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Innovation, Appropriability and Productivity Growth in Agriculture: A Broad Historical Viewpoint

Alessandro Nuvolari and Valentina Tartari

1. INTRODUCTION

The introduction and diffusion of innovations in agriculture has been one of the fundamental drivers of economic and social change on a world scale. This appears very clearly when we consider that the most common periodization adopted by economic historians regards the history of mankind as marked by two fundamental turning-points, both of them related to the introduction of innovations in agriculture: the Neolithic agricultural revolution and the industrial revolution (Cipolla, 1962).

The Neolithic agricultural revolution consisted in the transition from the hunter-gatherer lifestyle to a sedentary way of life based on the domestication of plants and animals. This transition first took place in about 8,500 BC in the regions of the Fertile Crescent of the Near East. Somewhat later, a sedentary lifestyle based on the domestication of plants and animals emerged also in other locations such as China, and possibly Mexico (Diamond, 1997: 100). From these early centers, the domestication of plants and animals spread at uneven rates but inexorably throughout most of the world, progressively becoming the predominant lifestyle. Furthermore, the emergence of agriculture permitted the formation of larger, denser and socially differentiated communities.

Interestingly enough, the predominant consensus today is that the emergence and diffusion of agriculture did not include among its effects a sustained improvement in per-capita material living standards. In fact, some historians have even suggested that the adoption of agriculture brought about an actual deterioration in material living standards, in terms of quantities and qualities of calories consumed, frequency of diseases and amount of leisure time (see Clark, 2007 for a particular "strong" version of this view). Material living standards began to rise steadily only at a much later

date, with the industrial revolution, which is, obviously, the second fundamental turning-point mentioned above.

One of the classic definitions of the industrial revolution is that of a structural shift from an economic system in which the majority of the population is employed in agricultural activities to an economic system in which this proportion is less than 5–10 per cent of the total. So it is clear that the transformation of the agricultural sector played a critical role also for the origins, consolidation and spread of industrialization in the world economy (Bairoch, 1973).

The aim of this chapter is to provide an historical survey of long-term patterns of innovation in agriculture and explore their relationship both with the dynamics of productivity growth and with the evolution of intellectual property rights regimes. We shall concentrate mostly on the experience of the Western world.

Both economists and economic historians have frequently suggested that in contexts of weak appropriability of economic returns of inventions, there will be a systematic underinvestment in inventive activities and as a result productivity will stagnate (see, for example, North (1981: 163–6) and Jones (2002: 196–7) for two authoritative formulations of this view and Chapter 2 in this volume for a thorough critical reassessment).[1] In this perspective, the historical development of agriculture is of particular interest, because it is a human activity that for a long time was characterized by a very weak appropriability regime, at least in terms of the existence of formal institutional arrangements conferring private property rights for inventions. Still, the evidence shows that agriculture during its approximately 11,000 years of history, most of them taking place in a context of extremely weak intellectual property protection, has witnessed the introduction of major innovations that have contributed to an increase in productivity of several orders of magnitude (Boldrin and Levine, 2008: 79). Concerning the rate of technological change in the most recent period, Federico (2005: 74–82) estimates that over the period 1800–2000, in most countries of the world, the rate of agriculture's total factor productivity growth (which is the index most commonly used by economists for gauging the rate of technical change) was positive (the average for the world is 0.58 per cent per year). Furthermore, in many countries, the rate of growth of total factor productivity in agriculture outperformed that of their manufacturing sector and that of the overall economy for significant periods (Federico, 2005: 79–80).

2. INNOVATION AND TRANSFORMATION OF AGRICULTURE: THE MAIN TRENDS

For schematic purposes, innovations in agriculture have been frequently classified in four main categories: (i) biological innovations (i.e., "new" types of plants and animals), (ii) improvements or transformations of practices of cultivation, (iii) mechanization, and (iv) chemical products (fertilizers and pesticides).

On the basis of this classification, historians have also frequently put forward a schematic chronology of the long-term innovation trends in agriculture: until the industrial revolution, innovations in agriculture were mostly belonging to the first two categories (biological innovations and improvements in cultivation), afterwards mechanization and chemical inventions assumed a predominant role. This state of affairs lasted until the 1930s, when biological innovation gained new momentum stimulated by developments in biological sciences (for example, the rediscovery of Mendelian genetics) and supported in many Western countries by a robust public research infrastructure. Interestingly enough, Olmstead and Rhode (2008) have recently challenged this view, arguing, in a rather compelling way, that biological innovation remained the fundamental form of innovation for the agricultural sector also throughout the entire nineteenth century and that previous accounts have largely exaggerated the primacy of mechanical innovation in this period.

2.1 Crop transfers and improvements in cultivation practices

If we take a long-run view, agriculture before the industrial revolution experienced two major transformations. The first is the great "Colombian exchange": that is the exchange of crops and livestock species between America and Europe with potato, maize, tobacco, tomato, hemp and turkeys going from America to Europe, and wheat, barley, grapes, cattle, sheep and chickens going from Europe to America (Federico, 2005: 85, see also Nunn and Qian, 2010 for a general reassessment).[2] The systematic introduction of foreign plant and animal varieties was particularly important in the development of the agricultural sector in the United States throughout the nineteenth century (Olmstead and Rhode, 2008: 390–5). This type of biological innovation taking place in the form of the transfer of crops and livestock from one location to another has clearly progressively diminished in significance, as over time all known types of crops and animals were systematically tried in most locations. According to Federico (2005: 86), this "saturation point" was probably reached at the end of the nineteenth century. Afterwards, the introduction of new plants and animals took the form of hybridization of pre-existing species, and more recently by means of genetic engineering.

