Introduction: Innovation and Technology Transfer in Agriculture

Nicholas Kalaitzandonakes, Elias G. Carayannis, Evangelos Grigoroudis, and Stelios Rozakis

Abstract Innovation has been an integral part of agriculture since its earliest days, when humans first began to make the shift from foraging to food production. It was only during the twentieth century, though, that private and public systems of formal research and development of innovations became common. With that came the need for formal systems to research, develop, and transfer technology from centers of discovery to end users. Continuing improvements in global food security, environmental sustainability, and economic development in the face of continuing population growth and climate change will require ongoing innovation and durable growth in agricultural productivity. Thus, a clear understanding on how to nurture innovation, from concept through development and all the way to the end user, is vital to our future. In this book we present a comprehensive treatment of the complex processes involved in the development and transfer of agricultural innovation.

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N. Kalaitzandonakes (✉)
Department of Agricultural and Applied Economics, University of Missouri, Columbia, MO, USA
e-mail: KalaitzandonakesN@missouri.edu

E.G. Carayannis
George Washington University, Washington, DC, USA

E. Grigoroudis
School of Production Engineering & Management, Technical University of Crete, Chania, Crete, Greece

S. Rozakis
Institute of Soil Science and Plant Cultivation, IUNG-PIB, Pulawy, Poland

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innovation, from concept through development and all the way to the end user, is vital to our future. In this book we present a comprehensive treatment of the complex processes involved in the development and transfer of agricultural innovation.

The time and material resources available to individual farmers for innovation was always limited, however. As civilization progressed, though, wealthier members of society saw opportunities in agricultural innovation and were able to take advantage of them. Some of the earliest achievements in this direction in Europe were "physic gardens," predecessors of today's botanic gardens and centers of investigation into medicinal plants. They were also among the first examples of university agricultural research; the first physic garden was established in 1543 at the University of Pisa. The practice soon spread throughout the rest of Europe. During the colonial period, national governments, most notably in Spain, France, and England, established botanic gardens to evaluate potential new crops brought back from their tropical colonies. During the eighteenth century, these governments also set up botanic gardens in their colonies to adapt tropical crops from other areas to local conditions (BGCI 2017). Private innovation efforts in both methods and machinery continued through the seventeenth and eighteenth centuries as well, and both public and private innovators went to considerable lengths to promote their ideas and inventions to individual farmers (e.g., Sayre 2010).

These early research programs anticipated our modern concept of agricultural research and development (R&D), which dates back only to the nineteenth century. During this era such noteworthy innovators as Thomas Edison, Henry Ford, and John D. Rockefeller instituted the practice of devoting specific shares of their firms' revenues to ongoing applied research aimed at the improvement of existing and the development of new products and industrial processes. The practice of applied research, itself a valuable innovation, soon spread to universities, augmenting their traditional roles of teaching and basic scientific investigation. Government agencies also established research laboratories, perhaps the first being the Department of Agriculture (USDA). The range of research performed or supported by the federal government steadily increased over the years, in step with the general scope of government activities. These two systems of public and private R&D have evolved separately and together, as has the nature of their interactions (Mowery et al. 2001). Innovation systems in countries around the world have gone through similar patterns of evolution, each in their own institutional environment. One outcome of these different histories is variation in the efficiency of innovation systems, which is a factor in the current state and future potential of individual national innovation systems (Carayannis et al. 2016).

A few of the contributions to this volume examine the current state of public and private sector agricultural R&D and trends that are under way. *Pardey et al.* look at changing patterns of public agricultural R&D worldwide. Using the University of Minnesota's InSTePP database, they describe trends in public R&D spending, noting significant differences between high- and middle-income countries, and in the relative amounts of public and private R&D spending in those same countries. *Fuglie, Clancy, and Heisey* focus on how the balance of public and private R&D spending in the USA has changed since 1990. *Kalaitzandonakes and Zahringer* discuss the emerging private R&D model in the global agricultural input sector, the factors that have shaped it, and the structural changes that enabled it. *Phillips* reviews the development of a completely new crop and market in Canada and chronicles the operation of a modern public-private R&D and technology transfer partnership.

