Technology Paradigms and the Innovation–Appropriation Interface: An Examination of the Nature and Scope of Plant Breeders' Rights[1]

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ABSTRACT *Technological change is crucial for the continued socio-economic development of a country. A number of factors underpin a society's ability to foster continuous technological change, one of which is necessarily the conditions for appropriability. These have become increasingly important since the location of technological change remains largely in the hands of organised research centres housed in large corporations. This paper examines a selection of the issues that interface between innovation and appropriability in the case of plant breeding. This industry has only lately become a subject of study, following the increasing industrialisation of farm-related activities, the technological restructuring of breeding through biotechnology, and the enhancement of the scope of intellectual property rights (IPR) in plant breeding.*

Keywords: plant breeders' rights, intellectual property, biotechnology, patents, seeds.

Introduction

The paper is organised as follows: it begins by identifying key relevant concepts in the evolutionary economics literature, such as technology paradigms, modes of learning, heuristics and search strategies. This literature notes the crucial importance of focussing on patent scope when examining the issue of innovation appropriability in a technology sector. Using the framework identified in this section, the following section explores the technology paradigm of plant breeding. This is achieved through an identification of some key characteristics of plant breeding and idiosyncratic properties of the product that embodies the innovation, the seed. These properties of the sector and the product are used to explain aspects of the innovation–appropriability interface. The third section is devoted to an examination of plant breeders' rights (PBR), in terms both of the conditions of grant and also changes in the scope of protection. The paper ends with a conclusion which notes some of the consequences of using this methodology to examine the innovation–appropriation interface.

The Evolutionary Approach to Studying the Innovation–Appropriation Interface

Technological Imperatives

Some contributors visualise the innovation process in a linear fashion where novel ideas

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are the progenitors, leading experimentation, developmental work and eventual commercialisation of either a product or process. This model of the innovation process as a linear progression of ideas culminating in products or processes has been rejected by many, including a group of evolutionary analysts who alternatively focus on technology paradigms. In this approach, emphasis is on the economic manifestation of technological achievements, where the specific techno-economic problems act as focussing devices for scientific attention.[2] Thus, even while technologies evolve through the progressive exploitation of specific, selected, novel ideas, there is a range of 'imperatives' which guide and substantially determine the trajectory of development.[3] Importantly, there is nothing predefined in ensuring the linear path of exploitation of novel ideas which culminate in the commercialisation of products or processes. The multitude of factors which constitute the notion of technology paradigms are:

> ... the needs that are meant to be fulfilled, the scientific principles utilised for the task, the material technology to be used. In other words, a technological paradigm can be defined as a 'pattern' of solution of selected technoeconomic problems based on highly selected principles derived from the natural sciences, jointly with specific rules aimed to acquire new knowledge and safeguard, whenever possible, against rapid diffusion to the competitors.[4]

Following Kuhn's (1970) work on scientific paradigms,[5] the notion of technology paradigms also incorporates a strong puzzle-solving dimension which manifests itself in artefact development.[6] Changes in specific techno-economic attributes of the artefact (the needs being fulfilled) help to map the trajectory of technological development. For example, in aircraft the trajectory has been marked by the trade-off between horsepower, gross takeoff weight, cruise speed, wing loading and cruise range.[7] Nelson and Winter emphasise the influence of the underlying knowledge base, the chemical and physical properties of the technological sector, and the socio-institutional setting of innovative activity in establishing the direction of technological development.[8]

An enquiry into socio-institutional settings involves an examination of the heuristic and search strategies adopted which, given their paradigmatic status, indicates a wide degree of 'shared cognitive structures'.[9] Herein one finds another allegiance to Kuhn's elaboration of the normalisation of scientific paradigms.

