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Grand missions of agricultural innovation

Brian D. Wright*,[1]

Department of Agricultural and Resource Economics, University of California, 207 Giannini Hall, MC 3310, Berkeley, CA 94720-3310, United States

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ABSTRACT

This paper discusses three related examples of mission-oriented agricultural institutional innovations associated with substantial crop yield increases in the 20th century. It begins with the implementation of the United States Land-Grant System and then discusses in turn the planning and implementation of the two grand missions that led successively to the yield increases in wheat and rice that heralded the onset of the "Green Revolution." It notes the remarkable role of the Rockefeller Foundation in identifying these two missions, and selecting personnel developed within the land-grant system to execute them with remarkable effectiveness.

> Whosoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together.
> Jonathan Swift, Gulliver's Travels

1. Introduction

The past century and a half have seen a high rate of increase in food demand induced by historically high rates of growth of both population and personal incomes. The percentage of that population working on farms has plummeted, while recruitment of new cropland has been relatively modest (Pardey and Beintema, 2001). The increased share of animal products in human diets has increased the plant calories needed as feed to support a given supply of food calories per capita. Yet the world's current population is both far larger and much better fed (Fogel, 2004).

How was this achieved? Machines have substituted for human labor. Off-farm inputs, including chemical fertilizers that have replaced on-farm nutrient recycling and fossil fuels, have replaced the original agricultural biofuels used as feed for animal draught power. But the major driver of the transformation of agriculture has been increased productivity of the handful of crop species that supply most of the caloric needs of the global population. This was made possible by innovations that public and nonprofit institutions have achieved in organizing and executing agricultural innovation.

The organization of agricultural innovation reflects the fact that, relative to other sectors, agricultural production of plants and animals is much more geographically dispersed and adapted to the local environment. The fundamental influence of the spatial heterogeneity of relevant features of the growth environment is especially important for plants. It means that research and development programs for the crops that supply most of the caloric needs of mankind cannot be centralized. Adaptive research is often needed to apply general agricultural advances in a given region, and continual applied innovation is often necessary to maintain existing local production capacity in a never-ending battle with pests and diseases.

Agricultural innovations with more widespread potential applicability will, *ceteris paribus*, tend to generate more social surplus. Since such generally applicable innovations usually require local adaptation, full development and diffusion might take years, if not decades. Source-region producers might gain from adopting innovations more quickly than their competitors, before prices are much affected. But most of the benefits from agricultural innovations shift to consumers as the innovations diffuse and make agricultural products more affordable and available. At best, producers tend to receive a minor share of the eventual benefits.[2] Not surprisingly, the national consensus needed to fund large innovative advances that will lower the price of food has rarely been observed. Until the

* Tel.: +1 510 642 9213.
E-mail address: bwright@berkeley.edu
[1] Member of the Giannini Foundation.

[2] If these innovations can be monopolized via patents or by other means, including hybridization, much of this surplus can be collected as rents. Hence, it has long been possible for the private sector to dominate the breeding of hybrid corn seed and many hybrid horticultural varieties.

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19th century, the rate of yield increase was very slow, and hunger was commonplace worldwide.

One area in which national innovative efforts that benefit agriculture have a long tradition is the introduction of new plants and animals from other countries. Since the dawn of recorded history, leaders have sent expeditions to acquire plant genetic material appropriate for given production environments or for meeting particular consumer needs. For example, in 1495 B.C., Queen Hatshepsut of Egypt sent an expedition to Ethiopia to collect frankincense or myrrh trees.[3]

At the onset of the industrial revolution, achievement of increased agricultural productivity, globally and nationally, was considered a noble goal, as the opening quote from Swift implies. Heightened recognition of the economic value of plants, and the need for their scientific documentation and classification, encouraged the spread of botanic gardens across Europe in the 18th and 19th centuries. In particular, Britain's Royal Botanic Gardens at Kew excelled in the acquisition, development, and dissemination of economically important plants (Juma, 1989). Experimentation with domestic plants by a London physician with boyhood experience of plant collecting in Jamaica led to his invention in 1829 of the Wardian Case, or terrarium, an enclosed glass container. This vastly increased the efficiency of international transportation of live plants between the new and old worlds (Schoenermarck, 1974). For example, use of the Wardian case reduced losses of plants shipped from China to England from 99.9% to 14%. Sir William Hooker of Kew Gardens imported six times as many plants in 15 years, using the case, as had been introduced to the Gardens in the previous century (Juma, 1989, p. 47). But significant increases in the growth of yields of major staple food crops did not occur until the 20th century.

In this paper, I discuss three related examples of mission-oriented agricultural institutional innovations associated with substantial yield increases in the 20th century. Section 2 discusses the implementation of the United States Land-Grant System as an institutional innovation that was the culmination of a grand mission. Then, in Sections 3 and 4, I discuss the planning and implementation of the two grand missions that led successively to the yield increases in wheat and rice that heralded the onset of the "Green Revolution." Human capital developed in the land-grant system at a time when it helped tilt the trends in United States crop yields sharply upwards and was crucial to the success of these later missions. They in turn provided the lead models that were followed by the larger group of centers that today constitute the Consultative Group on International Agricultural Research (CGIAR). In Section 5, I consider the relation in these grand missions between underlying motives, the choice of mission, and the technological solution. A brief conclusion follows.

2. The development of the U.S. land-grant system

From the beginning, U.S. political leaders, including George Washington, Benjamin Franklin, and Thomas Jefferson, understood the benefits of acquiring diverse plant and animal resources and endeavored to introduce improved plant varieties into the country. Echoing Swift, Jefferson wrote, "The greatest service which can be rendered any country is to add a useful plant to its culture" (1904–1905). He backed up his words with action, going so far as to smuggle rice from the Piedmont region of Italy into the United States, sewn into the lining of his coat pockets, even though such a crime was punishable by death (Fowler, 1994).

Henry Ellsworth, the first commissioner of the Patent Office, shared Jefferson's enthusiasm for the acquisition and distribution of novel plant varieties. In search of varieties that might be useful to farmers, Ellsworth distributed seed and plant material acquired from other lands. The U.S. Patent Office thus became the main repository for plant genetic material in the country, while the U.S. Navy imported foreign seed and the U.S. Post Office disseminated those seeds through the mail. Ellsworth produced a number of documents on proven and potential economic benefits of plant resources, and championed federal support for agriculture and the creation of an independent national agricultural research bureau. Since farmers have shared their seeds and their local innovations with neighbors from time immemorial, it is natural that the largely agrarian nation would support pubic distribution of new breeding materials. In 1839, Congress began formally to support seed collection, distribution, and research efforts by establishing the Agricultural Division of the Patent Office, which became the United States Department of Agriculture (USDA) in 1862 (Harding, 1940; Huffman and Evenson, 2006). By its very genesis, the USDA was identified with the encouragement of innovative activity and with the implicit recognition that private-sector investment alone would not suffice to achieve optimal innovation in the agricultural sector.

Also in 1862, in the foundational 1862 Morrill (Land-Grant Colleges) Act (7 U.S.C. § 301 et seq.), the government signaled that it recognized the benefits of technical education in a democratic system—especially one that suddenly lacked many states with large slave-labor agricultural systems. The adoption of the Act also confirmed the dominance of farmers in the geographically dispersed U.S. electorate. Named for Congressman and later Senator James Morrill of Vermont, the Act allotted 30,000 acres of federal land to each state to support the development of a college to teach agriculture, military tactics (reflecting the exigencies of the Civil War), and the mechanic arts, as well as classical studies, so that members of the working classes could obtain a liberal, practical education (7 U.S.C. § 304).

Like most great innovations, the Act originated in the mission of one man. Jonathan Baldwin Turner from Worcester, Massachusetts, a Yale-educated Congregational minister, moved to Illinois in 1833 to teach "rhetoric and belles-lettres" at Illinois College, an aspirational "Yale of the West." He was also a farmer who experimented in horticulture and is credited with identifying the Osage orange, a native of Arkansas, as the best hedge plant to choose for prairie fencing.[4] In 1848, after leaving Illinois College, he displayed visionary rhetorical creativity in suggesting to John Blanchard, President of Knox College, that the college should create a professorship in the "green Earth" (with vaguely specified responsibilities).

In 1851, Turner presented an address at Granville Illinois. His "Plan for an Industrial University in the State of Illinois" focused on the need to educate farmers and mechanics "in the science and art of their several pursuits" (Brown, 1962, p. 376). In the following year, in a letter to the *Prairie Farmer*,[5] Turner urged that "if farmers and their friends will now exert themselves they can speedily secure for this State, and for each State in the Union, an appropriation of public lands adequate to create and endow in the most liberal manner, a general system of proper Industrial Education . . .." (Turner, 1852).

