1

Introduction

In the fall of 1843, John M. Harlan of Chester County, Pennsylvania, lamented that his potato crop was afflicted "by a very strange fatality which the oldest inhabitants have never before witnessed. The potatoes have been attacked by a disorder somewhat resembling the plague, generally called the rot."[1] The press and government officials tracked the devastation as the strange disease swept across the Northeast and into the Midwest between 1843 and 1846. Farmers had little recourse but to abandon potatoes and many had to cull their livestock for want of feed. This little-known American episode was a harbinger of even greater destruction; the New World disease soon jumped the Atlantic, bringing sorrow and suffering to European cultivators who were much closer to the Malthusian abyss than their American brethren. The "rot" was first reported in Belgium in June 1845 and within a few months was causing havoc in the Netherlands and Germany. The disease arrived in Ireland in September 1845, and within a few years roughly a million Irish were dead and another million had emigrated. The chain of causation was anything but straightforward. A crop disease imported to Europe from the Americas induced a massive flow of population in the opposite direction. Thus, a biological incident was a driving force in the globalization process.

The potato blight was one of a great number of diseases, insects, and weeds that significantly altered economic opportunities in the 200 years before World War II. A few prominent examples include *Phylloxera*,

[1] Peterson, Campbell, and Griffith, "James E. Teshemacher," 754–6; *Cultivator* (December 1943), 197. For other accounts in Pennsylvania see the *Pittsfield Sun* (5 October 1843), 2; *Barre Gazette* (6 October 1843), 3.

which attacked grapes; the Hessian fly and various rusts, which fed on wheat; San Jose scale, which smothered fruit trees; the boll weevil, which ravished cotton; and foot-and-mouth disease and tuberculosis, which attacked livestock. Each of these menaces threatened the economic well-being of American farmers, and some raised the specter of complete failure and crop abandonment. Fortunately, after initial periods of high losses, farmers typically learned to beat back the attacks, discovering how to coexist with the threats. In every instance, success required biological innovation.

Thousands of individual farmers contributed to crop and livestock advances, and many achieved what had been thought impossible. In 1900, two of America's preeminent plant scientists, Willet M. Hays and Andrew Boss of the Minnesota Agricultural Experiment Station, hitched up their horse and buggy and set out on a twenty-five-mile journey in search of a prize. They were drawn by the improbable report of thriving alfalfa fields far north of where the crop was thought to flourish. The reports proved accurate – an obscure farmer, Wendelin Grimm, had laboriously been acclimating alfalfa for forty years and had succeeded in developing a winter-hardy variety that would soon vastly extend the legume's domain.[2]

Agricultural production is location specific, at the mercy of conditions that likely differed from one farm to the next and certainly differed across states and regions. Settlement required biological adaptation as farmers harmonized production systems with specific local soil and climatic conditions. Learning did not end when the first settlers gained an agricultural foothold because, as areas matured, farmers generally switched to more intensive production patterns requiring new rounds of experimentation.

In addition to defending agriculture from insects, diseases, and weeds and developing better varieties and breeds for new and sometimes hostile areas, farmers, public officials, scientists, and nonfarm enterprises invested heavily in basic and applied research, often with spectacular results.[3] With rare exceptions, biological technologies in the nineteenth century were not patented, and thus the large body of research that has equated innovation with patents has concluded erroneously that there was little progress. But why would the curiosity, spirit of innovation,

[2] Russelle, "Alfalfa," 252.

[3] When discussing crops, modern agronomists have abandoned the term "variety" and adopted the term "cultivar" in its place because of the subtle distinctions as to what properly constitutes a distinct variety. Because the historical literature we cite consistently refers to "varieties," we have chosen to use the outdated terminology.

and quest for profit that drove technological change in other sectors have ceased to exist as one exited the factory, climbed out of the mine, or stepped off the train?