> Men whose research is based on shared paradigms are committed to the same rules and standards for scientific practice. This commitment and the apparent consensus it produces are prerequisites for normal science, i.e. for the genesis and continuation of a particular research tradition.[10]

The notion of 'commitment' to particular research orientations has been incorporated by Dosi to suggest the 'exclusionary' effect of technology paradigms, such that the selection of particular trajectories generates a notion of 'progress', while alternative paths of development are seen as retrograde.[11] The literature has examined the wider socio-political aspects of technological development using a number of different notions, such as 'selection mechanisms',[12] 'bridging institutions',[13] and 'lobbies'.[14] It is through such institutional structures that the dominant technological paradigm provides its notion of progress to legitimate the preferred direction of technological change. For example, defence considerations not only provided the focus for the development of chemical, semiconductor and computer industries at various points in time, but also channelled the financial resources and ensured public acceptance for a particular mode of socio-technological development.[15]

In addition to the above socio-political factors which substantially determine the nature of technology systems, the literature notes the substantive influence of techno-economic imperatives in determining the trajectory of technological change. Particular mention is made of the characteristic feature of technological knowledge in that it is specific to the task it has been developed for; it is highly selected and finalised.[16] This conceptualisation of technological knowledge stands in contrast to the neoclassical characterisation, where technological knowledge is conceived as a book of blueprints.[17] The range of factors which leads to the focussed nature of technological problems is manifested in the selected characteristics of the artefact being modified, and thus, the narrow, bounded trajectories of technological change. Rather than witnessing indifference curves which map the entire range of the characteristics of an artefact, the trajectory is clustered along particular characteristics. This clustering is reinforced by lock-in effects, scale economies, path-dependencies and irreversibility.[18]

Conditions for appropriability are important in selecting the direction of technological change. The paradigm itself provides the means and strategies for safeguarding the diffusion of new knowledge. Empirical research demonstrates that the techno-economic characteristics of the sector substantially determine the preferred instruments of appropriation.[19] Consequently, in some sectors, specific strategies of appropriation prove to be more effective and reliable than those pursued in other sectors. For example, secrecy is a weak option in the case of innovations in the chemical-based industries since reverse engineering of products is easy.[20] Since inventions in this sector are relatively 'discrete' and relate to specific molecules, patents provide reasonable protection as it is easy to prove infringement through the presence or absence of the patented molecule.

The Economics of Patent Scope

Among the formal instruments of intellectual property protection, patents have been widely studied in terms of the following themes: the incentive and resource allocative role of patents,[21] the welfare economics of patents,[22] and patents as indicators of technical development and productivity.[23] Neoclassical analysis of patents has been confined largely to studying the trade-off between changing incentives for inventive effort and the deadweight losses arising because of the monopoly right.[24] For the most part, neoclassical economic modelling of patents has focussed on the period of protection as the main issue in determining the impact of patents.[25] Additionally, analysis has proceeded by focussing on singular features of the patent system with the objective of defining 'optimal' patents—in terms of optimal licensing,[26] optimal length[27] or optimal shape.[28]

Less attention has been devoted to another significant aspect of patents—the scope of protection which determines the range of competing products and/or processes which might be judged to be infringing.[29] The scope of protection has a crucial influence on technological change, not only in terms of the development of the technology, but also in directing the line of future improvements and the direction of technological advance. Apart from this very basic consideration, patent scope is determined by the discretionary powers of the court, leading to degrees of uncertainty. These three factors make it a prime candidate for economic analysis. Studying the impact of patent scope decisions on technological development requires a clear understanding of: (a) the legal doctrines employed by courts in demarcating the borders of the patent when called upon to interpret claims made by the inventor; and (b) the nature and historical stage of technological evolution in the industry. Analysis of the impact of patent scope requires a prior analysis of the mode of technological advance and the nature of competition in the market.

There is much more at stake regarding allowed patent scope in these cumulative

> technologies than in those where inventions are discrete and stand separately. Particularly when the technology is in its early stages, the grant of a broad gauged pioneer patent to one party may preclude other inventors from making use of their inventions without infringing the original patent. ... Alternatively, in multicomponent products, broad patents on different components held by several inventors may lead to a situation in which no one can or will advance the technology in the absence of a license from someone else.[30]

Thus, following the framework established in the evolutionary literature, this paper proceeds to identify and characterise the paradigmatic features of plant breeding. Here particular attention needs to be devoted to the product embodying the inventions, the seed. It is only after this analysis that an examination of the scope of PBR can be conducted.