The Institutional Environment, Incentives for Innovation, and Technology Transfer

Public policy has played a crucial role in shifting the division of labor of the private and public sectors in agricultural innovation through changes in the underlying incentives. Laws on intellectual property rights (IPR) have been particularly important. The debate over university patent policies started in earnest in the post-World War I era. The 1920s and 1930s saw an increase in public-private research collaboration to the point that many in the scientific community began to discuss how best to ensure the efficient exploitation of research results, to the benefit of society as a whole. The lines in the debate were quite clearly drawn. Many in the university community believed that universities, as public institutions, had the obligation to make all the products of their research freely available and that this was at least a sufficient, and perhaps even an optimal, means of technology transfer. Others maintained that private firms would be unwilling to expend significant resources developing university research results into viable products without the ability to protect their future returns with patents (Mowery and Sampat 2001). The question was seen as important enough that in 1933 the American Association for the Advancement of Science convened a special committee to address it. The final report came out in favor of university patenting, for a variety of reasons, but not unequivocally so. It also recognized the potential for holdup of subsequent research by overly broad patents, especially in the fields of medicine and research methods (Rossman et al. 1934).

During the interwar period, university patenting increased somewhat but remained quite rare. Major research universities, as well as many land-grant institutions, were at the front of the trend. Depression-era funding shortfalls led other universities to investigate patenting more seriously, as license revenues became more of an attraction. They still faced political and public opinion repercussions from potential participation in commercial enterprise, though, and generally lacked the expertise to effectively manage even a small patent portfolio. In order to deal with this situation, it became common for universities to assign their patents to a third party for management. Many institutions retained the services of the Research Corporation, a private firm founded by former faculty expressly for the purpose of technology transfer from universities to the private sector. Still, as late as 1950, most US universities had no patent policy, and some of those that did discouraged or prohibited faculty patenting (Mowery and Sampat 2001).

Patent laws and attitudes toward patenting are important parts of the institutional environment surrounding agricultural R&D. While this is perhaps a more contentious subject in the public sector, patents and patent transactions produce strong incentives for actors in the private sector as well. Another group of contributors look at the impact of this and other aspects of the institutional environment on R&D and technology transfer. *Smith and Kurtz* recount the history of yield increases in US corn production since the middle of the nineteenth century. They identify three types of factors that contributed to the adoption of hybrid cultivars and the resulting dramatic yield increase: genetics, agronomy, and policy, in particular policy concerning IPR. Some researchers have noted that IPR laws can inhibit as well as promote technology transfer. The concern is that excessive property rights assertions, such as patent thickets, can lead to the formation of an anticommons. *Lesser* examines evidence for and against the existence of an anticommons in agricultural R&D, specifically as it concerns the products of biotechnology. He investigates infringement issues in commercial use, research, and charitable product development. *Gjonca and Yiannaka* discuss how the characteristics of patents held by private firms might influence whether and how often those firms were merged, acquired, or spun off. Using a database of over 6000 private sector patents granted from 1976 to 2000, they relate measures of breadth of claims, value, enforceability, and patent holder nationality to patent ownership changes. On the other hand, *Tripp, Simkins, Yetter, and Yetter* look into the public production of patented innovations, specifically by land-grant universities that received research funding from the National Institute of Food and Agriculture (NIFA) at USDA. In separate analyses of samples of over 24,000 patents and nearly 4000 plant variety protection certificates, they assess the influence of university research and patenting on follow-on innovation and characterize differences between universities and private firms as to which subject areas and crop varieties were the objects of research and patenting. *Kalaitzandonakes, Magnier, and Kolympiris* also review private sector patenting activity in the Ag biotech and seed sectors from 1980 on and evaluate whether there are discernible patterns of strategic patenting that could limit competition. They also analyze how such IPRs have been shared across firms through licensing and cross-licensing agreements in the agricultural input sector over a 25-year period. They then evaluate how patenting and licensing agreements among firms in this sector affected the introduction of new products during this time.