Everywhere we look, we find biological innovations transforming American agriculture. The varieties of wheat, corn, cotton, tobacco, and fruits grown at the dawn of the twentieth century were dramatically different from the varieties grown a hundred years earlier. Breeders also transformed farm animals – the sheep, swine, and cattle of 1940 bore little resemblance to those of 1800. These changes revolutionized farm productivity. Contemporaries understood this and in many instances attached innovators' names, dates, and places to the key changes. Joining Wendelin Grimm are Walter Burling, who gave Americans a type of cotton that, once acclimated, increased picking rates fourfold, Robert Livingston, E. I. du Pont, and others, who imported and bred early Merino sheep which, when improved by other American breeders, increased wool clip weights several-fold; Canadians Jane and David Fife, who helped open the northern plains to wheat cultivation; U.S. Department of Agriculture (USDA) wheat breeder Mark Alfred Carleton, who imported new wheat varieties from Ukraine, Russia, and central Asia and tested over a thousand varieties for rust resistance; Stephen Babcock, who devised a way to test milk for its butterfat content; William J. Spillman, who created hundreds of hybrid wheat varieties, the best of which advanced production in the Pacific Northwest; C. L. Marlatt and Charles V. Riley, whose entomological research saved countless farmers from ruin; and Eliza and Luther Tibbets, who helped introduce the navel orange tree to California, and Albert Koebele, whose beetles saved those trees from destruction.

In the nineteenth century the popular press, agricultural journals, Patent Commission reports, the U.S. Censuses, the USDA, state experiment stations, leading scientists, and farmers' journals all testified eloquently to the immense importance of biological innovation. A review of the USDA's *Yearbooks* in the second half of the nineteenth century indicates that roughly two-thirds of all articles addressed biological topics and that very few dealt with mechanical developments. Similarly, a content analysis of the leading agricultural journals published between 1860 and 1910 reveals that the space devoted to articles on new machinery and tools made up, on average, one-twelfth of the space allotted to biological topics such as animal husbandry, plant cultivation (including the use of fertilizer), pests and diseases, and water control practices.[4]

4 Farrell, "Advice to Farmers," 209–41.

A similar picture emerges when one examines how Americans presented their agricultural sector to the world. We are familiar with the story of how Cyrus McCormick wooed the judges at the London Crystal Palace Exposition in 1851. But, before that, an 1839 London exhibition of Brother Jonathan – the mammoth, 4,000-pound American ox – drew 23,368 admirers, including "almost every branch of the Royal Family and the leading Agricultural Noblemen and Gentlemen."[5] The U.S. agricultural exhibit at the 1889 Universal Exposition in Paris (for which the Eiffel Tower served as the entryway) offers a sense of the balance between mechanical and biological displays. In addition to the wares of 32 farm equipment manufacturers, U.S. organizers exhibited 648 specimens of corn, wheat, and other small grains; 162 samples of tobacco leaf of every major type; 164 samples of cotton varieties covering the span of the cotton belt, including two complete "ready-to-pick" cotton plants; 159 examples of American wools including more than 140 fleeces; numerous examples and illustrations of citrus and deciduous fruits; 57 examples of grapes; 96 cases of assorted American wines, chiefly from California; and 349 specimens of carefully preserved insects that affected crops as well as 116 devices to combat pests and 40 different insecticides.[6] Biological topics, such as new plant varieties and animal breeds, harmful and beneficial insects, and fungal diseases, comprised the bulk of the 1,000-page report that Charles Riley wrote about agriculture at the 1889 Paris Exposition; his coverage of farm machines required less than 75 pages. This emphasis on biological innovation is not how we've been taught to view American history or the course of its agricultural development.

The Standard Account: The Primacy of Mechanization

According to the standard accounts, the period before the 1930s was primarily an epoch of mechanization – a time when machine makers such as Eli Whitney and Cyrus McCormick revolutionized American agriculture. In his influential history of American agriculture, Willard Cochrane argued that mechanization "was the principal, almost the exclusive, form of farm technological advance" between 1820 and 1920.[7] Yujiro Hayami

[5] *American Mammoth Ox*.

[6] U.S. Commission to the Paris Exposition 1889, "Number of Exhibitors in the United States Section," 342–3, and "List of the Exhibit Material," 861–76.