The second and surely the most significant transformation of agriculture taking place before the industrial revolution, was the so-called "agricultural revolution" of the seventeenth and eighteenth century. Traditionally, this agricultural revolution is conceived as the introduction of a number of improvements in the practices of cultivation, in particular the introduction of the system of "continuous rotation." This practice consisted in the introduction in the rotation system of a number of new crops (such as turnips, legumes or clover) capable of reintegrating the fertility of the soil, in combination with heavy manuring. These innovations permitted the elimination of fallow completely. It is not known the exact year in which these practices were adopted for the first time in Europe. However, the two locations in which "continuous rotation" was systematically introduced and refined were England and the Low Countries. By the middle of the eighteenth century the Norfolk rotation (turnips, barley, clover and wheat) had been widely recognized as "best-practice" (R. C. Allen, 2004: 110). Allen estimates that in England between 1300 and 1800 the average yield of wheat increased from twelve bushels to twenty bushels per acre. Approximately half of this 66 per cent increase in yields was attained mostly after 1600 by virtue of the introduction of nitrogen fixing plants in the rotation system (Allen, 2008).

Recent research has also recognized that the improvements in cultivation practices of the agricultural revolution were intertwined with a steady stream of biological innovations. In England, from the seventeenth century, farmers systematically collected seeds from the best plants (either exemplars that were high-yielding or resistant to disease) and cultivated them separately (R. C. Allen, 2004: 108). Similarly, the systematic adoption of various methods of selective breeding was responsible for a significant growth in the size and quality of the livestock (R. C. Allen, 2004: 109).

2.2 Mechanization and chemical products

Many historians, following an original cue of Douglass North (North, 1981: 163–6), consider the English patent system emerging from the Statute of Monopolies of 1623 as the first attempt at creating an institutional arrangement capable of establishing enforceable property rights for inventions (see MacLeod, 1988 for an history of the English patent system to 1800 and again, Chapter 2 of this volume for an overview of the development of patent systems in the major industrialized countries). It is, then, interesting to remark that most of the inventions of the agricultural revolution (consisting in the introduction of new crops and in improvements in cultivation practices) have instead left no trace in the patent records. Sullivan estimates that only 3 per cent of the English patents granted over the period 1711–1850 covered agricultural inventions (Sullivan, 1990). This share is probably even lower for the seventeenth century (MacLeod, 1988: 98–102). Of course, the chief explanation is that biological innovations and improvements in cultivation practices were in general considered as not amenable to patenting, as patents in the Statute of Monopolies were reserved for the "working or making of new manufactures" (MacLeod, 1988: 17).[3] Some inventors adopted the strategy of trying to appropriate the returns for the introduction of improvements in cultivation practices by describing them in detail in agrarian treatises and securing copyrights on them. This was the case of Jethro Tull with his treatise, *The Horse-Hoeing Husbandry* (MacLeod, 1988: 98).

During the nineteenth century, in most European countries and in the U.S. the bulk of patents in agriculture were represented by patents covering agricultural implements such as improved ploughs, seed-drills, etc. and machinery (threshing and winnowing machines). In fact, it is possible to trace back to the last decade of the eighteenth century the emergence of a modern industry specialized in the production of industrial machines and implements (MacLeod, 1988: 98). Since the industrial revolution, the agricultural sector in the Western world has been characterized by a trend towards the increasing mechanization of processes previously done by hand. Historians of technology have traditionally produced accounts of the contours of agricultural innovation in the nineteenth century that seem actually in line with the dominant role that mechanical inventions have in patent statistics for agriculture.[4] These accounts emphasize the role of inventions such as the cotton gin (1793), the threshing machine (1786), the reaping machine (1830s) and other later types of harvesting and picking machines in accounting for the substantial increase of agricultural productivity during the nineteenth century. Furthermore, the mechanization of agricultural operations was further stimulated by the advent and improvement of the gasoline tractor, which provided a small-scale and moveable source of power and that could be very effectively integrated into the agricultural production system (Olmstead and Rhode, 2003).

Chemical innovations contributed significantly to agricultural productivity from the late nineteenth century when chemical fertilizers began to be increasingly adopted (the key breakthrough in this area was achieved in 1909 with the development of the Haber-Bosch process for producing ammonia). Nitrogen fertilizers provided a very effective way of reintegrating soil fertility, without resorting to complicated systems of rotations and they were responsible for a very significant share of the productivity increase attained in agriculture over the twentieth century. Some scholars even claim that given its major contribution to the increase of yields, the Haber-Bosch process ought to be considered the most important invention of the nineteenth century (Erisman et al. 2008). The second contribution of chemical innovations to agriculture was the development of chemical substances that could be used effectively to fight pests and weeds. Also in this area, the first important results can be dated to the end of the nineteenth century.

The account we have outlined so far regards agriculture as a sector that, since the nineteenth century, has "received" innovations from other industries, in particular from machinery and chemicals. These two industries, in most Western countries, could rely on patent protection (although in some countries only chemical processes could be patented). Hence, at least at first glance, it would appear that for the agricultural inventions generated by these two industries, inventors could appropriate economic returns in a straightforward way using patents. In fact, patents feature prominently in the biographies of inventors such as Eli Whitney (cotton gin), Andrew Meikle (threshing machine) and Cyrus McCormick (reaping machine), the heroic inventors of the early mechanization of agriculture. All three used patents, albeit with different fortunes to reap economic returns from their innovations.