The Technology Paradigm of Plant Breeding

Plant breeding is an ancient practice with evidence of domestication and selection, in the case of wheat, as far back as 28,000 BC.[31] More recently, in the eighteenth and nineteenth centuries, much of the breeding involved the selection of varieties from those maintained by farmers on their fields.[32] Not until the beginning of the twentieth century did breeding transform itself from craft to science by focussing on maintaining the genetic improvements achieved in parents through successive generations in the form of uniform pure lines.[33] Plant breeders differentiated their activity from that of farmers by insisting that farmers return to breeders for fresh seeds after each harvest on the grounds that breeders were the only people capable of maintaining plant varieties at their true (genetic) potential.

> It is highly important to purchase fresh seeds every year from Brighton where the selection is continued, and without which no 'breed' of anything can be kept.[34]

The difficulties associated with differentiating the role of breeder from that of farmer and creating a lucrative business out of breeding still exist. These hurdles to appropriation relate to specific characteristics of the technology of breeding and the properties of the product embodying the innovations in this sector, the seed.

Paradigmatic Features of Plant Breeding

Plant breeding works under the two related constraints of selection and heritability—the breeder selects the best individual (defined in terms of the concentration of preferred genes) from within a population. The breeder's ability to assemble a range of characteristics in a variety is constrained by the heritability of the characteristics. Only those characteristics which can be inherited over a series of generations are assembled in a variety and the success of the breeding programme is confirmed by the retention of the selected characteristics. However, the very success of producing a variety with a particular combination establishes its heritability and allows it to diffuse through the mere propagation of the variety. For this reason, seed companies seek methods of suspending the mechanism of heritability, such as inducing incomplete heritability (e.g. hybrids),[35] planned obsolescence (e.g. narrow disease resistance spectrums),[36] or terminating heritability altogether (e.g. the terminator gene).[37] Changes in the legal scope of protection are also useful in controlling the use of harvested seeds, a point which will be discussed shortly.

The principles of breeding are well established, giving it the status of a finalised practice as conceptualised by evolutionary economists. The major developments in breeding have usually involved statistical techniques in assessing characteristics across populations, methods of 'growing out', and tools for identifying and assessing plant characteristics. Only in more recent times has the advent of biotechnology heralded significant changes in the knowledge base, heuristics and search strategies of breeders. The normalisation of breeding is probably most evident in the parental material used for the production of new varieties. Breeders tend to begin with advanced breeding material since they already possess the desired varietal characteristics which are well adapted to the local area.[38]

A compelling competitive reason prompts breeders to display this consensus with respect to the breeding material used as parents: these companies are concerned with the continuous production of new varieties, which is made easier through the use of well-adapted advanced breeding material.[39] This shared heuristic and search strategy in the production of varieties, because it involves the use of near-identical breeding material, leads breeders to follow a similar technological trajectory, to produce rather similar varieties.

Now, since some advanced breeding material happens to be protected, the feasibility of the paradigmatic inventive activity in breeding hinges on the limits to the scope of breeders' rights. In addition to legal rights, there exist codes and norms which govern the 'free' use of breeding material, especially when it is protected. The tension here is between the incentives to pioneering breeders who attempt to incorporate some novel characteristic in a variety, and others who will use this as parental material to produce subsequent varieties. Naturally, subsequent (derived) varieties entering the market threaten the market share of the pioneering variety. On the other hand, certain derived varieties may constitute significant improvement which pushes forward the productivity barrier of agriculture. Changes in the legal scope of protection and in the codes and norms of using protected varieties map the direction in which the balancing act has been negotiated.

Characterising the Seed

Agriculture begins and ends with the seed. The seed is both the means of production and the product (grain). More important in this duality is the fact that seeds replicate themselves (genetic information is heritable such that the harvested grain and sown seed are identical). In fact, most economically relevant plant characteristics are easily inherited.[40] Consequently, the saving and re-using of seeds is an economically attractive option for farmers, though it hinders the accumulation of capital by seed companies.[41] At the global level, the largest segment of the seed market (38%), valued at US$18 billion, is provided by farmers themselves.[42] While seed-saving has been historically practised, its contemporary status depends on the definition of the scope of PBR. Redefining the scope to make using saved seeds an infringing act would widen the sphere of accumulation.