[7] Cochrane, *Development of American Agriculture*, 200, also 107. Griliches' treatment is less emphatic, but appears to lead to the same general conclusion. Griliches, "Agriculture," 241–5.

and Vernon Ruttan's trailblazing analysis of comparative agricultural development repeatedly echoes this general theme, as reflected in their treatment of small grains: "the advances in mechanical technology were not accompanied by parallel advances in biological technology. Nor were the advances in labor productivity accompanied by comparable advances in land productivity."[8] Other scholars have emphasized that biological innovations had to wait for relatively sophisticated advances in the plant and animal sciences. In his Richard T. Ely lecture, D. Gale Johnson succinctly captured this general view: "While American agriculture achieved very large labor savings during the last century, which made it possible to continue expanding the cultivated area with a declining share of the labor force, output per unit of land increased hardly at all. . . . The revolution in land productivity based on important scientific advances began very recently; its beginnings were in the 1930's with the development of hybrid corn and followed over the next several decades with equally major improvements in the yields of grain sorghum, wheat, rice, and cotton."[9] More generally, Johnson maintained that land-augmenting investments were relatively unimportant until the World War II era.

The notion that the nineteenth century was largely an era of labor-saving productivity change in agriculture is also part of the mantra of most economic historians. William Parker and Judith Klein's classic study found that, between 1840 and 1910, output per unit of labor increased more than fourfold, whereas output per unit of land only increased by about 10 percent. They attributed the vast majority of the increase in efficiency to mechanization.[10] Jeremy Atack and Fred Bateman's prominent contribution, *To Their Own Soil*, echoes this general proposition: "The great improvement in acreage yields lay almost a century into the future when chemical fertilizers, hybrid seeds, irrigation, and various scientific developments became available to farm operators. Some technological devices designed to raise labor productivity were, however, becoming available during the nineteenth century. Mechanical rather than chemical or biological, these improvements operated primarily through their effect on the usage of labor."[11] Peter McClelland's treatise on the first agricultural revolution in North America, in the period 1783–1860, devotes about 15 pages to crop rotations, fertilizers, and animal breeding (in

[8] Hayami and Ruttan, *Agricultural Development*, 209.
[9] Johnson, "Agriculture and the Wealth of Nations," 7–8.
[10] Parker and Klein, "Productivity Growth in Grain Production."
[11] Atack and Bateman, *To Their Own Soil*, 186.

appendices) and about 330 pages to farm implements.[12] Perhaps the strongest statement of the view that biological innovations were unimportant comes from the trio of eminent economic historians Atack, Bateman, and Parker: "Land abundance that encouraged extensive rather than intensive agriculture contributed to the general lack of interest in land productivity by nineteenth-century American farmers, while stimulating their interest in mechanization to substitute for labor."[13] In their view, not only did American farmers fail to invest much in biological innovation to increase land yields, *they were not even interested in doing so*. The view that mechanization was the dominant source of nineteenth-century agricultural productivity change is now a prominent fixture in standard economic history textbooks.[14] Scholars within the USDA, including Wayne D. Rasmussen, America's most eminent agricultural historian of the second half of the twentieth century, also steadfastly subscribed to the primacy of laborsaving mechanization.[15] It is little wonder that the view has permeated the broader literature on American history. Laborsaving technical change in agriculture is often equated with mechanization, as if one does not exist without other.

Induced Innovation and American Agriculture

The induced innovation hypothesis represents one of the most prominent models employed to explain technological change in American agriculture. The hypothesis, which is essentially a long-run version of the factor-substitution argument, treats the evolution of technology and institutions as endogenous responses to the forces of factor supply and product demand. In terms of its simplicity, intuitive appeal, and number of adherents, it has no close competitor. Hayami and Ruttan's book, *Agricultural Development: An International Perspective*, is the flagship of a large literature that develops, refines, and tests the induced innovation model in various national settings. The model suggests that rational farmers should have invested in saving labor because, according to the model's strongest advocates, labor was the scarce factor of production, and it was becoming