However, more recent evidence points to the existence of a large volume of inventive activities undertaken in the field of agricultural machinery without patent protection. Even if we consider agricultural implements such as ploughs, we find that inventors frequently preferred not to use patents, but either kept innovative plough designs as trade secrets or made them publicly available in order to enhance their own reputations (Brunt, 2003: 451; Mokyr, 2009: 183). Petra Moser (2012) provides a very interesting snapshot on the volume of inventions outside the coverage of the patent system by looking at how many inventions exhibited at the Crystal Palace exhibition in 1851 were not covered by patents. Moser shows that only 19.9 per cent of the British exhibits and 37 per cent of the American exhibits in the category of "agricultural machinery" were patented. Overall, these low patenting rates indicate that, even in a field like agricultural machinery where patents could be used most effectively, inventors preferred to adopt mechanisms of appropriability and did not contemplate the use of patents for protecting their inventions. Moser's findings of a low patenting rate in the area of agricultural machinery are fully corroborated by a more recent exercise carried out by Brunt et al. (2012) who look at the prize competition for agricultural machinery and agricultural implements organized by the Royal Agricultural Society of England. They find that only a share of about 20 per cent of the inventions that entered into the competition were patented. Additionally, Brunt et al. (2012) also show that, at least in the area of agricultural machinery, prizes (in particular prestigious non-pecuniary prizes) represented a very powerful inducement for inventive activities.

Similar considerations also hold for chemical inventions. This is clearly another domain in which patents can be used most effectively as a tool for appropriating returns from innovations. However, even in this field, patents were not used in isolation. For example, the Haber-Bosch process for the production of ammonia was protected by a number of patents, but at the same time the details of the catalyst system were protected as a trade secret (Arora et al., 1999: 227). It is also interesting to notice that some scholars have also argued that the innovative performance of the emerging German chemical industry was also stimulated by the very limits of patent protection in chemicals. German patent law allowed only process, but not product patents: in this way, German firms were stimulated to systematically search every possible way to obtain specific compounds. Furthermore, this limitation in patent scope had also the effect of enhancing the technological competition among German chemical manufacturers with positive reverberations on their innovative performance (Dutfield and Suthersanen, 2005: 136–8).

2.3 Innovation without patents?

As we have seen the agricultural revolution of the seventeenth and eighteenth centuries was essentially constituted by a stream of biological innovations and of improvements in cultivation practices that remained completely outside the scope of patent protection. The historical significance of the agricultural revolution then raises the question of why inventive activities were not discouraged in a context of relatively weak appropriability. A tentative answer to this question has been recently attempted by Allen (2009: 67–74). Allen suggests that the agricultural revolution was actually based on two co-existing innovation models: (i) the "experimental" landlord model and (ii) the collective invention model. In the landlord model the owners of large estates acted as experimental stations introducing new crops and cultivation practices. Successful innovations were adopted by the landlords' tenants and, subsequently, spread further by means of imitation. An example of this model is the case of the introduction of the turnip and of the four-field crop rotation system. These practices were the outcomes of the experiments of Charles Townshend in his estate of Raynham. Landlords could appropriate some returns from their inventive efforts by means of higher rents. However, it seems that non-pecuniary motives such as reputation also played a role. Several country gentlemen assumed that agricultural research was one of their civic duties: for example, the famous experimental agricultural station of Rothamstead was created and funded by Sir John Bennet Lewes (Hayami and Ruttan, 1985: 207). The spread of the agricultural innovations developed in these estates was enhanced by the detailed description of cultivation practices in agricultural treatises, which became a very popular literary genre during the eighteenth century. Agricultural improvers also keep abreast of novelties by means of public discussions in agricultural societies and of correspondence networks, sharing information on the relative success of new crops and cultivation methods in different conditions (Fussell, 1932 and Mokyr, 2009: 185–97).

Intensive knowledge-sharing was also a feature of the second model of innovation identified by Allen. Concerning this second model, most of the literature has regarded open-field farmers as retrograde and unwilling to introduce novelties. Instead, on closer inspection, the evidence shows that open-field farmers engaged in what Allen has called "collective invention." In collective-invention settings, a group of competing actors prefers to share the innovations they have introduced, rather than protecting them by means of patents or other instruments or keeping them secret. Collective invention was first recognized for industrial technologies such as blast furnaces (Allen, 1983) or steam pumping engines (Nuvolari, 2004). In these cases of complex industrial technologies where the understanding of the different factors affecting the performance of the artifact can be understood only after prolonged experimentation, collective invention was found to be a particularly effective way of organizing inventive activities, because by sharing information, inventors can build on each other's experiences and fruitful lines of technological advance can be promptly identified and pursued (Allen, 1983; Bessen and Nuvolari, 2011).