Turner's proposal,[6] including the land-grant idea, was circulated in Illinois and beyond as the "Granville Plan." In June 1852,

[3] Juma (1989) gives several other examples of early plant-collecting expeditions.

[4] The account here on Turner's role in the mission to establish a national land-grant educational system relies principally on Brown (1962).

[5] *Prairie Farmer*, XII (March, 1852), 114.

[6] The Turner initiative was innovative in combining familiar elements in a new application. The idea of practical tertiary education was embodied in the private Rensselaer Polytechnic Institute founded in 1824, and the use of land-grants to support education had been implemented by the Congress of Federation, which in

the plan was presented by Turner's ex-student, Illinois delegate Richard Yates, to a meeting of the United States Agricultural Society in Washington D.C., which Justin Morrill attended as a Vermont delegate. In 1853, the plan won the support of the Illinois General Assembly, and Horace Greeley supported it in his *New York Tribune*[7] as responding to the demands for practical education expressed by farmers and industrialists. The Illinois resolution was presented in the House and Senate of the U.S. Congress in 1854. Morrill tirelessly advocated an essentially similar plan as his own. Originally blocked by Southern states—perhaps because many Southerners associated its advocates with the abolitionist cause, or perhaps they did not believe in spending public funds on educating their labor force, slave or free—the Morrill Act was passed in the window of opportunity that opened after the South seceded.[8]

Research was added to the educational mission of the federal-state land-grant system by federal support for State Agricultural Experiment Stations (SAESs) via the1887 Hatch Act (7 U.S.C. § 361a et seq.). This Act provided additional federal lands to conduct and disseminate research in the SAESs associated with land-grant colleges. The second Morrill Act (1890) (7 U.S.C. §322 et seq.) ensured that the much-needed regular funding of the colleges would rise to $25,000 per year, and that African Americans could receive education in the established colleges or new colleges designed for that purpose. Recognizing that technology-transfer mechanisms helped diffuse the potential benefits of research, the 1914 Smith–Lever Act established the Cooperative Extension Service to distribute knowledge for the local adoption and application of innovations.

Thus, it took six decades to enact the suite of legislation necessary for the full functioning of the land-grant system as the engine of U.S. agricultural innovation. Together, the acts balanced federal and state interests by combining federal financial support with state management of the administration and direction of research. The acts constituted a system for practical education of the common people in technology and a way to address local research needs while also exploiting interstate competition to motivate fruitful research. As early as 1888, states began to establish substations that addressed needs distributed at even finer geographic scales (Huffman and Evenson, 2006; Ruttan, 1982). But it was not until the third decade of the 20th century that the full potential of the system became apparent.

Before the establishment of the SAES system in the United States, European institutional innovation had firmly established the central role of experimentation, universities, and scientists in agricultural development. Rothamsted Agricultural Experiment Station in England, currently the oldest continuously operating agricultural experiment station, was founded in 1843 by John Lawes, a fertilizer manufacturer who had received a patent on an important fertilizer, superphosphate, the previous year (Huffman and Evenson, 2006; Finlay, 1988). Like his transatlantic contemporary, Patent Commissioner Ellsworth, Lawes apparently recognized that private markets, on their own, would not maximize the prospective national benefits to be had from the application of modern science to agricultural production.

Around the same time, Justus von Liebig, a German chemist who founded the first modern chemistry laboratory and identified the role of nitrogen as a fertilizer, established himself as one of the forefathers of agricultural science with his 1840 publication, *Organic Chemistry in Its Relation to Agriculture and Physiology* (Brock, 1997). Agricultural research institutions that were arising in the states that eventually formed Germany began to demonstrate the potential power of a group of experts working on a focused field. They highlighted the importance of consistent funding and provided valuable experience navigating the link between science and practice. They also demonstrated the merits of inter-institutional, inter-regional competition. In the year of Liebig's death, 1873, the newly united Germany had 25 agricultural research stations. The German development of successful university-based agricultural chemistry research laboratories and experiment stations became the model followed throughout the United States and continental Europe, where numerous agricultural experiment stations were established during the second half of the 19th century.

Samuel W. Johnson, the first director of a U.S. agricultural experiment station, was trained by a founder of the German system. The first U.S. stations continued the heavy emphasis on agricultural chemistry established in Germany, and by the time the Hatch Act was passed, 15 primarily state-funded experiment stations were already in operation.

Evenson (1980) found that during 1870–1925, agricultural productivity was strongly correlated with total real public agricultural research spending over the preceding 18 years. Early advances in U.S. agriculture were largely borrowed from innovations in Europe. Only after several decades of development and learning did the U.S. land-grant/SAES system acquire the scientific capacity and research base necessary to become an efficient system of innovation (Huffman and Evenson, 2006).

The well-known story of the development and introduction of hybrid corn illustrates the merits of regionally focused agricultural research that benefited both local farmers and consumers generally. This innovation originated as a by-product of basic research in corn genetics beginning in the late 19th century at Michigan State University. Decades of adaptive research followed. The location at the Connecticut Agricultural Station of a key innovation, the production of double-crossed hybrids, probably owed more to the proximity of Yale University than to the agricultural needs of the state. Commercialization began in the heart of the Midwestern corn belt (Alston et al., 2010, pp. 263–264). It then spread across the states at a pace reflecting, among other factors, differences in potential profitability and in the timing of establishment of state adaptive research programs (Griliches, 1957).

In the diffusion of hybrid corn, private-sector seed breeders played an important role. The nature of the hybrids made it unprofitable for farmers to save their own seed. Thus protected against competition from their customers, a private corn-seed industry (prominently including Henry Wallace's Pioneer Hi-Bred Corporation) developed in the 1930s and soon began to displace experiment stations as producers of commercial maize seed. Much later, the private seed-corn industry was able to eliminate dependence on public parent varieties.

The early involvement of large private corporations in United States hybrid corn-seed breeding is, however, an anomaly. Farmers often discovered or introduced new field crop varieties and went on to make a business of selling seed.[9] In general, however, large-scale grading, improvement, and distribution of seed were dominated by the public sector until the closing years of the 20th century. Though private-sector innovations in farm machinery became important much earlier, Evenson long emphasized that until the end of the 19th century, all the crucial mechanical inventions in agriculture were the work of farmers and local blacksmiths, rather than of large machinery producers.[10] During the 20th century, private industry

the Northwest Ordinances of 1787 reserved one 36th of the land allocated to each western township for the maintenance of public schools within the township.

[7] *New York Tribune*, March 1, 1853.

[8] Turner later laid the foundation stone of the University Building at the University of Illinois on September 13, 1871 (Hildner, 1963, p. 67).

[9] Here we concentrate on food and feed crops. For a discussion of private breeding of cotton, and the challenges presented by informational problems and cross-fertilization, see Olmstead and Rhode (2003, 2008).

[10] Robert Evenson, personal communication.

became increasingly important in the development of off-farm inputs, including crop-protection chemicals, and in food processing and marketing.

Upward trends in yields of other field crops, including wheat, also began after 1930, though their research programs remained concentrated in the public sector. For example, U.S. wheat yields increased only 1.75 bushel per acre between 1866 and 1939 (Olmstead and Rhode, 2002, pp. 931–932), but by the late 1930s, average yield began to increase at around 2.25% per year, doubling over the next four decades.

Observing the constancy of yields prior to the trend breaks in the 1930s, prominent agricultural economists such as Cochrane (1979), Johnson (1997), and Hayami and Ruttan (1971) inferred that, in contrast to mechanical innovation, the biological sciences contributed little of significance to advances in crop production before that date. But Olmstead and Rhode provide convincing evidence that, beginning far earlier, the land-grant system continually furnished crucial contributions to wheat production, in the form of regional adaptive research of the kind for which the system was designed. As the center of gravity of wheat production marched westward to less-favorable environments, wheat breeders in the land-grant system identified and selected varieties that could tolerate drought, cold, insect pests, rusts, and other fungal diseases in their regions. Similar adaptive research was conducted in the public sector in Australia and Canada. Without the biological research contributions of these public institutions, the new production regions that became so important in the 19th century would otherwise have had much lower yields, or even not been planted at all.