[12] McClelland, *Sowing Modernity*.
[13] Atack, Bateman, and Parker, "Farm, the Farmer, and the Market," 263.
[14] For examples, see Walton and Rockoff, *History of the American Economy*, 334; Ratner, Soltow, and Sylla, *Evolution of the American Economy*, 264–5; Atack and Passell, *New Economic View*, 280–2; and Hughes, *American Economic History*, 275–6.
[15] Rasmussen, "Impact of Technological Change," 578–91; Loomis and Barton, "Productivity of Agriculture," 6–8.

scarcer over the nineteenth century. As an example of this reasoning, "the evolution of the mechanical equipment is designed to bring about larger output per worker by increasing the land area that can be operated per worker. Furthermore, it seems apparent that the production functions which described the individual grain-harvesting technologies, from the sickle to the combine, were induced by changes in relative factor costs, reflecting the rising resource scarcity of labor relative to other inputs."[16] The model's advocates claim that the history of American agriculture conforms nicely to the model's predictions – there was a well-ordered design as farmers single-mindedly innovated to save labor. It is time to take a closer look at the induced innovation hypothesis and examine more closely the data that define the broad sweep of America's agricultural development.

The agricultural history of the United States plays a pivotal role in Hayami and Ruttan's analysis by providing a prime testing ground for the model. In their view this history, at least until about 1940, is the example *par excellence* of a high-wage economy focusing its inventive energies to save labor. A useful entry point into their analysis is the decomposition of changes in output per unit of labor into changes in output per unit of land and changes in land available per unit of labor. These two forces are viewed as "relatively independent" and are associated with two alternative development paths – one is typified by the U.S. experience, in which progress in mechanical technology "facilitated the substitution of other sources of power for human labor," and the other is typified by the Japanese experience, in which progress in biological technology increased the productivity of land. In the United States the dominant trend has been the rising land-to-labor ratio associated with the mechanical path of development.[17] Biological innovation became significant only in the 1930s when, according to Hayami and Ruttan, an increasing scarcity of land and a rapid decline in commercial fertilizer prices made such innovations profitable. This general story has been widely reproduced.

Hayami and Ruttan claim impressive empirical support for the induced innovation hypothesis, noting that it has been tested successfully against the historical records of the United States, Japan, Taiwan, Korea, the Philippines, Denmark, France, Germany, and Great Britain. On the basis of these tests, they argue that their "model provides powerful insight into

[16] Hayami and Ruttan, *Agricultural Development*, 79.
[17] Ibid., 171.

the development process in both developed and developing countries."[18] However, their brief history of the "dynamic sequences" of the evolution of key agricultural inventions rests entirely on technological change in wheat production, focusing chiefly on the diffusion of the mechanical reaper. But the wheat sector was not representative of the larger agricultural economy: between 1880 and 1930 the land-to-labor ratio in the major wheat-growing regions increased 115 percent, while over the same period the increase for the rest of the nation was only 11 percent – less than the increase in Japan. In the Pacific states the ratio actually fell. (Chapter 8 will explain why the change in the land-to-labor ratio in this progressive and highly mechanized agricultural region fell.) Thus, for the period before 1930, the key generalization about the entire country is evident only in the interior, wheat-growing states.[19]

At the very core of the test of the induced innovation story in the United States is the repeated assertion that, over the course of the nineteenth century, the price of land fell relative to the wage rate, thereby inducing laborsaving mechanization. This assertion about relative price movements has been repeated so often that it has become one of the key stylized facts of American history. Scrap one more stylized fact because, throughout most of the nineteenth century, the price of land relative to wages was *rising*, not falling. The changes were dramatic. Between 1790 and 1850 the number of days of farm labor required to purchase an acre of agricultural land more than doubled.[20] After 1850 the data become more abundant, and we can provide an index of the key relative price ratios for a 130-year period. Table 1.1 shows that the price of land relative to the wage ratio roughly tripled from 1850 to 1910. This means that real agricultural wages expressed in terms of land fell to about one-sixth of their 1790 level. Thus, the long-run relative land and labor prices were inexorably moving in the wrong direction to explain mechanization in the crucial period before 1910.

Table 1.1 also shows that the price movements after 1910 fail to support the assertion that an increasing relative scarcity of arable land and

[18] Ibid., 92.