Inherent in a packet of (certified) seeds are two distinct properties: (a) the genetic information which characterises the variety, reflecting the result of the breeder's efforts; and (b) physical attributes of the seed resulting from the seed production process.[43] The genetic information characterising a variety distinguishes it from other varieties and consists of agronomic features and attributes such as disease resistance. This conglomerate of genetic characteristics—'software'—is the subject of PBR.[44] The second set of properties includes features such as the seed's germination rate, level of purity and physical attributes, all of which pertain to the seed—'diskette'—production process. Seed production is controlled by regulations devoted to ensuring the authenticity of the embedded genetic software and the reliability of the diskette. Ironically, PBR and seed certification schemes end up producing homogenous genetic software in reliable diskettes. Consequently, some commentators note that genetic software is a public good.

> ... not only can living organisms be reused and recycled, but they can also be *multiplied.* Consequently, the problem faced by a breeder is much worse than that of a typical durable-good monopolist, because the breeder, in a sense, gives away the technical know-how to customers together with the good itself[45] (original emphasis).

However, there is more to the public good status of genetic software which involves: (a) maintaining the purity of the software; and (b) ensuring the viability of the diskette. In some instances, such as soy bean, the harvested seed is not viable,[46] and, at times, saving seeds is problematic when the seed is the edible part of the crop, as with fodder and vegetable crops.[47] In cross-pollinated species, care is required to maintain varietal purity on the farm. Consequently, various activities have to be undertaken in processing grain into seed and restoring the purity of the software.

The above are some of the problems associated with maintaining the durability of genetic software. It is important to note that genetic software forms part of the market strategy of seed companies, such that varieties are a constituent part of a larger socio-technical system. It is in this matrix that one can conceive of breeding strategies aimed at limiting the lifespan of varieties. This may be achieved through changes in one or some of the components of the system which would render the variety incompatible. Alternatively, the variety may be bred to become obsolete in a (planned) short space of time; for example, by maintaining narrow disease resistance spectrums which would then render the variety susceptible to evolving pathogens. In the UK, the case of wheat research demonstrates a causal relationship between the development of varieties with narrow disease resistance spectrums, and the increased incidence and severity of plant diseases.[48] The treadmill of increasing popularity of varieties followed by increased incidence of specific plant diseases leads to the variety's exit from the market. Another reflection of this strategy of planned obsolescence is evident in the decrease in the average age of varieties. This has fallen from over 6 years in the late 1960s to under 3 years in the early 1990s.[49]

Examining the Scope of Plant Breeders' Rights

Establishing intellectual property rights in plants poses a number of problems. Historically, breeders had to convince society of the value of human intervention in producing new varieties, since plant varieties were largely considered to be the products of nature.[50] In an effort to validate the inventive step executed by breeders, it was often argued that breeders created new varieties in much the same way as chemists produced new products by recombining naturally occurring material.[51] In addition, there was socio-political and cultural resistance to the granting of property rights in plants, more so because of the food–seed duality.[52] This factor was reflected in the exclusion of specific tuber-propagated species from the ambit of the 1930 Plant Patent Act (PPA) in the US.[53] The exclusion was because this 'group alone, among asexually reproduced plants, is propagated by the same part of the plant that is sold as food'.[54]

Apart from these hurdles, the introduction of intellectual property protection in plant varieties had to clarify such issues as defining the subject matter of protection, the scope and duration of protection, and methods for identifying the subject matter of protection. The debate in the 1950s–60s in Europe among agronomists, breeders and the industrial patent lobby focussed on these issues.[55] The breeders' lobby played an active role in formulating the framework of protection which became the International Union for the Protection of New Varieties of Plants (UPOV):

> It is for agronomists to say what it is they consider should be protected, and to indicate the conditions under which protection should be granted, in order to make it effective and legitimate.[56]

The effectiveness and legitimacy of the PBR system are intrinsically related to the techno-economic features of the paradigm of breeding and the idiosyncratic aspects of the seed.