Allen (2009: 69–74) contends that seventeenth-century open-field farmers also adopted the collective invention model. This is indeed not surprising because the successful introduction of new crops and new rotation practices always requires a prolonged phase of experimentation in order to adapt the crop to specific local circumstances.[5] Thus, new crops such as sainfoin, clover or turnips were first tried and perfected on small portions of land and if successful adopted on a larger scale by open-field farmers.[6] A later example of this collective invention model is perhaps provided by Moser and Rhode (2012) in their recent study of the development of rose breeding in the United States. Moser and Rhode show that hobbyists developed a significant number of new high-quality rose varieties before 1930. Interestingly enough, hobbyist rose breeders in this period typically shared these advances freely, without restrictions, sometimes within the framework of formalized institutions such as the American Rose Society (Moser and Rhode, 2012: 430).

From the second half of the nineteenth century, the English model of innovation that we have outlined here was superseded by the German model. This model is essentially geared around the systematic public funding of agricultural research. The chief objective was the application of scientific knowledge in the sphere of agriculture. For this purpose, the German system was based on the creation of publicly funded agricultural experimental stations, where scientific insights (in particular from chemistry) could be systematically tried and assessed. The advantage of the public system was that individual farmers have often limited resources for carrying out systematic experimentation. The efficacy of the system was obviously dependent on the spread of the innovations developed by the publicly supported research institutions. Hence, public support involved not only research, but also diffusion policies and education.

The United States substantially imitated the German system. However, besides publicly funded research stations, the American system was based on the creation of specialized colleges and universities for both agricultural research and training, funded by means of the donation of federal lands (for a detailed account of the American public research system in agriculture, see Huffman, and Evenson, 1993). The major success of the U.S. public research system pertained to the area of biological innovations, in particular the development of scientific hybridization of corn varieties around the

1920s (Hayami and Ruttan, 1985: 218–19). The success of hybrid corn, developed mainly by publicly funded agricultural experiment stations, seems indeed to confirm the notion that biological innovations, because of their weak appropriability, were dependent on public research funding. More recently, public research efforts at an international level have also been geared towards the creation of broadly accessible clearinghouses of crop genetic resources. In fact, on a more general level, it should be noted that plant breeding is inherently based on what already exists and, for this reason, inventive activities in this field require free access and use or sharing of materials. One of the main motivations leading to the creation of the International Board on Plant Genetic Resources (IBPGR) in 1973 was precisely the constitution of an international clearinghouse for the conservation of plant germplasm in order to make it available for future research (see Chapter 10 of this volume).

3. THE EVOLUTION OF THE INTELLECTUAL PROPERTY REGIME FOR BIOLOGICAL INNOVATIONS

3.1 The twentieth-century history of intellectual property rights for plant varieties

As we have seen, during the twentieth century, biological innovations were developed by virtue of the fundamental contribution of public research funding. However, the legal framework was not static and from the beginning of the twentieth century the case for introducing some systematic form of protection for private breeders for the creation of new plant varieties gained momentum. Overall, the picture emerging is that of a progressive deepening and extension of intellectual property over biological innovations in agriculture. This trend is mostly visible in the U.S., but it is also traceable in Europe and, via TRIPS, at a global level. The extension of intellectual property in the realm of biological innovation grew out of the strong lobbying actions of inventors and companies involved in chemical and biotechnological research. Dutfield (2009: 47) argues that a significant component of these lobbying activities were aimed at securing not only a favorable rearticulation of intellectual property legislation, but also what he calls the "interpretive custody" of the patent system. This means that the lobbying strategies of the companies were not limited to obtaining support for specific reforms, but were also aimed at shaping the conventional wisdom of both government and society on the nature of biological innovation and, in particular, at removing from the public eye many of the ambiguities arising from the establishment and enforcement

of intellectual property rights in this area, so that many critical questions could be perceived as merely technical matters to be left to the decisions of experts. Only recently, with the debate over TRIPS this "interpretative custody" of the patent system by chemical, pharmaceutical and biotechnology companies has been explicitly challenged by alternative viewpoints (Dutfield, 2009).

In the U.S., during the second half of the nineteenth century, the reduction of transport costs and the consequent formation of larger national markets generated a pressure from animal breeders and nurserymen for the creation of some form of intellectual property protection. When markets were local, breeders and nurserymen competed by relying chiefly on reputation. This became more difficult in a large national market where transactions became more impersonal. In order to protect their innovative assets, animal breeders developed systems of registration certifying the pedigrees of the animals in publicly available studbooks (Kevles, 2007).[7] Leading nurseries instead lobbied to obtain some specific form of federal intellectual protection for plants.[8] A first attempt was made in 1906 with the proposal of a trademark approach to protect plant varieties (this is, for example, the case of the "Stark Delicious" apple). The attempt failed, partly because of the patent-like goal embedded in the proposal: protection of a product was obtained by protection of a registered name (Bugos and Kevles, 1992). Moreover, "trademarking protected only the name: it did little to defend the breeder against the fact that the same rose by any other name might be marketed to smell as sweet" (Bugos and Kevles, 1992: 98).