[19] Olmstead and Rhode, "Induced Innovation (1993)," 100–18, and "Induced Innovation (1998)," 103–19.

[20] Christensen, "Land Abundance," 313; Lindert, "Long-Run Trends." Rental rates are a better measure of land scarcity than land prices, and rental rates did not rise nearly as fast as the price of land. Better accounting for this and other issues improves the performance of the induced innovation model in tracking American agricultural performance. Olmstead and Rhode, "Induced Innovation (1998)," 103–19.

TABLE 1.1. *Long-Run Trends in Factor Price Ratios in U.S. Agriculture*

1910 = 100	Land Value/ Wage Rate	Wage Rate/ Machinery Price	Land Value/ Fertilizer Price
1850	34	38	
1860	41	54	
1870	63	30	
1880	64	54	24
1890	71	70	40
1900	64	79	47
1910	100	100	100
1920	73	154	93
1930	69	128	110
1940	58	104	79
1950	43	164	123
1960	56	183	289
1970	56	210	583
1980	99	185	812

Source: Olmstead and Rhode, "Induced Innovation (1993)," 105.

the falling price of fertilizer over the previous decades induced the biological innovations of the 1930s.[21] In actuality the price of land relative to farm wages was falling between 1910 and 1950. Thus, not only were farm wages (relative to land values) falling in the early period when, according to the model, they should have been rising, in the later period they were rising when they should have been falling. The table further shows that the actual trend in the relative price of fertilizer was almost always moving in the wrong direction to support the induced innovation interpretation of American agricultural history. The upshot is that the biological revolution of the post–hybrid corn era simply could not have begun at a worse time for the adherents of the hypothesis that changing relative scarcity induced innovation. More generally, over the entire span for which we have data, the two key relative price series that represent the empirical foundation for the induced innovation model were almost always moving in the wrong direction. If one adheres strictly to the model's predictions, nineteenth- and early twentieth-century American farmers should have invested significantly in biological, land-augmenting technologies. The historical record actually supports this prediction.

[21] Hayami and Ruttan, *Agricultural Development*, 174, 177–8, 192–3.

The induced innovation model emphasizes the role of demand in determining the pace and pattern of invention and innovation, but there are also supply-side forces at work. Many argue that biological innovations were conceptually more difficult than mechanical changes and so the former had to await fundamental advances in basic science.[22] This critique applies to the modern genetic revolution, but the term *biological innovation*, when applied to other countries, such as Japan, simply refers to nonmechanical innovations – new plant varieties, fertilizers, pesticides, irrigation or drainage systems, improved cultural practices, and the like. This is also our meaning of "biological innovation." Such innovations did not require a high level of sophistication – although for their day many innovations represented significant scientific advances. It makes no more sense to assert that plant and animal scientists and farmers could not innovate because they did not understand how to splice genes than it is to question the achievements of the machinists who created industrial technologies because they knew nothing of theoretical mechanics.

Most scholars who emphasized the historic role of mechanization were impressed by crop yield data. In the United States, national average yields per harvested acre of most crops increased little, if at all, over the broad span of the nineteenth and early twentieth centuries. Yields typically shot upward sometime between 1930 and 1950, depending on the crop. But this does not imply that there were few biological innovations before 1940, nor does it warrant classifying this earlier period as primarily an era of mechanical change. Figure 1.1 offers evidence on the growth in the productivity of land and labor. Between 1910 and 1940, crude indicators show that output per unit of land grew at a rate of about 0.94 percent per year. Between 1940 and 1980, output per unit of land grew by 1.95 percent a year, more than double the previous rate. But a look at the change in the growth of labor productivity shows a striking result. Between 1910 and 1940, labor productivity in agriculture grew at a rate of 1.4 percent per year, but between 1940 and 1980 it grew at a rate of 5.5 percent per year, or more than three and one-half times as fast. Both land and labor productivity growth rates soared in the post–World War II era, but to dub this period the era of biological change is clearly misleading. It is important to emphasize that measures such as changes in output per acre might offer a crude index of the growth in land productivity, but they reveal nothing about biological innovation. Let's see why.

[22] Cochrane, *Development of American Agriculture*, 201–2.