In 1919, more than three-quarters of wheat acreage in the United States was planted with varieties that had been unavailable when the Morrill Act was passed. Scientists also developed strategies to combat pests and weeds that included early implementations of integrated pest management. Varietal turnover was rapid in the race to keep ahead in the battle with pests and diseases. The system of spatially and politically decentralized research stations vastly augmented the effective supply of grain land and the level of agricultural labor productivity well before national yields began to rise as the land base stabilized. Olmstead and Rhode (2011) argue that locally adaptive research institutions' ability to respond to changes in climate encountered as wheat acreage expanded westward indicates how similarly valuable decentralized research institutions could now be in helping the world adjust to climate change.

Unlike hybrid corn, wheat was a self-pollinated plant that the farmer could replant for several years and sell extra seed to others. Given this competitive threat from potential customers, wheat breeding was privately unprofitable, and thus necessarily located mainly in the public sector. Similarly, the onus is on the public sector, foundations, or non-governmental organizations to produce basic science and undertake research that may be high-risk, have long lag times, or create unpredictable and non-excludable benefits, which often accrue mainly to consumers (Alston et al., 1998; Huffman and Evenson, 2006; Just and Huffman, 1992; Stokes, 1997).

High marginal rates of return to public investments in different types of agricultural technologies persist, implying that those investments have generally made productive use of public funds, but also that the level of funding has been inadequate (Huffman and Evenson, 2006; Judd et al., 1986). Alston et al. (2010) (Tables 11–15, p. 369) report the overall marginal social rate of return to USDA intramural research to be 22.7% per annum, averaged across state (with substantial intra-state variation). The social benefit–cost ratio, a measure the authors believe to be more meaningful, is 32.1, averaged across the measure for each state (Alston et al., 2010, Tables 11–14, p. 368).

Several empirical studies suggest that inter-regional externalities in the United States significantly affect state research investment levels (Guttman, 1978; Huffman and Miranowski, 1981; Rose-Ackerman and Evenson, 1985). Citing unpublished work, a masterly study by Alston (2002) reports that, averaging across U.S. states, over half the measured within-state productivity gains may be derived from the benefits of public research investments made elsewhere. Alston et al. (2010) show that the average marginal internal rate of return of public research accruing within the source state is 18.9%, and the within-state marginal benefit–cost ratio is 21.0. While both are relatively high, they are substantially lower than the overall internal rate of return and cost–benefit ratio for the nation as a whole (22.7% and 32.1, respectively), indicating that spillovers are non-negligible. Such spillovers, both within and among nations, lead to underinvestment in research, which is countered by federal subsidies in the U.S. land-grant system.

The figures quoted above overstate the benefit to state producers and landholders, because they do not distinguish the price-reducing effects of innovation, which favors consumers at the expense of producers. Nationally or globally, consumers are the main beneficiaries of agricultural research, since low price elasticity of demand for agricultural products means that higher productivity achieved by freely accessible innovation will translate into lower prices (Guttman, 1978). However, in a world of highly efficient global transportation, the relatively small share of benefits from lower prices that accrues to consumers in a single state tends to limit within-state consumer support for agricultural research that primarily increases national or global productivity (Rose-Ackerman and Evenson, 1985).

For any region-specific, production-oriented research project focused on locally specific problems, the negative price response on international markets might be difficult to perceive, relative to not carrying out this research in the state in question. Local farmers tend to capture a substantial share of the differential benefits of this type of research, given the level of other research activity in the rest of the nation. Political support tends to be high for region-specific innovation, suggesting that farmers recognize the benefits of this type of research spending, whether basic or applied. But it is natural to expect farmers to reduce their support for local production research if they can free-ride on spillovers from research investments of other states. Further, they will be reluctant to invest in innovations that mainly benefit consumers elsewhere.[11]

Empirical studies support the above conjectures. U.S. state spending on agricultural research significantly and positively correlates with state characteristics such as per capita income, the share of rural population, the number of large farms, the political influence of farmers, and the number of firms producing agricultural inputs. In contrast, spending is negatively influenced by the ability to adopt technology produced in other states (Guttman, 1978; Huffman and Miranowski, 1981; Rose-Ackerman and Evenson, 1985). But the U.S. federal government helps compensate for the externality by supplementing and offering matches for agricultural research activities performed by the states. It also conducts federal intramural research and collects and publishes useful information as a complement to state activities.[12]

[11] Indeed, they have effectively constrained nonprofits from pursuing research directed at grain producers in exporting nations (such as Argentina) as being contrary to the national interest.

[12] Since crop yields began to increase in the 1930s, further protection against the price-depressing effects of innovation has been provided by programs initiated in the New Deal of the Roosevelt Administration, first via supply restrictions, later by direct payments to farmers, independent of current prices, and recently by diversion of grain and oilseeds to production of bioethanol and biodiesel, respectively.

Thus, the United States as a whole obtains the benefits of research decentralization, while federal financial support and research activities should ameliorate the tendency of states to under-invest in generally useful technologies and projects that benefit consumers nationwide. Historically, much federal support has been awarded in the form of sustained grants that encourage the kind of multi-year commitment that is often needed to develop new agricultural technologies. Unfortunately, political pressures increasingly encourage the shorter-term, more applied projects that can promise “predictable benefits” to key constituencies (Huffman and Just, 2010).

In many cases, national producers command a small share of the world market but have idiosyncratic production challenges requiring research. The minimal price effects of the latter, given open markets, means that producers (for example, Australian grain farmers) can be willing to tax themselves with an output levy to match public funding of research that meets their needs, or to fully fund that research (Alston and Pardey, 1996).

The next section presents two outstanding examples of grand missions in which the proximate objectives were consistent with the humanitarian goal expressed in the quote from *Gulliver’s Travels*. The planning and execution of these missions exploited skills and knowledge acquired by scientists and administrators within the U.S. land-grant system who had participated in sustained research programs that led to dramatic yield increases in wheat and maize between 1930 and the 1950s.

3. Mission-oriented institutional innovation: wheat in Mexico

The story of the improvements in wheat and maize that were later described as the “Green Revolution” began in a world with concerns and opportunities very different from those of the United States. In 1940, after presidential elections in the United States and Mexico, President Franklin D. Roosevelt asked Vice President-Elect Henry Wallace to represent the United States at the inauguration of the newly elected President of Mexico, Manuel Avila Camacho. Before Roosevelt’s inauguration, Wallace drove to Mexico City with his wife. An Iowa farm boy who had founded the Pioneer Hi-Bred Seed Company and served as United States Secretary of Agriculture, Wallace naturally took a keen interest in assessing what he could see of Mexican agriculture along the way.[13]

During his month-long stay, at the invitation of Agriculture Secretary-designate Marte R. Gomez, he traveled around rural regions and discussed problems with Department of Agriculture personnel. He learned that Mexican agriculture was in trouble, yields were low, and the people were hungry. He shared his concerns with Ambassador Josephus Daniels, a Southerner who had seen the positive effects of Rockefeller-supported technical assistance programs in a South still devastated by the Civil War. Since 1919, the Rockefeller Foundation had cooperated in a Mexican public-health program to combat infectious diseases, and its International Health Division had noted the need for improved agricultural production to provide better nutrition to the Mexican population in order to complement its efforts in health. Secretary Gomez told Wallace that the incoming Mexican government was interested in strengthening agricultural research and training the scientists needed to improve agricultural productivity.

Returning to Washington, however, Wallace found that a federally funded Mexican agricultural program was politically unfeasible. Government funds were committed to national defense. Where else to turn? In 1941 there was no FAO, no USAID, no Marshall Plan to copy, and no World Bank. The paucity of alternatives makes it less surprising that Wallace turned to the Rockefeller Foundation for help in raising corn, wheat, and bean yields in Mexico, even though the foundation was not experienced in conducting agricultural research. When he met with foundation President Raymond B. Fosdick and Dr. John D. Ferrell of the foundation’s International Health Division on February 3, 1941, the timing was propitious. The foundation had extended its reach to China by establishing the Peking Union Medical College, the “Johns Hopkins of China,” in 1921, and by contracting with Cornell University for agricultural research and extension services beginning in 1924. But these initiatives had been halted by the onset of war, so the foundation was willing to consider new alternatives.