European countries were also experimenting with a similar approach: in France, Germany and the Netherlands a de facto protection of breeders' rights was in place by means of a system of *catalogue* and *certification*. The United Kingdom was very late in adopting any form of legislation to ensure the purity of the seeds on the market and the government approach to this issue was shaped by strong anti-interventionist concerns.[9] Between 1912 and 1921, several plant-breeding research institutes were established with public funding in the UK. They had the mission of developing better seeds for the market (this was of course accompanied by huge concern from the private seed traders), and they were founded in the belief that Mendelian genetics would drastically transform plant-breeding practice (this belief was not shared by all the biologists). The principal institutes were the Plant Breeding Institute at Cambridge (1912), the Welsh Plant Breeding Station in Aberystwyth (1919), and the Scottish Plant Breeding Station in Corstorphine (1921). The organization claimed as a model for these institutes was the Swedish Seed Association, which provided varieties for a joint stock seed company, whose profits were, in turn, used to finance research, with any residue shared among the shareholders. Although acceptable in Sweden, this model was not accepted by the British seed trade. This was not the only problem related to the plant-breeding research institutes: they were in fact characterized by a very poor performance in adoption and commercial terms. Virtually all new varieties produced in the UK were not considered profitable by farmers, who were looking for greater quantity than quality. This failure was the result of a lack of communication channels between agricultural scientists and farmers (Palladino, 1990).

Formal attempts to introduce patent protection for plant varieties started literally a few weeks after the failed effort to introduce plant breeding in the U.S. trademark system. Congress was presented with a proposal to amend the utility patent statute to accommodate plant innovation. This attempt also failed and two main motives were put forward. First, there was the "natural products" objection against patenting living subject matter. In fact, plant patenting had been already discouraged in 1889 by the U.S. Commissioner of Patents, when an application for a patent covering a fibre created using the needles of a pine tree was rejected. The commissioner regarded it as "unreasonable and impossible" to allow patents upon the plants of the earth (Bugos and Kevles, 1992). This position was somewhat softened in 1891, when the respected plant scientist Liberty Hyde Bailey of Cornell stated that "when the time comes that men breed plants upon definite laws and produce new and valuable kinds, then plant patents may possibly become practicable" (cited in Bugos and Kevles, 1992: 80). Moreover, the proposed amendment to patent law required disclosure of the new plant varieties just in terms of identification and not of replications as is required for standard utility patents.

Despite this unpromising start, the U.S. was still the first country to offer patent protection for new plant varieties. With the Townsend-Purnell Plant Patent Act of 1930, patent-like protection (*sui generis*) was offered to new plant varieties asexually reproduced, explicitly excluding plants reproduced via seeds.[10] Two main factors can account for the introduction of this distinction between asexual and sexual reproduction. Plants that reproduce asexually are essentially ornamentals and fruits: this Act was indeed heavily pushed forward by the lobby of the flower nursery operators (led by Paul Stark of the Stark Brothers Nursery, the largest breeder in the country). Moreover patent protection for plants of critical importance for food supply was not felt politically acceptable during the Great Depression. The idea of food as a scarce resource still had strong roots in public opinion, so that policymakers were extremely reluctant to allow the establishment of, even a temporally limited, monopoly power in this area. The gloomy economic landscape of the Depression on the other side facilitated the passage of the Bill, as the prevailing conventional wisdom on how to respond to the recession was to stimulate private investments and to reduce public expenditure. Protection for plants was further strengthened in 1939 with the Federal Seed Act which imposed standards on seeds sold in interstate commerce: this certification not only protected consumers against unreliable seeds but also defended high-quality seed from competition from low-quality alternatives.

In a recent contribution, Moser and Rhode (2012) have provided an appraisal of the effects of the Plant Patent Act of 1930 on the rates of innovation in plant variety looking at the evolution of the U.S. rose-breeding industry over the period 1930–70 (nearly 45 per cent of the plant patents granted between 1931 and 1970 were for roses). Moser and Rhode found also that in this period the patentees who were granted most patents were all connected with major companies. Additionally, Moser and Rhode also established that the majority of rose patents were systematically assigned to commercial breeders. These two pieces of evidence may perhaps suggest that the Plant Patent Act exerted a favorable impact on inventive activities stimulating the creation of new rose varieties suitable for commercialization. However, Moser and Rhode (2012) provide a different interpretation. In their view, large U.S. commercial breeders were forced to use plant patents for protecting new varieties to shield themselves from the threat of litigation rather than for directly appropriating economic returns from the breeding activities. In fact, comparing rose patents with the variety of roses registered with the American Rose Society (breeders use these type of registrations not as tool for direct appropriation, but rather as authors' rights, i.e. for establishing the name of the new variety of rose they had created and for claiming reputational credit), they estimate that only 16 per cent of the new rose varieties created between 1931 and 1970 were patented. Hence, on closer scrutiny, the Plant Patent Act did not actually provide a significant stimulus to inventive activities in this field. Furthermore, registration data also indicate that European and not U.S. breeders developed the majority of new rose varieties introduced in the U.S. in the period 1930–70.

European countries also moved towards the developing of *sui generis* forms of intellectual property protection for plant varieties. These systems were harmonized in 1961 with the establishment of the International Union for the Protection of New Varieties of Plants (or UPOV). The system supported by UPOV included protocols to describe and evaluate the characteristics of new varieties in order to guarantee their distinctiveness, uniformity and stability. It required member states to provide protection for plant breeders' rights for at least twenty years. The system also contained important limitations to the monopoly right: breeders could use protected seeds without authorization to create new varieties, and compulsory licensing was possible in case public interest required the use of the plant (Dutfield, 2009: 206). The underlying idea was to protect breeders' efforts without disadvantaging farmers or jeopardizing the food supply.