Production and licensing of patents may be the most measurable technology transfer flow in the agricultural innovation system, but it is not the only one. Perkmann et al. (2013) found other forms of knowledge and technology transfer, such as collaborative research, consulting, and informal relationships among researchers, to be much more common than producing and licensing intellectual property. Their review indicated that three to four times as many university researchers engaged in such one-on-one activities, which they collectively termed "engagement," than in patenting or creating spinoff firms. Engagement is most popular with high-achieving, more senior faculty, and such relationships may provide academics with resources unavailable at their home institutions. Private firms place a high value on academic engagement as well, as it gives them access to expertise that may be otherwise hard to come by. Finally, they found that the century-old debate described earlier still has influence in academic attitudes; most faculty members view engagement as an extension of and compatible with traditional academic roles, but see patenting and commercialization as a different sort of activity. Engagement is thus a very important mode of technology and knowledge transfer but is difficult to study as much of it occurs in forms that are not easily recorded and quantified.

Academic publications are one form of knowledge and technology transfer that can readily be analyzed. In recognition of the important role played by land-grant universities in agricultural R&D and technology transfer, *Tripp, Grueber, Yetter, and*

Yetter assess the knowledge output, in the form of peer-reviewed journal articles, which resulted from NIFA-funded projects at land-grant universities and evaluate how such outputs were paired with resources from other pools for continuing research.

Formalizing University Technology Transfer

Beginning in the 1950s, increased federal research funding led to more R&D activities at many universities. As the greater volume of research produced more potentially patentable inventions, interest in patenting also grew. The pace of federal funding accelerated again in the 1960s and shifted to more basic research, especially in the biomedical disciplines. As research activity and the flow of patentable inventions continued to grow, more and more schools found it practical to manage their own patent portfolios, founding technology transfer offices (TTOs) and hiring professional staff (Mowery and Sampat 2001). Increased federal funding also meant that federal government policies became increasingly important in the technology transfer arena, not only for government labs but also for supported research in universities and private firms. By 1960, it was becoming clear that federal policy was probably inhibiting public-to-private technology transfer. There was no comprehensive policy concerning the patenting of inventions resulting from government-sponsored research. Each agency had its own rules; some operated under statutory restrictions on what could be patented, while others had more discretion. Around 1965, some agencies, notably the Department of Health, Education, and Welfare (HEW) and the National Institutes of Health (NIH), started to make it easier for universities to patent and license their inventions, but not all agencies made those changes. Throughout the 1960s and 1970s, the debate on patenting the products of federally funded research continued, finally culminating in the passage of the Bayh-Dole Act in 1980. This Act granted substantial rights to recipients of federal funds to patent and license inventions resulting from that research and made federal policy broadly and explicitly supportive of public-private technology transfer. Thus Bayh-Dole was the culmination of a decades-long process of institutionalizing university patenting (Berman 2008). University patenting is now a common practice, so much so that recent studies indicate that the former pioneers, land-grant universities, no longer seem to play a disproportionately large role in generating patentable innovations (Friedman and Silberman 2003).