Fosdick’s response constitutes an impressive example of the Rockefeller Foundation’s expertise in mission-oriented research direction. On the advice of Warren Weaver, Director of the Division of Natural Sciences, Fosdick decided to send an investigatory team of experts to Mexico to assess the situation. In a general staff meeting only 15 days later, Fosdick announced the appointment of a committee comprised of Dr. F.B. Hanson and Dr. H.M. Miller, Jr. of the Division of Natural Sciences, and Dr. A.R. Mann, Vice President of the General Education Board. The latter, ex-dean of Agriculture at Cornell, a land-grant institution, observed: “Experience has shown that the greatest practical contributions to agriculture come through the fields of genetics and plant breeding, plant protection, soil science, livestock management and general farm management” (Stakman et al., 1967, p. 22). The committee, accordingly, decided to select three experts (two from land-grant institutions) with vast experience in the first three fields: Dr. P.C. Mangelsdorf of Harvard, Dr. E.C. Stakman of the University of Minnesota, and Dr. R. Bradfield of Cornell. They constituted a Survey Commission, which would visit Mexico starting on July 7, 1940 with the mandate: “Go to Mexico and find out whether you think the foundation could make a substantial contribution to the improvement of agriculture, and if so, how?” (Stakman et al., 1967, pp. 24–25).

After meeting with the Secretary of Agriculture and related officials, and visiting by automobile 16 of 35 Mexican states, the three investigators returned to report that the key problems, in approximate order of importance, were improvement of soil management and tillage practices, provision of better-adapted, higher-yielding, higher-quality crop varieties, more rational and effective control of plant diseases and insect pests, and provision of better breeds of animals, better feeding methods, and animal-disease control (Stakman et al., 1967, p. 33). They recommended that the foundation send to Mexico an agronomist and soils expert, a plant breeder, a crop-protection expert, and an expert in animal husbandry. (Note that these conclusions aligned with the opinion of A.R. Mann and the priorities implicit in the composition of the Survey Committee.). They further recommended a “top–down” approach: research first, then education, then extension of the research results.

In 1942, following the recommendations of the Survey Committee, the foundation created the Mexican Agricultural Program, identifying Dr. J.G. Harrar as Project Leader. Farrar was able to leave his position as head of the Department of Plant Pathology of Washington State College, Pullman (another land-grant institution) and came to Mexico by 1943. In that year, Mexican Secretary of Agriculture Gomez and the Rockefeller Foundation agreed to form an Office of Special Studies (OSS), an independent unit within the Ministry of Agriculture to cooperate in: (1) varietal and cultural improvement of corn, wheat, and beans; (2) soil improvement; (3) plant introduction and testing, and (4) animal husbandry. In 1943, the Mexican government created the Office of Special Studies and put Harrar in charge.

Over the next few years, after intensive searches directed by the foundation, new scientists were hired: Dr. E.J. Wellhausen, a corn

[13] The material in this and the immediately following paragraphs relies heavily on Stakman et al. (1967), Chapter 2, on Borlaug’s biographical interview (Wessels Living History Farm n.d.), and on Osler et al. (1978).

breeder, Dr. N.E. Borlaug, a plant pathologist, and Dr. William E. Colwell, a soils expert. (Wellhausen and Borlaug made careers in Mexico.) The choice of Harrar, a plant pathologist and student of Stakman (though he was not of farm background), as leader, made sense: Harrar was already established as a leader and educator and had spent 4 years as a professor of biology at the College of Agriculture in Puerto Rico. Note that there was no wheat breeder; Borlaug, who undertook this task, was a forest pathologist trained by Stakman. The foundation wisely adopted procedures developed over 40 years of experience in program management in other areas that helped identify appointees who would handle new challenges very effectively.

During the next 17 years, the Mexican program achieved substantial increases in yields of corn and beans, but its most dramatic achievement was in wheat breeding. The program also helped establish institutions to train a large cadre of Mexican scientists, many of whom started as workers in the program. By 1960, some of these scientists would replace their American mentors. Finally, the Rockefeller-funded program established a basis for an effective system of extension based on dispersed research trials.

This is not the place for a detailed study of the merits of the OSS, whose closure in 1960 is cryptically characterized by Stakman et al. (1967, p. 273) as "not lamented."[14] I focus instead on features of the wheat program, in particular, that are important for a study of mission-oriented research. Wheat-yield progress in Mexico was in one sense easier to achieve than for corn or beans, since the crop was largely restricted to irrigated land, where the environment was less heterogeneous and easier to manage. But wheat had been ravaged by stem rust during the early years of the program, and here, Borlaug's training by Stakman in plant pathology at the University of Minnesota proved invaluable. His team made one cross after another to fight off waves of rust infestations of different genetic backgrounds, each wave a threat to the latest "resistant" varieties.

Borlaug, who was not an experienced breeder at that time, took over the wheat program in 1945 from Harrar. He decided that, to keep breeding ahead of rust infestations, and to expose varieties under development to more infestation opportunities, the breeding cycle must be sped up from the traditional one-crop-per-year (Vietmeyer, 2009a,b, vol. 2, chap. 2). He identified an opportunity offered by land available in Sonora, in the Northwest, where a second winter crop could be planted, using seed recently harvested from the highlands near the experiment station not far from Mexico City. He proposed a system to produce two crops in sequence each year by shuttling seeds between the two sites.[15]

This plan flew in the face of established practice. Experts believed that to yield a good harvest, wheat seed needed a period of rest before being replanted. Further, a failed experiment in shuttle breeding was an expense the program could ill afford. Harrar, as head of the Office of Special Services, initially allowed Borlaug to go ahead, but with no increase in financial support, provided the foundation was not informed of the plan. In fact, Borlaug started without a vehicle or a tractor, cultivating by human labor he and a few Mexican workers could provide. After several seasons, foundation visitors sent back reports of the existence of the shuttle-breeding program. Since it was against precedent, and as yet had shown no real results, the reports were not positive. Eventually Harrar told Borlaug he was terminating the shuttle-breeding plan. Borlaug then declared that he would resign.

However, the foundation proved itself capable of preventing "over-direction" by the otherwise highly forceful and effective leader of this "top–down" program. Stakman, Borlaug's and Harrar's erstwhile mentor, happened to be visiting, and it was very likely his counsel that persuaded Harrar to reverse his decision. By 1948, two new varieties bred by the program were released via effective collaboration with private-sector farmers who helped produce and disseminate sufficient seed.

Borlaug was surprised to find that the new varieties were not only rust-resistant but also early maturing (CIMMYT, 1987, p. 8). Adaptability to environments differing in elevation, photoperiod, soil type, pest and weed load, and water availability proved essential to the later rapid international diffusion of the gains in wheat breeding made in Mexico. As a process innovation, shuttle breeding avoided the time and expense of developing and distributing the much larger number of varieties that would have been needed if each were suited to only a narrow set of conditions.

One of the under-educated young helpers Borlaug recruited to chase away birds, Reyes Vega, contributed another key process innovation. According to Borlaug, his assistant saved "man-years" of work by developing a new method of pollination far faster than the technique Borlaug was using (Vietmeyer, 2009a,b, vol. 2, pp. 126–127). Using these methods, the team was able to make thousands of crosses, twice each year. This ability appears to have been crucial to their ultimate success in developing rust resistance. It would also help them meet their next challenge.

After achieving progress against rust, Borlaug faced the problem of developing plants capable of taking advantage of innovations that reduced the price of nitrogen fertilizer.[16] In 1952 he searched for strong-strawed varieties by growing out many samples from the USDA World Wheat Collection, but without success. Later, a visiting USDA scientist, Burton Bayles, told him that Dr. Orville Vogel of Washington State University had successfully used a semi-dwarf variety, Norin 10, in crosses with American winter wheats. Norin 10 was a Japanese variety selected at Iwate Prefectural Agricultural Experiment Station, in Morioka, Japan, by Gonjiro Inazuka and identified in postwar Japan by a USDA scientist, S.C. Salmon. Noting their resistance to lodging and their excellent yields under heavy fertilization, he brought samples back to the United States (Reitz, 1968). Norin 10 was a semi-dwarf winter wheat with short-stature (only two feet high), stiff straw, and large seed-heads. It was the progeny of a cross made at the Ehime Prefectural Agricultural Experiment Station that used Turkey Red as mother and Fultz-Daruma as father.[17] Inazuka, who continued to work on breeding cold-resistance in progeny of the Turkey Red cross with Fultz-Daruma, identified a special dwarf type that was further developed and released as Norin 10 in 1935 for planting in Iwate and Yamagata Prefectures.

Borlaug obtained a handful of seeds of crosses of Norin 10 with Brevor, an American winter wheat, but the first year's planting was completely killed by rust. In the second year, some of the plants, raised indoors, survived. Years of shuttle breeding were spent introducing the semi-dwarf genes of Norin 10, later denoted (Hedden, 2010), into adapted Mexican spring wheats, thereby overcoming problems of rust susceptibility, male sterility, promiscuous out-crossing, and grain quality.