Creating Technical Space: The DUS Criteria

Under patent law, an applicant is expected to supply a detailed description of the invention which is being claimed as novel. The description of the invention (specifications) is legally required to disclose the invention so that others skilled in the art may replicate the invention, thus ensuring that (new) knowledge is socially diffused. More importantly, the specifications and the claims made by the inventor define the technological territory of the invention (the scope of the invention), which then identifies the acts which would constitute an infringement of the patent, if and when granted.[57] A parallel in the case of PBR are the triple conditions for the granting of protection—distinctness, uniformity and stability (DUS).

Pure Lines, Uniformity and Professionalising Breeding

The DUS criteria require the plant variety to be distinguishable in at least one characteristic feature from all other varieties of common knowledge, and to remain sufficiently uniform with respect to this distinguishing characteristic when examined across a population. The variety must also retain its distinguishing characteristics across generations. These triple conditions for granting protection enable the identification of a variety in terms of distinguishing characteristic(s) both at the time of grant as well as throughout the period of protection.[58] The principle is reinforced by requiring the breeder to ensure the availability of the variety in terms of its distinguishing characteristic(s), the expiry of the grant, or face forfeiture of the grant. Consequently, the breeder has the responsibility of maintaining the variety as a photographic 'snapshot' throughout the period of the grant.[59]

It is possible to examine the DUS conditions with the principle expressed by Laclavière.[60] Effective and legitimate protection requires, in this case, that agronomists articulate the need for, and method of, granting protection. It is crucial to note that the DUS conditions replicate the method of breeding pure lines.[61] Pure lines emerged as the paradigm of breeding at the beginning of the twentieth century, when breeders were attempting to professionalise and distinguish plant breeding from farming.[62] The critical factor on which breeders focussed was the production of genetically uniform varieties, emphasising the role of the breeder in maintaining varietal purity. These two factors, intended to demarcate the role of the breeder, formed the twin requirements of uniformity and stability in the conditions for granting of PBR. However, because of the variability that characterises plants, problems arose in effectively demarcating territory in genetic space.

Erecting Entry Barriers

Before the founding of the UPOV, many breeding stations preferred a policy which allowed farmers to participate in varietal development. This policy was premised on the principle that, by releasing heterogenous genetic material to farmers, they would be able to exploit the local adaptability of the (unfinished) variety and develop superior genetic material. By exploiting on-farm variability, farmers would themselves participate in varietal development. However, there were problems.

> ... we are, here in Sweden, of the opinion that the first selected new lines should be multiplied and put at the disposition of the farmers in spite of the fact that it is still rather heterogenous ... We are fully aware that in many countries a good deal more stress is put on the importance of homogeneity than is done in Sweden and that the controlling institutions are unwilling to approve varieties of self-fertilised crops which are markedly heterogenous ... As especially wrong, we would like to censure the use of exaggerated requirements in regard to homogeneity as a means of preventing the introduction of varieties in order to protect the interests of the country's own breeders.[63]

Using homogeneity conditions as trade barriers suggests that the development of DUS conditions went beyond the validation of the new profession of plant breeding. Trade in seeds was still in its infancy and differing terms and standards were holding back the formation of a 'common market'. However, each national system was also a means of protecting domestic breeding interests from foreign competition. This difference in national practice was also evident at the level of defining plant varieties.[64] The move towards harmonising the differing national systems was initiated by European Productivity Agency projects aimed at evolving a standard international system of terminology for the designation of certified seeds moving in international trade.[65] Simultaneously (in 1953), the International Code of Nomenclature of Cultivated Plants agreed upon a definition for plant varieties, and norms for granting varietal names began to develop.[66] It is within these arenas that the details of the DUS system evolved.[67]

Identifying plant varieties defines the technological territory which becomes the property of the breeder. The variety is grown over a number of generations to confirm the distinguishing characteristic(s) of the variety, which can be understood to parallel the claims of the inventor in terms of patent law. The main factor in establishing territorial claims in PBR is identifying distinguishing characteristic(s). This gives rise to the issue of 'minimum distance' between parents and derived varieties in cases where the latter may also become the subject of protection, a point which has been raised by ornamental breeders.[68]

