the chief asset of the family farm—cheap, flexible labor—without taking on the burdens of fixed capital, the costs of wage labor, and the biological risks associated with live production. The fact that this system emerged out of an agrarian structure in the upcountry South marked by small marginal farmers who were looking for alternatives is hardly a historical anomaly. For a discussion, see Boyd and Watts (n. 14 above).

book on the subject, may not only be creating some very serious public health problems but may also be undermining its own biological foundations.[100] The problem of nature, previously considered as a set of obstacles to be overcome via the industrialization of avian biology, has reemerged as a question of ecological risks and vulnerabilities.

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100. Schell (n. 47 above). For a more recent popular account of food safety issues, see Nicols Fox, *Spoiled: The Dangerous Truth about a Food Chain Gone Haywire* (New York, 1997).