By 1960, the wheat program provided Mexican wheat producers with superior varieties with better rust resistance and much-improved yields. However, the project to produce acceptable semi-dwarfs had yet to show concrete results. The foundation informed Borlaug that he would need to find a new job within

[14] A critical review of the OSS is found in Jennings (1988). For very different Mexican perspective see Ortoll (2003).

[15] My colleague David Zilberman informs me that Borlaug told him that a Mexican bureaucrat suggested the idea of shuttle breeding.

[16] This paragraph follows Borlaug's account in CIMMYT (1987, pp. 10–11).

[17] See Inazuka (1971). Fultz-Daruma was a cross made at the Central Agricultural Research Station at Nishigahara, Tokyo, of Daruma with Glassy Fultz, a glassy derivative of Fultz. Turkey Red and Fultz were introductions from the United States. Daruma was a Japanese variety of uncertain origin (Kihara, 1983).

the organization or elsewhere; his days working on wheat were numbered.[18] Borlaug reports that he was happy to cede command to a Mexican colleague, Dr. Ignacio Narvaez (Stakman et al., 1967, p. 90 and 273; Borlaug, *Mexican Program*, in Wessels, n.d.). The next year, the Office of Special Studies was terminated, apparently with the blessing of the both the Mexican Secretary of Agriculture, Julián Rodríguez Adame, and the Rockefeller Foundation (Osler et al., 1978, p. 7). By then the OSS's 14 foreign employees were complemented by 100 Mexican staff, many with advanced training.[19] The OSS's responsibilities were handed over to the newly formed National Institute of Agricultural Research (INIA). In 1962, the wheat program released in Mexico two semi-dwarf varieties, Pitic 62 and Penjamo 62. Both had mediocre grain quality, but resisted lodging and produced world-class yields under irrigation with nitrogen fertilizer and good management.

Borlaug stayed on in Mexico for a time as Director of the Wheat Improvement Project of the Inter-American Food Crop Improvement Project, founded by the Rockefeller Foundation in 1959, which also included corn and potato programs. By then, wheat programs also existed in Columbia and Chile. Borlaug proposed to the Rockefeller Foundation that he work on heat tolerance in soybeans using genes from relatives from Indonesia. Harrar rejected this proposal as too risky. Borlaug looked elsewhere. He had already accepted a private-sector job working on banana breeding in Honduras, at twice his Mexican salary,[20] when he was sent by Rockefeller on a trip to 12 countries across North Africa, the Middle East, Pakistan, and India, organized by the United Nations Food and Agriculture Organization (FAO). Borlaug wrote a report in which he expressed optimism about the potential contribution of the Mexican wheats to breeders in these areas, but emphasized the lack of trained scientists and the need for practical orientation of those who are trained (Borlaug, *India and Pakistan*, in Wessels, n.d.). This report encouraged the FAO to support a new wheat research training program in Mexico, with Mexican government support, and Borlaug stayed on to work in the program.

In 1962, Mexican President Adolfo Lopez Mateos, on a visit to the newly inaugurated International Rice Research Institute (IRRI) in the Philippines, was "pleasantly surprised" to find that it was modeled on the recently terminated Mexican Office of Strategic Studies.[21] By that time, it was apparently becoming evident to the Rockefeller Foundation that collaborative regional research efforts of individual countries would not produce the global spillovers potentially available from a coordinated international crop-breeding center. After returning to Mexico, President Mateos proposed that his government and the foundation establish an international agricultural research center in Mexico to develop and diffuse new technology for maize and wheat production for other developing countries.

In 1963 the International Center for Maize and Wheat Improvement (CIMMYT) was inaugurated in an agreement signed by the Mexican Minister of Agriculture, Julian Rodriguez Adame, and George Harrar (who by then was president of the Rockefeller Foundation), with Mexican President Adolfo Lopez Mateos presiding. After a shaky start, CIMMYT would later become, with enhanced support and a new location near Mexico City, a member of the Consultative Group on International Agricultural Research (CGIAR) near Mexico City. Borlaug's work became part of the Center. In the same year, in 18 wheat nurseries testing a set of common varieties in Mexico and in a diverse set of 11 Near-Eastern nations, five Mexican wheats had the highest average yields.

Borlaug continued his mission when the Ford and Rockefeller foundations collaborated in arranging for him to visit Pakistan and India in 1963. In both countries, the negative effects of ill-directed research were apparent, but so was the struggle by a new generation to make the system more effective. In India, influential members of the Planning Commission opposed the new seeds as unsuited to India, delaying their introduction (Parayil, 1992, p. 90). Moreover, leading breeders opposed the adoption—and even the testing—of the foreign germ plasm. At one Pakistani research station, high-performing Mexican wheats (planted by junior scientists trained in Mexico with FAO funding) had to be hidden at the far end of an experiment station.[22]

However, a bad harvest forced a change of national attitudes. In India, the change was highlighted by the transfer of Chidambaram Subramaniam, who held the key Ministry of Steel and Mines, to Minister of Agriculture. Subramaniam immediately began to pursue needed institutional reforms. In 1964, Borlaug's former successor in Mexico, Ignacio Narvaez, was invited to Pakistan to help with the wheat program; this development testifies to the maturity of the Mexican wheat program he headed, as well as to a new willingness on the part of the Pakistani administration to accept help with yield-increasing technology. In 1965, 250 tons of Mexican seed wheat were sent to India. This wheat's generally superior performance in geographically dispersed Indian nursery yield trials in a second year of drought, 1965–1966, boosted farmers' demand for these wheats and led them to be used to breed better locally adapted crosses. The next year, India imported 18,000 tons of seed wheat from Mexico. Pakistan purchased 350 tons of seed in 1965–1966 and a huge 42,000 tons in 1967–1968 (Dalrymple, 1978, p. 16). India and Pakistan, despite the 1965 war between them in Kashmir, had the infrastructure to deliver these seeds and the necessary fertilizer effectively. Production recovered in 1967 (Herdt, 2012, p. 181). The next year, the new semi-dwarfs covered almost a third of the wheat land in India and a greater share in Pakistan, and their locally adapted progeny were soon to dominate wheat plantings in both nations. The ultimate influence of this Grand Mission was to transform the plant architecture and yield potential of wheat worldwide, thus making a historic contribution to world nutrition.[23]

4. Mission-oriented institutional innovation: rice at the International Rice Research Institute

By 1950, the Marshall Plan had become a widely recognized example of the mission-oriented, development-related research later epitomized by the Rockefeller Foundation's pioneering Mexican Agricultural Program. President Truman appointed Nelson Rockefeller to the International Development Advisory Board to expand the Marshall Plan and Truman's related Point Four technical assistance program and to recommend a new government agency to execute this expansion (see Anderson, 1991, p. 61). Rockefeller's report[24] identified underdevelopment as a key global problem, one that demanded that the United States widen "the boundaries of U.S. national interest." The report stated that the first objective should be to increase food production by 25% in underdeveloped areas. Extractive industries and manufactures would follow. The Rockefellers had a long history of interest in agricultural assistance, but Rockefeller also noted the U.S.'s national interest in helping

[18] Here I rely on Vietmeyer (2009b, Vol. 2, pp. 265–268.).

[19] At its maximum, the number of foreign staff working at the Office of Special Studies was only 18 (Osler et al., 1978).

[20] My sole source for the information about Borlaug's proposal and his acceptance of the Honduran position is Vietmeyer (2010, pp. 21–23).

[21] This paragraph relies on Osler et al. (1978, p. 8).

[22] Baum and Lejeune (1986, pp. 9–10); Vietmeyer (2010, Vol. 3, pp. 76–81).

[23] See Pardey et al. (1996) for an assessment of the benefits to the United States from semi-dwarf wheat technology originating at CIMMYT.

[24] Rockefeller (1951).

governments contain communist uprisings. Observing the high cost of military intervention, Rockefeller argued that agricultural aid presented an economically attractive option. Further, the market demand unleashed in developing economies as they converged on Western income levels would be very attractive to the West.

The communist challenge was evident to the United States and to nations of Asia as the Rockefeller Foundation turned its attention to that continent. In 1950, P.L. Mapa, Secretary of Agriculture and Natural Resources of the Philippines, wrote to John D. Rockefeller III, asking him to look into conditions in his country, noting the recent role of the foundation in "raising the standard of living of the masses" in Mexico through agricultural research and development. In 1951, the year when Nelson Rockefeller produced his report, the foundation renamed its Division of Natural Sciences the Division of Natural Sciences and Agriculture.

In a 1951 report to the trustees, entitled "The World Food Problem, Agriculture and the Rockefeller Foundation," an advisory committee identified the relation between hunger and the appeal of communism in the Philippines, and suggested that the United States had a special role to play there.