At the same time that legislative and policy changes in the USA were encouraging more university patenting, other countries were making similar modifications to promote university technology transfer. The resulting widespread increase in technology transfer made the role of TTOs steadily more important (Grimaldi et al. 2011). More recently, the concept of academic entrepreneurship has become broader, no longer restricted to patenting and licensing intellectual property but encompassing activities such as faculty startup firms and curriculum changes, among others (Kolympiris et al. 2015). The role of the TTO has expanded congruently, from patent portfolio management to more general support of entrepreneurial activity (Siegel and Wright 2015). In this collection several authors examine the TTO operations and performance as well as the factors that contribute to their success. *Smyth* studies the performance of Canadian university TTOs. He describes much of the relevant history of how different research frameworks and changes in public policy affected university technology transfer in Canada. *Hoenen, Kolympiris, Wubben, and Omta* give a detailed account of the development of the technology transfer system at Wageningen University and Research. They identify several factors that have contributed to a successful program at one of the leading agricultural universities in Europe, describing the impact of formal policies, the cultural environment of the university, and the general, regional promotion of private R&D activities. *Cartalos, Svoronos, and Carayannis* review the operations of the TTO at the Agricultural University of Athens. This program is a good example of the expanding concept of TTO duties. This TTO provides a broad range of business support services not only to university researchers but also to licensees of university IP. Recognizing that one hallmark of TTO operations is that they must make decisions regarding innovations whose true potential is unknown, they also develop a model for optimal choices of services and projects TTOs can support. Along that same line, *Zahringer, Kolympiris, and Kalaitzandonakes* explore how the technology life cycle can influence the potential market value of university inventions as well as their optimal commercialization and technology transfer strategies.

Transferring Agricultural Innovation to Producer Fields

Much of public and private agricultural R&D is focused on the development of improved agricultural inputs and production practices. Thus for agricultural innovations to be useful, they must be passed along to agricultural producers. Universities have become significant centers of innovation over the last 150 years or so. Through the mid-1800s, American universities saw themselves as primarily teaching institutions. In creating land-grant colleges with the Morrill Act of 1862, the Congress sought to extend that mission beyond the traditional urban, upper-class clientele to rural and working-class Americans, emphasizing agriculture and the mechanical arts. It soon became clear that the educational mission of the land-grant schools would suffer without a quality research program to feed it. Therefore, in 1887, Congress passed the Hatch Act, establishing state agricultural experiment stations (SAES) in all states (Cash 2001). Quality education supported by research strengthened agricultural innovation, but it was not enough; most university students did not study agriculture, and only some of those that did returned to the family farm. Without a formal technology transfer program, there was a growing knowledge gap between academic researchers and the farmers they meant to serve. The US Congress supplied such a system by establishing a cooperative extension service in every state through the Smith-Lever Act in 1914. Finally, the land-grant system of agricultural research with results made freely available to all practitioners through teaching and extension was firmly in place (McDowell 2001). Variations of such public agricultural innovation systems based on research, teaching, and extension services were established in other countries as well with varying levels of funding support and organizational effectiveness.

Extension continues to be a major path for technology transfer from university researchers to producers. *Koutsouris* reviews extension research and practice and takes issue with the standard diffusion theory and linear transfer models, going on to describe several newer paradigms that emphasize two-way communication and the ties between research and practice. He charts out in detail the changes in the literature and organizational strategies as scholars developed more complex and realistic models of technology transfer.

Availability of improved inputs and production practices, whether from the private or the public sector, is not the same as use and adoption. The adoption and decision-making processes of agricultural producers are an essential part of the technology transfer process. Modern adoption paradigms are largely based on the diffusion of innovation (DOI) theory of Rogers (2003), who postulated that individuals are heterogeneous in their willingness to adopt and are normally distributed along that continuum. Early versions of this model looked only at adopter characteristics and thus had a strong pro-adoption bias, implicitly assuming that all innovations were worth adopting. Suri (2011) pointed out that adoption, from the DOI perspective, focused primarily on user learning as the main determinant, neglecting user interaction with both the transfer agent and the innovation. Later extensions took into account characteristics of the technology and its impact on users (Meade and Islam 2006). Recent models are more comprehensive and less linear, emphasizing the impact of innovations and the roles of policy, social institutions, and infrastructure in adoption (Doss 2006). *Ugochuckwu and Phillips* focus on the end user of agricultural innovation in their comprehensive review of the adoption and diffusion literature and also describe the contributions and drawbacks of DOI theory. They use studies of the adoption of a range of specific technologies to describe the variety of theoretical and practical approaches and the different factors identified as impacting adoption.