In the same years, and under the stimulus of UPOV, the U.S. Congress started considering the possibility of legislation to extend patent rights to seed-grown plants. New aspects had emerged in the breeding landscape that forced congressmen to revise the status quo in terms of plant protection. First of all, the promises of hybridization as a mean to protect varieties were falling short for several plants, notably wheat. Moreover, the seed market was becoming increasingly globalized and demand for seeds was increasing not only in the developed countries, but also in developing countries, as shown by the Green Revolution. European agriculture had recovered from the Second World War and returned to the international markets as a strong competitor of the U.S. Finally, the extremely high post-war demand for U.S. agricultural products (which meant that quantity was preferred over innovation) was declining (Bugos and Kevles, 1992). In 1971, the Plant Variety Protection (PVP) Act was passed, which guaranteed *sui generis* protection for sexually reproduced (i.e. through seeds) plants. The criteria for protection were novelty, distinctiveness, uniformity and stability.[11] Moreover, when filing an application for a patent protecting a plant variety, a seed deposit was required (this is a way to manage the issue of public disclosure). However, there remain fundamental differences between the PVP regime and the utility patent regime: first, in the PVP there is no requirement of non-obviousness; moreover, the disclosure requirements are not comparable to the ones found in general patent law. Furthermore, PVP contains two limitations that are not present in patent law: the research exemption (as long as it is *bona fide*) and the saved seed exemption (farmers are allowed to save part of their harvest to extract seeds for the next season) (Janis and Kesan, 2002; Williams, 1984).

In the U.S. a further step towards the strengthening of intellectual property protection was made with the well-known *Diamond v. Chakarabarty* decision of the U.S. Supreme Court in 1980 (which ruled that a live, human-made micro-organism is a patentable subject matter). After this decision, genetically modified plant varieties were more likely to be protected using a utility patent rather than a PVP certificate. In the U.S., the legislative landscape became even more favorable to granting patents for living organisms in 1988, with the OncoMouse (or Harvard Mouse) patent. The protected mouse is a genetically modified mouse engineered to carry a specific gene (an activated oncogene) which increases the mouse's susceptibility to develop cancer, making the animal particularly suitable for cancer research. The patent granted in the U.S. explicitly excluded humans, in order to address widespread concerns about patents on human beings and on the human genome (Kevles, 2002). In Europe, the history of this patent is more complex. The Examining Division of the European Patent Office (EPO) initially refused to grant a patent for the OncoMouse, as the European Patent Convention (EPC) excludes animals from patentability (art. 53b). This decision was however appealed, as the convention in article 53b excludes plant and animal varieties from protection, but not animals as such. Following this appeal, an EPO patent for the OncoMouse was granted in 1992. This patent was then opposed on the grounds of another article of the EPC, which excludes from patentability inventions contrary to public

order or morality (art. 53a). The opposition took place in 2001 and the patent was maintained in an amended form, limiting claims to mice. In order to address the exception contained in article 53a, the EPO employed a utilitarian balancing test, weighting the potential benefits of the invention (in this case the expected medical benefits to humanity) against negative aspects (in this case the suffering of the mouse). Another appeal took place in 2004, which was unsuccessful, and the patent is thus maintained in the amended form.

Until the beginning of the 1990s, the protection of plant varieties has been essentially an exclusive characteristic of developed countries. However, following the Uruguay Round of the WTO, the international efforts to harmonize intellectual property protection systems have also accelerated the diffusion of plant variety protection systems in other countries. Article 27.3(b) of the TRIPS agreement states indeed that vegetable varieties can be excluded from patent protection but they must be granted an effective *sui generis* protection (Srinivasan, 2005). Table 8.1 contains a summary overview of the historical evolution of the intellectual property regime for biological inventions.[12]

Table 8.1 The historical evolution of intellectual property protection for biological inventions

Year	Country	Key facts
1889	U.S.	Rejection of the application for a patent on a fibre obtained from pine tree needles.
1906	U.S.	Proposal of a trademark approach to protect plant varieties: failed.
1906	U.S.	Proposal to amend the utility patent statute to incorporated creation of new plant varieties: failed.
1912–1921	UK	Establishment of publicly funded plant-breeding research institutes.
1930	U.S.	Townsend-Purnell Plant Patent Act: patent-like (*sui generis*) protection offered to asexually reproduced plants.
1939	U.S.	Federal Seed Act: setting of standards on seed sold in interstate commerce.
1961	Europe	International Convention for the Protection of New Varieties of Plants: creation of the Union for the Protection of New Varieties of Plants (UPOV).
1971	U.S.	Plant Variety Protection (PVP) Act *sui generis* protection offered to sexually reproduced plants.
1978	U.S.	Ratification of the Convention for the Protection of New Varieties of Plants (accompanied by major revisions).
1981	U.S.	*Chakrabarty v. Diamond*: first patent on a living human-made micro-organism).
1988	U.S.	OncoMouse patent (1992 in Europe).
1986–1994	Worldwide	TRIPs Agreement: plant varieties must be granted at least *sui generis* protection.

3.2 The impact of plant variety protection on productivity

Since the enactment of the PVP Act, there have been claims that this reform increased the number of plant varieties available on the market. Several studies (Butler and Marion, 1985; Perrin et al., 1983) found that the PVP Act has had a significant impact on private variety research in terms of the number of new varieties introduced in the market. However, it is important to take into account that one of the effects of the Act was also to increase the incentive of breeders towards the production of varieties with a shorter lifespan, in order to induce farmers to adopt new varieties every year. In fact, the empirical evidence on the quality of PVP-protected varieties is still not conclusive.