The foundation's trustees sent Harrar, Mangelsdorf, and Weaver to Asia in 1951.[25] In 1952, these three reported that two different types of activities made sense: those that attacked complex problems of ignorance and tradition, and those that provided solutions to "isolable" technical problems that were so important that they would surely be accepted and applied. Harrar, Mangelsdorf, and Weaver identified one agricultural problem in the latter class as most important: breeding "improved hybrid rice varieties." Despite good research on rice in Japan, and Indian research supported by the FAO, an opportunity existed for the Rockefeller Foundation. The three consultants recommended that the foundation send an expert plant breeder to study current rice breeding activities in "The Orient." Though it followed a logic similar to that of the orderly on-site investigation of Mexican possibilities in which Mangelsdorf had participated in 1943, their recommendation was not adopted.

Harrar and Weaver visited the area again in 1953 (Chandler, 1992, p. 3), at a time when Asian rice was becoming identified in U.S. policy circles as a national-security issue. John King, an economist who later joined the CIA, argued that a response was necessary to counter advances in agriculture made in communist China (King, 1953).[26] In December, the trustees authorized the renamed Natural Sciences and Agriculture Division to start a program on the basic problems of food. The next year, Weaver and Harrar (1954) submitted to the Board a remarkable report entitled "Research on Rice." Appealing to the interest of John D. Rockefeller III in population, they noted the possibility of imminent neo-Malthusian doom if population were not controlled. Unlike the Paddock brothers 15 years later (Paddock and Paddock, 1967), they viewed the threat as a call to action rather than a justification for callous neglect of the world's least advantaged. The grand mission they identified was a global increase in rice yields.

Their report was grounded in three simple observations:

(1) the most important food crop in the world was rice;
(2) rice was the subsistence crop for a large portion of Asia;
(3) little scientific information was available on the rice plant.

Noting the lack of scientific knowledge in Asia and the lack of research incentives, they identified a signal opportunity: "It is . . .high time that [a study of the factors affecting yields] be made for one (or more) of the great food plants of the world: and it is considered well within possibility that such a study would reveal yield potentialities not now viewed as possible" (Weaver and Harrar, 1954, p. 2). They speculated that yields could far outpace current maxima, moving closer to the putative photosynthetic limit. Even now, this soaring optimism is impressive, coming from seasoned scientist-administrators intimately familiar with the ongoing struggles with wheat and rice breeding in Mexico who were addressing a crop outside their own scientific expertise.

The fundamental physiological, biochemical, and genetic problems, they argued, were essentially independent of geography and political boundaries. They could be addressed from a single center, economizing on duplication of equipment and facilities and enhancing communication.

On the other hand, they noted, nation-states tend to focus on problems specific to their local environment that are more pressing, can be more quickly addressed, and can offer more concentrated benefits within their borders. Not surprisingly, Weaver and Harrar were reluctant to support an international center offering the benefits of global scientific progress beyond any individual nation's borders, and only after years of investment.

This problem, that spatially dispersed producers were unwilling to invest sufficiently in scientific and technical advances that were, in the language of economists, public-producer goods, would have been familiar to scientists who had worked in the land-grant system in the United States. There (as I noted earlier), the problem had been addressed by federal support of centralized research as well as subsidization of the state agricultural experiment stations. In the international arena, the opportunity was open to entities such as the Rockefeller Foundation to fund a centralized research effort to achieve sustained increases in international yields of rice.

Since the estimated cost of $5 million was too great, given the risks, to be borne by the foundation alone, Weaver and Harrar recommended, for the short term, improvement of existing institutions in Asia. The board, in response, allocated $1 million per year for the period 1955–1960. In the absence of a complementary funding source, there were no plans for a single rice research center.

To survey the agronomic issues and the research institutions, the Rockefeller Foundation chose Richard Bradfield, a Cornell agronomist. His task was reminiscent of his assignment as part of the Mexican Survey Committee in 1943, which set the broad agenda and chose the leaders for the Mexican Agriculture Project. On his travels, he made grants for books, fellowships, and projects at numerous agricultural colleges and experiment stations across Asia. (Robert Chandler Jr., who had accompanied Bradfield on much of his survey trip, continued this work.) Bradfield concluded that established institutions, such as existed in India, had a problem of research hierarchies, reluctance to go to the field, and insufficient zeal, observations that pointed to the advantages of a new institution.[27]

In India, the scientific base was far superior to what Harrar had encountered in Mexico in 1943. In particular, Weaver and Harrar identified India's Central Rice Research Institute in Cuttack as "the best rice research program, group, and facility in the world" (Anderson, 1991, p. 74). The U.S. Agency for International Development (USAID) had supported agricultural colleges modeled on the land-grant system, and the foundations had educated hundreds of scientists overseas. The vast majority had returned to India.

[25] See Anderson (1991), especially pp. 67–88. Details differ from the briefer account in Chandler (1992, pp. 1–4), upon which I also rely for related material.

[26] The foundation's persistent attention to the agricultural problem was not matched within the Philippine government, within which the enthusiasm for agricultural development expressed by Mapa in his 1950 letter had dissipated: "[T]here is even some sentiment against greatly increased agricultural production.̋(J. George Harrar, memorandum to file, September 1953 (RAC), as quoted in Anderson, 1991, p. 70.).

[27] Parayil (1992) gives general support to Bradfield's observation with respect to India.

However, the civil-service system and social attitudes apparently prevented scientists from effectively addressing obvious challenges. The Rockefeller Foundation was well aware of the problems. For example, in 1953, the Indian Secretary of Agriculture approached the foundation for help with a program of adaptive research designed to bring to India the benefits realized by hybrid maize in the United States. Why maize, which covered only 3% of Indian cropland? As recorded by Lele and Goldsmith (1989, pp. 313–314), the answers were hardly encouraging:

1. The Indian Agricultural Research Institute believed that Indian programs for the much more important crops, rice and wheat, needed no foreign help.
2. Some policy makers believed that failure in maize would have a smaller opportunity cost.
3. Due to lack of attention to maize, few Indians scientists would be threatened by new research approaches.

Contemplating this list, one can more easily understand why it might take a crisis to focus key players on a grand mission to increase food production.

In August 1958, Chandler and Harrar attended a meeting at the Ford Foundation to discuss cooperation in supporting an Indian agricultural college. Also in attendance was Forrest F. Hill, an agricultural economist who had been provost at Cornell, who was Ford's vice president for overseas development.

Ford's largest effort in India, led by Douglas Ensminger, a rural sociologist, provided financial support for an Indian community-development program that started in 1951. This was a bottom–up effort, based on self-help and adoption of existing improved technology, in contrast to the top–down, research-first approach of Rockefeller. The Ford program was motivated, as was Rockefeller's, by the concern that population would outrun food supplies and cause a humanitarian crisis. (For those insufficiently moved by humanitarian concerns, the expressed motivation could be extended to deterring poor nations from embracing communism.) But the Ford program had failed to improve production.

A Ford Foundation team studied the situation in consultation with Indian collaborators. In sharp contrast to the conclusions of Weaver and Harrar (1954), they concluded: "Most of the improvements needed to double yields are already known to some people. Many improved practices have been adopted by some cultivators, in some areas. But until this knowledge is more widespread and acted upon, food production targets cannot be achieved (Ford Foundation Agricultural Production Team, 1959, p. 17). Wider extension of best practices was the key. Along with a host of other recommendations in its 259 pages, the report advocated better fertilizer supply and many other useful initiatives.

Ford was soon to implement an "Intensive Agricultural Districts Program" to extend knowledge, demonstrate best practices, and provide seed-fertilizer packages to farmers. Though no evaluation of the program's effects was published, some have claimed that it increased yields in at least some areas. In addition, it no doubt provided experience in public involvement in fertilizer distribution. Although evidence of its overall success was lacking, the program somehow became the model for many later "Integrated Rural Development Programs." A critical review of some of these subsequent programs conducted by USAID indicates the disappointing record of the integrated approach, noting that those programs that were most successful focused on just a few activities (Kumar, 1987).

Prior to the 1958 meeting, Hill, the Ford Foundation's vice president for overseas development, had visited Ford's development projects worldwide and concluded that Ford's extension-oriented programs were misguided. The technologies needed to achieve large yield increases had not yet been developed. Heavy fertilization increased seed production, but caused plants to lodge (fall over) before harvest, so the net effect was unimpressive (Chandler, 1992, pp. 5–6). More generally, like Harrar and Weaver, Hill saw that cereal yields in Asia were stagnant. Except in Taiwan and Japan, personnel were scarce, budgets were too small, and facilities were inadequate to produce the research needed to keep pace with rapidly rising population. Ford had more money than viable projects.