The Fundamental Scope of PBRs

The fundamental scope of protection, prior to the 1991 revision of the Convention, extended to commercial acts involving the propagating material of the protected variety. Transactions involving the protected varieties were allowed if one of the two conditions were not met—either the act was non-commercial, or parts other than the propagating material were used. The manner in which the scope of PBR was defined in the 1960s reflected the technology paradigm of plant breeding. First, the regenerative and replicable properties of the seed lay at the root of the practice of saving harvested grain to reuse as seed in the following planting. Such seeds were exchanged and sold within the farming community. Secondly, the activity of producing new varieties was predicated on crossing assembled plant genetic resources. Often the latter consisted of varieties developed and released by other breeders. Both these activities lie at the border of the scope of PBR, where one is non-commercial (using varieties as parental material), the other does not involve the propagating material. During the debate and introduction of PBR in the 1960s, this view prevailed and was widely rationalised.

> The breeders' rights should be confined to acts done for the purpose of trade. This will, for example, exclude from the purview of the breeders' right the production and use of seed saved from the current crop for sowing in a later season. The breeder would not have the right to demand royalty on this seed. We do not think he would find this a serious disadvantage.[69]

In fact, the Committee argued that allowing a charge on saved seeds would amount to legalising a double payment for the same seeds.

Securing the Borders of a Variety—Controlling Genetic Space

The research exemption clause allowed the use of a protected variety (the 'initial') as parental material in the production of another variety.[70] Also permitted was the subsequent grant of protection for the 'derived' variety (if it fulfilled the DUS condition) only as long as the protected variety (the 'original') was not used repeatedly in the production of the derived variety. This limitation, the notion of dependency in terms of plant breeding, applied principally to the breeding of F1-hybrids. Consequently, UPOV provided judicial legitimisation to the paradigmatic feature of breeding, both in terms of sanctioning the use of existing protected varieties as parental material and in terms of hinging the grant of protection on distinctness. This has been criticised in comparisons of the scope of PBR with that of patents,[71] and has prompted others to term the UPOV a 'copier's charter'.[72] Given the tendency of commercial breeders to work closely with the same set of genetic material, the varieties on the market were cosmetically differentiated. As a result, any existing protected variety was quickly threatened by potential competition from near identical varieties.

The 1991 revision to the Convention introduced the notion of 'essentially derived varieties' (EDV) which retained the 'expression of the essential characteristics that result from the genotype or combination of genotypes' of the initial variety. By introducing the notion of EDV, the Convention established the principle of 'minimum genetic distance' between existing protected varieties and potential entrants. Only when the derived variety does not express the essential characteristics of the initial variety will it be granted protection. This is complex and unwieldy, moving confusingly between genotypic and phenotypic factors in establishing distinctness.[73]

Utilising the principle of EDV, it will be possible to introduce genetic distance between the initial (protected) variety and potential entrants which use it as parental material. In this manner, the technological territory controlled by a breeder is not limited to the snapshot of the plant variety as it existed at the time protection was granted. In that breeders tend to focus on select characteristics and use similar genetic material as parents, the notion of EDV will allow breeders to widen the borders of a plant variety to include close substitutes. Naturally, the limits to this activity will depend on what is considered to be infringing. A degree of ambiguity persists and the possibility of judicial interpretations will lead to uncertainties.

Saved Seeds and the Appropriation of the Means of Production

Seeds replicate and regenerate themselves, allowing farmers to access the embedded genetic software in the seed. This grain–seed duality lies at the foundation of the age-old practice of on-farm seed processing—the saving of the grain for use as seeds in subsequent harvests—and the implied exemption from the scope of PBR. Under this exemption, seed saving was beyond the scope of PBR. In fact, the Plant Variety Protection Act (1970) in the US allowed farmers even to sell a portion of seeds saved from the harvest of a protected variety, as long as the name of the variety was not used. This practice of 'brown-bagging' has been strongly criticised by seed companies,[74] which have gone to court on a number of occasions.[75] A result of one case (*Asgrow v. Winterboer)* is that farmers are now allowed to save only enough seed to replant the crop.