Clearly, the overall assessment of the impact of plant variety protection on the performance of the agricultural sector is a very difficult one. Seeds are a peculiar factor of production because, at least potentially, a farmer could produce his own seed by withdrawing a small portion of his crop from the market. This procedure is usually quite easy and not very costly. Of course, seed companies need to convince the farmer not to do so, and to buy new seeds every year. There are then two possible strategies for the seed producer. The first involves economies of scale: the producer should be able to produce seeds of the appropriate quality cheaper than the farmer, which is not often the case. The second consists in reaping monopoly profits by creating seeds that have a very short lifespan or are consumed in the production process, in other words, that are not self-reproducing (see Chapter 9 of this volume for a more extensive discussion).

There are two possible ways to do so: the first is by hybridization, which already started at the beginning of the twentieth century, the second is through the employment of genetic use-restriction technologies (GURTs). These technologies come in two broad types: variety-level (they are designed so that a seed producer can inoculate the seed with a specific regulator that renders the plant infertile, thus making it pointless to save seeds) or trait-specific (in this case seeds can be saved for reproduction but the valuable trait, such as disease resistance, must be activated with a highly specific and proprietary compound) (Wright et al., 2007). The profits derived from the employment of such technologies can be considerably high, especially in a commodity market like the one for seeds, and this has had a strong influence on the direction of breeding research, especially in Europe and in the U.S., and on the concentration of the market (Berland and Lewontin, 1986). For example, the protection via hybridization was strong enough in the U.S. to foster the creation of a profitable private seed industry in the 1930s (Wright et al., 2007).

For these reasons, the assessment of the impact of intellectual property reforms in this area requires an approach which can properly take into account these specificities: the legislation which grants intellectual property rights over plants, the level of enforcement of such legislation, the specific biological characteristics of the crop, the state of the technology used and the actions of both seed producers and farmers. If we analyze the trend of granting PVP certificates from 1973, we note that more than 60 per cent of all certificates have been awarded after 1990, while the majority of certificates are withdrawn before the end of the protection period (Srinivasan, 2005). The total number of certificates is increasing, but this is mainly due to new countries entering the UPOV agreement. In Europe and in the U.S. the situation is stagnant: European countries have indeed opted for a community certificate (CPVO), while the protection in the U.S. is shifting towards utility patents. The decline in UPOV certificates in the U.S. is accompanied by a large increase in the number of patents granted to plant varieties (Srinivasan, 2005). A study conducted by Frey (1996) in the U.S. highlighted that the PVP Act of 1971 has been beneficial only for some specific varieties. Other studies pointing to empirical evidence support the claim that the strength of the intellectual property system is positively correlated with the number of PVP certificates granted (Pardey et al., 2003; Srinivasan et al., 2002).

These studies, however, do not take into account the impact of the introduction of plant varieties protection on overall welfare and productivity. Indeed, it is not surprising that the introduction of a stronger form of intellectual property protection for plants has induced more private research investment in this field. Interestingly enough, studies which have tested the effect of the PVP Act on agricultural productivity, found that the Act's effect on yield improvement was not statistically significant (Perrin et al., 1983; Babcock and Foster, 1991; Alston and Venner, 2002). Concerning overall welfare, even studies pointing to a positive impact of stronger appropriability (comparing hybrid and non-hybrid crop varieties) on the increase of yields, note the detrimental impact of stronger appropriability on the spread of innovations (see again also Chapter 9 of this volume).

An example of the importance of diffusion for a developing country is represented by the case of the soybean in Argentina. Argentina introduced legislation for plant breeders' rights following the UPOV guidelines in 1994, but still refrained from allowing full patent protection for plant varieties. Thus, the transgenic variety of Roundup Ready soybean patented by Monsanto in the U.S. and Europe was not recognized as patentable subject matter in Argentina. This resulted in a particularly rapid diffusion of this particular variety and in a sustained growth of soybean output establishing Argentina as one of the world-leading producers of this crop (López, 2009). In 2004 Monsanto withdrew completely from the Argentinian market blaming infringement of intellectual property and black market competition. Later, Monsanto adopted the strategy of starting infringement actions against importers of Argentine soy in Europe where the transgenic seed by Monsanto had been patented in 1996 (Kranakis, 2007: 723–4). To date, both a UK court and the European Court of Justice ruled against Monsanto, while holding that patent protection on the gene was extendable to soy by-product imports (see Cohen and Morgan, 2008 for an analysis of the UK court decision).

Finally, we should add that several scholars have pointed out that stronger intellectual property protection for new plant varieties may degenerate in what in the literature is called the "anti-commons" tragedy, that is a situation in which inventions are underutilized because they are subjected to multiple, fragmented property rights. In order to avoid the risk of the anti-commons tragedy several "open-source" initiatives aimed at facilitating the sharing of knowledge in the field of agricultural biotechnology have recently emerged (Wright et. al., 2007 and Chapter 10).