At the end of the 1958 meeting on supporting an Indian agricultural college, Hill reportedly turned to Harrar and said: "[S]omeone should undertake to work with rice the way you Rockefeller Foundation people have with corn and wheat." He noted the complementary strengths of the two foundations: "We have some money. You have experience in conducting agricultural research in the developing countries. We are both interested in doing what we can to solve the world's food problem. Why don't we get together and see what we can do?" (Chandler, 1992, pp. 4–5.)

With these informal remarks, Hill was diverging from Ford's unpromising bottom–up approach to development and current orientation to extension, proposing instead an unprecedented, mission-oriented research partnership with Rockefeller, an institution with no track record in rice research. Finally, this partnership had adequate resources and talent to respond to the invitation of Philippine Secretary of Agriculture and Natural Resources P.L. Mapa that had been extended 8 years earlier. In June 1959, the Ford Foundation trustees approved the initial capital grant for an International Rice Research Institute (IRRI) in Los Baños, The Philippines. Rockefeller contributed the operating expenses.

Little more than a year later, the leaders of IRRI moved to temporary offices at Los Baños. IRRI proceeded to hire in plant genetics, rice breeding, plant protection, plant physiology, agronomy and soils, rice chemistry, agricultural engineering, and agricultural economics. For rice chemistry they looked to Japan, which was the clear leader in the field. For all other fields, recent graduates or young faculty at United States land-grant institutions dominated: before 1966, hires (including many international students) were associated with Cornell, University of Minnesota, Wisconsin, Purdue, Ohio State, and the University of Hawaii. The larger mission of the land-grant system proved well suited to training personnel not only for program management, but also for the more focused mission of rice breeding to increase food supply in the Third World.

IRRI scientists established a world rice collection. They also adopted the shuttle-breeding innovation Borlaug had used in Mexico, both to speed up identification of promising breeding material and crosses and to select for broad adaptability. IRRI scientists conducted basic studies related to their work. They also studied sterility in Japonica–Indica rice crosses, seed dormancy, and grain-quality traits. They addressed plant physiology and were well aware of the promise of short-statured rice varieties, which had been known in China for a thousand years and was used by Japanese farmers in the 19th century to solve the problem of lodging under high-nitrogen fertilization (Parayil, 1992). Crosses between dwarf Japonica and tropical Indica varieties promised better fertilizer response and a higher ratio of seed to total plant matter. In the terminology of patenting criteria, one could argue that such crosses were experiments "obvious to try." Breeders quickly discovered that, in contrast to the case of wheat, tall plant stature in rice was a trait controlled by a single dominant gene that was absent in the popular short-stature rice parent variety, Taichung Native 1 (Chandler, 1992, p. 104). The fact IRRI breeders were apparently the first to obtain this result, via a simple Mendelian experiment, is an indication of the extent of the global neglect of research on rice identified earlier by Harrar and Weaver.

Most importantly, within 2 years after IRRI was established, a cross between a short-statured Chinese variety from Taiwan, Dee-Geo-Woo-Gen, and a tall, tropical Indica variety, Peta, from

Indonesia, resulted in a selection to become famous as the first widely planted high-yielding semi-dwarf rice, IR-8. It had been obvious for many years that crossing a dwarf Japonica parent with a tall Indica variety might result in a semi-dwarf progeny highly responsive to nitrogen fertilizer. Clearly, national rice breeders in India and elsewhere (though not, as we shall see, in China) had for some reason been unable to seize obvious opportunities. Using IR-8, IRRI subsequently bred a series of better-adapted high-yielding varieties with higher grain quality. These varieties were to transform the global rice-supply situation over the next decade. Ironically IRRI, which owed its existence to Rockefeller's experience in Mexico and was modeled on the Office of Strategic Studies in Mexico (Osler et al., 1978, p. 7), inspired a visiting Mexican president to re-evaluate the merits of continued collaboration with Rockefeller and to support the establishment of CIMMYT in Mexico.

5. Motives, missions, and outcomes

I have so far focused on three missions: the founding of the United States Land-Grant College System, the work of the Office of Special Services in Mexico, and the generation of the first high-yield rice varieties at the International Rice Research Institute in the Phillipines. Each was born in a different era and operated at a different scale. These three missions, in turn, generated the U.S. system of land-grant universities and state agricultural experiment stations, the foundation of the wheat-breeding program in Mexico that later evolved (in part) into CIMMYT, and the establishment of IRRI in the Philippines. Each of the first two bestowed positive spillovers on its successor. Many of the personnel who featured in the accomplishments of CIMMYT and IRRI had been trained and/or employed in the U.S. land-grant system at a time when U.S. grain yields were starting to soar. In many cases, new agricultural educational institutions in developing countries were designed to emulate land-grant universities, and in particular, their lack of stultifying hierarchy and practical orientation.[28] Graduates of these new schools helped adapt and adopt the new wheat and rice varieties that later became available.

The experience of the Rockefeller Foundation and its personnel in Mexico prepared its small and lean team of long-term managers and researchers to address the challenge of initiating a new era of wheat and rice breeding in Asia. A food crisis created the political climate in which moribund research institutions could be revitalized, and in which available scientific expertise could be reoriented to the obvious, urgent task at hand.

Due to the downward crop-price trend, which continued for more than 40 years, the global long-run gains that have accrued from yield increases to farmer/landowners as producers have been modest relative to the total welfare benefits achieved. Because benefits to consumers tend to be diffuse, their interest tends to have little influence on agricultural innovation. This factor explains why research on general (rather than local) yield-increasing innovation in staple crops is an anomaly; attention is usually paid to cash crops, for which demand is more elastic and gains are more evident to producers with large marketable surpluses, who tend to be politically influential. What, then, motivated the establishment of these early agricultural research institutions?

This study does not explore the history of the British and then German innovations in agricultural research stations that were later emulated in the United States. However, it is striking that the oldest, Rothamsted, was founded by a manufacturer who had patented an important fertilizer, and that von Liebig, the key influence on the proliferation of the German research stations, was a chemist who had identified the potential of nitrogen as a fertilizer and was interested in agricultural uses for products of the nascent chemical industry. Input providers may have more to gain from yield-increasing innovations derived from use of the products they sell than do farmers as a group. In the United States, unusually wide geographic dispersion of farmers across diverse environments generated advantages in local research that would accrue in large part to local farms, and federal subsidies encouraged state research that generated spillovers.

The motives that drove the individuals who spearheaded the chain of events that led to the initiation of Rockefeller Foundation support for wheat and maize research in Mexico in 1940 were no doubt complex. Henry Wallace was a liberal, influenced by his boyhood acquaintance with George Washington Carver, and a known friend to Mexico, who later advocated universal health insurance when he ran for president of the United States. (His later political career suffered because of his sympathy with the Soviet Union.) However, he was also an agricultural-input provider, the founder of the leading and highly successful commercial hybrid corn-seed corporation, Pioneer Hi-Bred, whose very existence was the product of basic and applied agricultural genetic research conducted mainly within the land-grant system. The Wallace family also founded Hy-Line, a leading breeder of hybrid egg-laying chicks, in 1936; no doubt, both businesses would have expected to gain from development of more productive farms in Mexico.[29] However, contemporary accounts and Wallace's subsequent political record suggest that concern for the welfare of Mexican farmers mainly impelled Wallace to advocate for assistance to them.

President Franklin D. Roosevelt, who sent Wallace to Mexico, wanted to improve relations with Mexico after Mexico's 1938 nationalization of U.S. oil interests and did not wish to see Mexican oil sold to likely enemies of the United States. In addition, he was no doubt disposed to advance the cause of politically powerful American oil producers. The Rockefeller Foundation, which funded the researchers, might well have hoped that gains to Mexico would improve prospects for U.S. oil producers to resume Mexican operations (Koppes, 1982).

Ten years later, the Rockefeller Foundation found itself in a very different world as it contemplated supporting research to increase Asian rice production. The communist threat loomed large in the American consciousness, and Nelson Rockefeller was an ambitious liberal Republican who had already been involved in the extension of the Marshall Plan, which was commonly seen as part charity to a war-torn Europe, part a plan to revive potential trading partners, and part an effective anticommunist initiative.[30] Higher rice yields might well have been thought to be helpful in preventing countries from embracing communism, given that China's food production was known to be rapidly rising after the devastation of the war and revolution.