The revision introduced in the 1991 Convention makes the use of saved seeds of a protected variety an optional exclusion, leaving it up to the legislating state to decide the details and limits of the exemption from the scope of PBR. However, the measures must not conflict with the breeder's legitimate interests. One route towards curtailing the practice of seed saving has been adopted through Community Plant Variety Rights, whereby a royalty rate on saved seeds is paid by farmers.[76] Arriving at this compromise has been difficult because of the extensive practice of seed saving throughout Europe.[77] For example, after much negotiation, farmers, breeders and seed merchants in the UK agreed on a phased introduction of a royalty rate that would rise to 53% in 3 years.[78] In fact, the UPOV recognised the obstacles to appropriating the means of production and noted the political hurdles that existed in prohibiting the right to use saved seeds. It is because of the inherent duality of seeds that the legal solution adopted by UPOV left the details of the implementing legislation open to member states.

The expansion of the scope of PBR to include the use of farm-saved seeds effectively usurps the reproductivity of plants. In their drive to secure the spheres and limits to appropriation, breeders have sought a number of alternative strategies to undermine the property of plants to replicate and reproduce. Some of these strategies involve such technical solutions as F-1 hybrids and the terminator gene, while others involve planned obsolescence.

Conclusion

This paper has examined the innovation–appropriation interface relationship in plant breeding. This is a unique sector in that the product embodying the innovation, the seed, displays properties of replicability and easy reproducibility. The central focus of breeding strategies has been to subvert the mechanism of heritability. This is one route toward sustaining the spheres of accumulation. A number of technological attempts have been designed to achieve this end, such as F-1 hybrids and, more recently, terminator technology. The paper also explores efforts to revise the scope of PBR to eliminate the use of farm-saved grain as seed in the next harvest. The DUS conditions for a grant of protection highlighted the factors which historically created hurdles to the introduction of PBR. The DUS conditions are important in two critical respects. In providing a judicial legitimisation for a particular mode of plant breeding (pure lines) they helped establish a distinction between breeders and farmers. By establishing a market with conditions for entry, the DUS criteria helped in sustaining the sphere of accumulation for breeders.

Notes and References

1. Earlier versions of this paper were presented at conferences on Future Location of Research in a Triple Helix of University–Industry–Government Relations (State University of New York, January 1998) and New Developments in Intellectual Property: Law and Economics (St. Peter's College, Oxford, March 1997). The contribution of participants at both conferences is acknowledged, as is advice received from Paul Auerbach, Jean Pierre Berlan, Vince Daly, Stephan Lemairie and Stuart Macdonald.

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34. Advertisement by Major Hallett, a British breeder, in 1887 in J.-P. Berlan, *The Political Economy of Agricultural Genetics, mimeo*, nd. The attempt was clearly to emphasise the necessity of continuous selection and that these varieties would deteriorate in the hands of the farmers.
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36. A narrow disease resistance spectrum would make the variety susceptible. Thus, the repeated cultivation of a susceptible variety might induce increased prevalence of a particular pathogen which then contributes to the enhanced vulnerability of the variety. In this manner, the lifespan of varieties is curtailed and farmers maintain their dependence on breeders for new varieties.
37. This is an entirely new technology announced in a recent US patent (no. 5723765) issued in March 1998 and granted jointly to the US Department of Agriculture and the Delta and Pine Land Company. The technology genetically modifies plants so as to prevent seeds from germinating in the next generation.
38. Advanced breeding material consists of 'lines', released varieties and varieties being trialed by breeders. These varieties are well adapted to local conditions and are quite homogenous in their characteristics as they have already been through a number of cycles of selection. In addition, there is good documentation on the material. See R. J. Cook, V. A. Johnson and R. E. Allen, 'Wheat', in *Traditional Crop Breeding Practices: An Historical Review to Serve as a Baseline for Assessing the Role of Modern Biotechnology*, OECD, Paris, 1993, pp. 27–36; V. A. Johnson, 'Future prospects in genetic improvement in yield of wheat', in *Genetic Improvement in Yield of Wheat*, Crop Science Society of America and American Society of Agronomy, Madison, WI, 1986, pp. 109–14; J. Poehlman and D. Sleper, *Breeding Field Crops*, Iowa State University Press, Ames, 1995; R. M. Rejesus, S. Smale and M. van Ginkel, 'Wheat breeders' perspectives on genetic diversity and germplasm use: findings from an international survey', *Plant Varieties and Seeds*, 9, 3, 1996, pp. 129–47.

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