4. CONCLUSIONS

We think that our review of the literature warrants two important conclusions. The first is that innovation processes in agriculture rely on the exploitation of different knowledge bases such as mechanical and chemical technologies, biology, etc. As a result, the institutional arrangements supporting inventive activities are extremely variegated, with a number of different actors involved. It is clearly important to take this specificity into account in the design of future intellectual property reforms. Secondly, it is also clear that in agriculture a large share of inventive activities has been carried out for very long spans of time in regimes of weak intellectual property protection. This is clearly the case for biological innovations. The recent contribution of Olmstead and Rhode (2008) has the merit of bringing to our attention the dramatic rate of progress attained in plant and animal breeding in the U.S. throughout the nineteenth century, well before the introduction of formalized intellectual property protection. It is worth quoting from the conclusions of their study:

> [W]ell before plants received patent protection there was a plethora of private sector inventive activity, where leading farmers and seed companies made significant contributions to plant improvement. State and federal agencies added to this brew. Animal breeders were at least as active, and many developed national markets for their creations. A large and important literature has identified inventions with patents. The absence of patent records for a large class of biological activities has led to the inference that little has happened. However, a search of the press, farm journals, Patent Commission reports, and various state and federal commission reports suggests that innovators were making great strides in the introduction of new and more productive plants and animals.
>
> (Olmstead and Rhode, 2008: 400–1)

To this we should add, that even in areas where patents were available and could be used effectively such as agricultural machinery, it is frequently possible to find examples of inventors using successful appropriability

strategies that do not rely on formalized intellectual property rights. When the recent discussions on intellectual property protection reform for agriculture are considered in this light, one cannot avoid the impression that excessive emphasis has been put on the implementation of strong intellectual property regimes and that, instead, a more sober and pragmatic approach to this issue is in order. In this respect, our historical survey of agriculture resonates well with the broader concerns emerging from the analysis by Cimoli et al. in Chapter 2 of this volume.

NOTES

1. "Strong" and "weak" appropriability in this chapter refers to the degree of enforceability of intellectual property rights.
2. A major invention, greatly enhancing the transportation of plants over long distances, was the so-called "Wardian case" invented by the Englishman Nathaniel Bagshaw Ward (1791–1868) in the 1830s. The "Wardian case" was an almost airtight glass case in which plants could be kept alive for very long periods of time. Interestingly enough, Nathaniel Ward did not patent his invention, rather he published a detailed description of it in 1842, *On the Growth of Plants in Closely Gazed Cases* (D. E. Allen, 2004). Using portable Wardian cases, in 1851 Robert Fortune was able to transfer more than 2,000 plants and 17,000 seedlings from China to India (Boulger and Baigent, 2004).
3. The non-patentability of plants in the framework of the early English patent system was not really clear and MacLeod was able to identify three patents for "new crops" granted during the second half of the seventeenth century (MacLeod, 1988: 98).
4. Parker and Klein (1966) is a classic growth-accounting exercise of the sources of productivity growth in American agriculture during the second half of the nineteenth century showing that "mechanization was the strongest direct cause of productivity growth" (Parker and Klein, 1966: 543). For a revision of Parker and Klein's estimates which, instead, emphasizes the predominant contribution of biological innovation, see Olmstead and Rhode (2008: 57–62).
5. It is interesting to note that in most cases, given the atomistic structure of most agricultural markets, the quantity produced by each farmer has a negligible impact on price. Hence, the sharing of technical know-how with neighbours is not likely to determine a competitive backlash. Further, in this context, if knowledge sharing is reciprocated, this may lead to a generalized welfare improvement. These characteristics of agriculture can account for many cases of the cooperative approach taken by farmers with respect to the introduction of inventions that are highlighted in the literature. See Braguinsky and Rose (2009) for a discussion and formalized treatment.
6. Havinden (1961) contains a detailed case study of the introduction of sainfoin and turnips in Oxfordshire open-fields.
7. Bugos (1992) contains a detailed case study showing that US chicken breeders, even without resorting to patent protection, could effectively appropriate economic returns from innovation using a variety of methods such as the establishment of quality standards, trade secrets, etc.

8. According to Boldrin and Levine (2008: 53), the lobbying activities for IP protection of plant breeders suggests a slowing down of the innovative dynamism of the industry with respect to its early years: "Innovative and dynamic industries emerge because intellectual monopoly is not present or because it can be easily bypassed. They grow rapidly because competition and imitation allow and force their firms to innovate or perish. In fact, in the early stage, agricultural innovators often would provide their customers with incentives to copy and reproduce their seeds, as a tool to spread their use. However, as the industry grows more powerful and opportunities for further innovation diminish, the value of monopoly protection for insiders increases, and lobbying efforts multiply and most often succeed."
9. Charnley (2013) shows that, even in late nineteenth-century England, i.e., a context without formalized intellectual property rights and limited public funding, a system based on reputation (which he terms "moral economy of plant breeding") provide plant breeders with significant incentives for engaging in inventive activities.
10. Thomas Edison also provided support to the Plant Patent Act of 1930 in congressional debates. He argued that plant patents "would give us many Burbanks." Luther Burbanks was a successful breeder who had successful developed many plant varieties and was a personal friend of Edison. To this statement, Fiorello La Guardia retorted that "Luther Burbank did very well without patent protection" (both passages cited in Moser and Rhode, 2012).
11. A variety must be (i) "distinct, in the sense that the variety is clearly distinguishable from any other variety the existence of which is publicly known or a matter of common knowledge at the time of the filing of the application," (ii) "uniform, in the sense that any variations are describable, predictable and commercially acceptable," (iii) "stable, in the sense that the variety, when reproduced, will remain unchanged with regard to the essential and distinctive characteristics of the variety with a reasonable degree of reliability commensurate with that of varieties of the same category in which the same breeding method is employed."
12. For a recent overview of the evolution of intellectual property rights for plant varieties in global perspective see Campi and Nuvolari (2013).

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