Given the complex motivations of the actors, then, it is easy to argue—as have many critics—that the interests of their capitalistic funders determined the technologies chosen for the "green revolution" in wheat and rice. But what is interesting about historical arguments over the "green revolution" is that neither side typically pays any attention to policy choices in other regimes concerned with food supply.

[28] Parayil (1992) lists six Indian agricultural universities modeled on U.S. land-grant universities.

[29] Sutch (2011) suggests that Wallace's personal financial interests motivated his exaggeration, as Secretary of Agriculture, of the merits of adoption of hybrid corn in the United States.

[30] For a recent reinterpretation of the effects of the Marshall Plan, see De Long and Eichengreen (1991). They argue that the plan's main effect was to influence governments to adopt policies more favorable to economic growth, such as highly successful structural-adjustment programs. Similarly, a major contribution of the new crop varieties was to encourage the emergence of more effective national crop research, extension, and input supply programs.

In the first decades of the 20th century, the Italian breeder Nazereno Strampelli used a Japanese introduction, Aka Komugi (which possessed a gene later identified as *Rht8*), which reduced height by 10 cm, and another, Ppd-D1, for daylight-insensitivity, which advanced flowering by 8 days.[31] New varieties released around 1918[32] were adopted in Italy and in Argentina. In 1931, while Benito Mussolini was pursuing his "Wheat Battle," a grand mission for self-sufficiency, Strampelli released San Pastore, a very successful short-stature, fertilizer-responsive wheat. This variety was adopted after World War II in Eastern Europe, including Yugoslavia, where further crosses raised average yield in a key production region from 1.36 t/ha to 5.21 t/ha, and yields over 10 t/ha were observed. Both fascist and communist regimes embraced, in times of crisis, essentially the same new semi-dwarf wheat technologies associated in the West with the "new plant type" (Reitz, 1968, p. 236) associated with the later green revolution.[33]

The kind of dwarfing technology developed by IRRI was also pursued by a very different regime. As Stavis (1974, pp. 26–27) reports, in 1965, 1 year before the release of IR-8 by IRRI, China had almost 3.3 million hectares of very-high-yielding varieties of rice, mostly in the "high- and stable-yield" areas. Contemporary Chinese scientists described them as follows:

> The short stalk varieties, in general, are characterized by such features as short notches, powerful tillering, short and straight leaves, good light infiltration in clusters, and well-developed roots. The combination of these features generated the high-yield characteristics of absorption of fertilizer, resistance to lodging, and greater number of ears.[34]

As Stavis notes, this description is remarkably similar to that later written for IR-8 in a Philippine rice-production manual. Like IR-8, the Chinese varieties required careful irrigation and plentiful fertilizer, were susceptible to diseases, and generally were not good to eat. Only one of four high-yield rice varieties was reported to be good for cooking; growers generally delivered the others to the state to fulfill their quota. (Unlike IR-8, these varieties were suited to more northern climates.) Whatever the motivations, however, two very different social and economic systems seem to have delivered very similar types of technological innovations at about the same time. Both innovations favored the high- and stable-yield areas.[35] The Chinese achievements in developing high-yield rice varieties adapted to their environment no doubt contributed to the fact that China's 61% increase in calorie consumption between 1964[36] and 2000 was far greater than the increase for any other area between 1961 and 2000 (Fogel, 2004, Table 1, p. 644).

Thus, regimes with very different worldviews and strategic objectives found that a common mission would advance their ambitions: a mission to produce more grain. Mussolini, no doubt, saw the political advantages of making Italy food-secure, even if the initiative was economically unsound. In order to combat the spread of communism, many conservative Americans who were unconcerned by the plight of the global poor supported policies that enabled Asians to have more rice. Mao doubtless understood that ensuring that Chinese consumers had access to more rice would help restore popular support for his regime after the disaster of his Great Leap Forward.

Thus, semi-dwarfs highly responsive to fertilizer were key targets of innovative missions to increase yields of wheat in Italy, Yugoslavia and Eastern Europe, and Mexico, and of rice at IRRI and in China, independent of the political and economic systems or underlying motives of those who supported invention and adoption of innovations that promised to increase grain supplies. The common goal of higher grain yield, not the sharply different underlying motives, determined the nature of the yield-increasing innovations.

6. Conclusion

The three cases considered here are prime examples of effective mission-oriented innovation. Each mission was embraced politically in a time of war or civil disturbance, when it seemed possible that entrenched interests could be challenged more successfully. Each mission helped facilitate later missions; in this sense, the sequence of innovations was state-dependent. Each mission also demonstrated the value of having champions for the cause, the importance of a clearly definable immediate objective, the need for a mix of fundamental and applied research activities, and the key role of accumulated specialized experience in mission formulation, funding, and execution.

The development of the U.S. agricultural research system was the culmination of a grand mission. In addition to establishing a novel nationwide system of tertiary education accessible to the masses, it created and supported a long-sustained federal-state research structure. By compensating states for national spillovers from their mainly locally-focused research programs, and by offering producers enhanced local adaptive research capacity, the national research system ensured support for general advances that led to lower prices and great social benefits. The system itself did not determine the choice of technologies, but it did make it possible for scientists to acquire and exercise their professional skills in solving applied problems. Like many other successful grand missions, the establishment of the land-grant system required the efforts of dedicated and persistent champions and could be implemented only when a time of crisis offered a window of political opportunity during which opponents of disruptive innovation were at a disadvantage.

Internationally, the inability to internalize international spillovers long discouraged national research efforts from supplying globally beneficial levels of innovation. In the development of semi-dwarf rice and wheat, the Ford and Rockefeller foundations played key roles in financing and executing sustained research programs that produced innovative crop-breeding approaches. When food-supply crises motivated politicians in hungry nations to embrace the mission to produce more food, the politicians were able to ensure the rapid adoption of new varieties by national producers and the development of better-adapted successors by their research institutions.

The Rockefeller Foundation, in particular, appears to have developed a unique capacity to identify a mission and hire talented managers (who often had administrative experience in the land-grant system). These managers in turn established a remarkable record in selecting young, outstanding scientists who would determine the means of execution and devote the years necessary to complete the task. These scientists, educated and developed in the land-grant system at a time when it helped set yields of major United States crops on unprecedented upward trends, were able eventually to "work themselves out of their jobs," confident that

[31] Material in this paragraph draws heavily on Borojevic and Borojevic (2005) and C. Qualset (personal communication, 2012).

[32] The varieties include Villa Gloria, Ardito, and Damiano (Borojevic and Borojevic, 2005). Not all were short. Mentana was tall, but daylight-insensitive. It was used by Borlaug to breed some of the first of his semi-dwarf releases (Dalrymple, 1978, p. 15).

[33] The dwarfing genes in Norin 10, though they originated in wheat found in Japan, are *Rht-B1b* and *Rht-D1b*, which are distinct from the dwarfing gene in Aka Komugi and the Italian derivatives (Hedden, 2010, p. 1).

[34] Rice Scientific Technical Group of the Chinese Academy of Agricultural Sciences (February 1966).

[35] Stavis's report is supported in general terms by Hsu (1982) and Lardy (1983, p. ix).

[36] Fogel takes 1964 as the base to avoid the unusually low yields of the prior years affected by the Great Leap Forward.

other opportunities would then become available within the organization.

Whether the land-grant system, the foundations, and/or the CGIAR Centers can still meet grand challenges is an open question. The ability to separate the motives that determine a mission from the research program's choice of means of execution is crucial. It appears to be difficult to sustain this ability when research funding is determined jointly by more than a few parties, as is currently the case in the Centers of the CGIAR. When this ability to distinguish motives from means is lost, the choice set tends to narrow for political reasons, so that short-term projects with predictable results but fewer spillovers are favored. Indeed, except in dire emergencies, a tendency has arisen to impose the kinds of constraints that have chronically constrained national breeding programs. The directors of the centers are increasingly preoccupied with fund raising, and funders influence research execution and choice of technology as well as research direction.

Herdt (2012) suggests that foundations have also changed. Laws now governing foundations in the United States have forced them to seek partners early in project development, thereby reducing their ability to operate independently, respond quickly to opportunities as they arise, and commit the time needed to complete programs successfully. Meanwhile, the land-grant system is facing unprecedented cuts in funding that threaten its core missions; indeed, governments are slashing budgets across the Western world. When the next food crisis descends upon us, and political leaders re-focus on the mission to supply sufficient food for their consumers, will they again be able to call on institutions that through foresight, persistent effort, and astute management are able to respond to the challenge and bridge the gap between national incentives and global needs?

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