When farmers decide whether to adopt an innovation, they must consider factors that do not apply to more conventional industrial pursuits. There are some important production conditions over which farmers have minimal control, notably weather, pests, and diseases. This production risk is heterogeneous across producers and regions and sometimes even across individual farms. Farmers are likewise heterogeneous in their risk preferences. Thus risk management is a major and variable concern in all producers' decision-making. Farmers, then, do not consider only the effect of an innovation on average yield but also on yield and cost variability (Koundouri et al. 2006). The adoption decision, then, can be as much a risk management tactic as an income-increasing one. Producers are also heterogeneous in the costs they bear and the benefits they enjoy from adopting agricultural innovations, especially in developing countries. For instance, Suri (2011) showed how variable infrastructure quality and other social conditions can dramatically affect fixed costs of adoption of new crop varieties in Africa. Such costs can be considerable in some cases, making the adoption of otherwise highly attractive innovations uneconomical.

Two of the chapters in this volume address some of the practical aspects of moving agricultural innovations into actual field use. *Akhundjanov, Gallardo, McCluskey,* *and Rickard* investigate how contract terms can either promote or inhibit the transfer and use of technological innovations covered by IPRs. Using game theory and an experimental auction, they examine how contract exclusivity, payment structure, and time duration affect producer willingness to adopt a hypothetical new apple variety developed at a land-grant university. Technology transfer to developing countries is key to future increases in global productivity and food security; *Edge, Oikeh, Kyetere, Mugo, and Mashingaidze* describe the history of a large technology transfer project in Africa. Water Efficient Maize for Africa (WEMA) began in 2008 to develop and encourage adoption of drought-tolerant hybrid corn. They identify a number of factors that can contribute to the success of large public-private partnerships of the sort. They go on to discuss further challenges that may accompany the possible future introduction of transgenic varieties.

Benefits from Agricultural Research and Innovation

Return to research investments is a topic of continuing interest and an important part of assessing the effectiveness of research programs. The benefits of research and innovation can be evaluated from different perspectives. *Shafer and Strauss* offer a practical view of how public agricultural R&D affects us all, as they describe the many areas of USDA-sponsored research and the impact it has had on American diet. *Martha and Alves* shift the view internationally, as they discuss the public agricultural research system in Brazil. They describe the government's comprehensive program for agricultural modernization, of which research support is but one part. They go into detail about the multiple activities of Embrapa, the government-owned research firm that is the major player in agricultural innovation in Brazil, and give some measures of returns to Brazilian research investments. In order to facilitate a greater understanding of the subject, some of our authors identify and analyze alternative definitions, measures, and models related to calculating estimates of monetary returns to research expenditures. *Huffman* identifies potential definition and measurement problems that can lead to inaccurate estimates of returns to research if not taken into consideration. *Qin and Buccola* discuss the measurement of knowledge production. They construct two measures based on Bayesian reasoning that potentially express knowledge production in a way that could be directly comparable across different R&D projects. They go on to demonstrate how those measures might be used in explaining research productivity and assessing the relative contribution of various characteristics of research programs.

We see, then, that technology transfer is a complex process and a complicated research area. As Bozeman (2000, 627) quipped, "In the study of technology transfer, the neophyte and the veteran researcher are easily distinguished. The neophyte is the one who is not confused." Agricultural research takes place in universities, government, and private laboratories and experiment stations. Some technology and knowledge are embodied in specific, explicitly traded products or processes, and some are shared through more informal means. Some innovations are released into the public domain, and some are protected through IPRs and other means. Some reach producers by way of the cooperative extension system, and some come as products marketed by private firms. What is clear is that modern agricultural productivity is a direct result of technological progress in improved genetics, manufactured and other inputs, and agronomic practices. Further improvement in productivity will be essential to increasing food production, possibly as much as a 70% increase by 2050, to keep up with a continually increasing world population (Meyers and Kalaitzandonakes 2012). Thus a clear understanding of the transfer process, in all its complexity, and how to improve it is crucial to our future. Contributions in this volume present a comprehensive treatment of the complex processes involved in the development and transfer of agricultural innovation. Toward this end, our concluding chapter offers a synthesis of lessons learned from the various contributors.

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