# Can TRIPs deter innovation? The anticommons and public goods in agricultural research

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# Can TRIPs deter innovation? The anticommons and local public goods in agricultural research[1]

## Introduction[2]

Recent years have seen substantial expansion in the scope and application of intellectual property rights (IPRs) in the area of plant genetic resources and associated technologies. For example, subject matter previously deemed either obvious or non-patentable is considered patentable; former privileges that circumscribed the application of patents have been compromised; the threshold to meet utility requirements has been lowered; the duration of protection has been extended; and through TRIPs the enforcement regime has been strengthened while the geographical application of the rights has been expanded. Concerns have been repeatedly expressed about the implications of these developments on agricultural research and access to seeds. For example, the Berne Declaration (2001) wants to 'keep crop seeds patent free' while the FAO's International Treaty on Plant Genetic Resources for Food and Agriculture (2001) seeks to maintain certain categories of genetic resources free from intellectual property rights and promote facilitated access to plant genetic resources. National and international public agricultural research institutions have made similar policy pronouncements. Reflective of these concerns is Boyle's (2001, p5) characterisation of problem as the removal of "anti-erosion walls" around the public domain. The implication of the erosion of these 'anti-erosion walls' on agricultural research is the concern of this paper. In particular, we focus on the paradox that promotion of intellectual property rights, initially aimed at solving the incentive problem, might curtail innovation.

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[1] The title of this paper is motivated by Heller and Eisenberg (1998).

[2] The paper began as a presentation at the meeting of the Advisory Committee of the IPGRI project, 'Rights and responsibilities over genetic resources: the role of the public domain in producing international public goods', 14-15 November 2002, Northwestern Law School at Lewis and Clark College, Portland, Oregon, USA. Earlier versions of the paper have been presented at the International Conference on 'Health care and food: Challenges of intellectual property rights, biosafety and bioethics' at the National Institute of Science, Development and Development Studies, India. 1-5 December 2002 and the conference on 'Science and Citizenship in a Global Context: Challenges from New Technologies' at the Institute of Development Studies, University of Sussex, Brighton, UK, 12-13 December 2002. The discussion with and comments of participants at these meetings and conferences are kindly acknowledged.

The paper begins by outlining the concept of an anticommons property regime and then presents the notion that knowledge is a local (quasi) public good. It is with this conceptual foundation that the policy issue of an anticommons property regime in agricultural research is discussed. While the latter discussion is quite speculative, it focuses on three policy problems: access and consolidation within the industry, transaction costs and uncertainty, and orphan crops/regions and research capacity

## The concepts

### Anticommons

The notion of anticommons has recently been revived in the law-economics literature. An early articulation of the notion by Michelmans (1982)[3], though couched in terms of 'regulatory regime' to critique the presumption of efficiency in private property, presented a scenario where everyone had rights in an object while nobody was privileged to deploy their rights without prior authorisation of others. Heller (1998) suggests that with the absence of any real-world replica this concept fell into disuse. Yet, a study of the impact of patent scope decisions across different industries alluded to the notion of 'anticommons' [Merges, 1990 #12][4]. However, recent interest has been prompted by growing apprehension that policy measures to promote incentives to invest in R&D, such as expanding IPRs and allowing the public sector to seek IPRs, have paradoxically hampered the innovation process [Heller, 1998 #1]. Heller (1998, pp623-4, emphasis in original) defines an anticommon as follows:

> "… a type of property regime that may result when initial endowments are created as disaggregated rights rather than as coherent bundles of rights in scarce resources. More generally, one can understand anticommons property as the mirror image of commons property. [ ] In an anticommons, by my definition, multiple owners are each endowed with the right to exclude others from a scarce resource, and no one has an effective privilege of use. When there are too many owners holding rights of exclusion, the resource is prone to underuse – *a tragedy of the anticommons*.

[3] Frank I. Michelmans, 1982, Ethics, economics and the law of property, Nomos; cited in Heller (1998).

[4] Notable examples in this study include Selden's patent in automobiles and Edison's patent in the incandescent-lamp industry.

Interestingly, the above articulation is not much different from the scenario presented by Merges and Nelson (1990, p882), though with the nuance of referring to different technological regimes:

> There is much more at the stake regarding allowed patent scope in these cumulative technologies [viz. automobiles, electric bulbs, airplanes] than in those where inventions are discrete and stand separately [viz. razor blades]. … [Moreover], 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. As we shall see, these are not just theoretical possibilities; they describe the development of several important technologies.

Common to both articulations is the fact that the tragic outcome of underuse of a particular resource, and hence the stalled development of a technology, occurs when multiple agents possess effective ‘rights of exclusion’, thus frustrating attempts of any one agent in accumulating a core bundle of rights. This contrasts with the case of a commons where the ‘privilege to use’ does not encompass the ‘right to exclude’: “the peasant may use the open commons as pasture for his sheep; he may not prevent others from doing the same” [Buchanan, 2000 #3, p3]. To be precise, the ‘open commons’ that are pastures are not necessarily a commons: at times these may be ‘open access’ resources where no one has the right to exclude others (i.e. *res nullius*), whereas in other instances they may be collectively managed by members of a group through forms of shared contracts [Hess, 2001 #13, pp57-9]. Returning to the anticommons, Heller (1998, pp665-72) emphasises a series of elements of this notion. First, the definition recognises the possibility of a limited group of individuals possessing rights of exclusion. In contrast, Michelman’s (1982) notion of ‘regulatory regime’ required everyone to possess a right to exclude. Second, there is no a priori requirement for the right to exclude to be necessarily or entirely legal. Non-legal rights, such as the informal rights possessed by the mafia, are compatible with this notion[5]. Finally, there is no hierarchy between different right-holders[6]. Assuming that all right-holders are equal explains why society will not recognise the decision of any one right-holder as well as why there are no clear rules for conflict resolution. It is within this setting that the tragedy is possible: rational individuals acting separately may

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[5] Heller’s (1998) work is based on analysing the paradox of empty Moscow stores in a milieu where street kiosks are flushed with products. The presence of the mafia with non-legal ‘rights to exclude’ is one factor in explaining this phenomenon.

[6] This is important to avoid the potentially resolvable situation of a pioneer and subservient patent.

collectively waste a resource by underconsuming it in comparison to the social optimum [Heller, 1998 #2, p677].

However, there is no *a priori* rationale for an anticommons property regime to result in a tragedy. For example, adopting a "pessimistic view of human capacity for trustful cooperation", one might conclude that situations of anticommons might prevail [Heller, 1998 #2, pp676-77], whereas evidence of informal arrangements and norms within communities of IP-holders, such as patent pools and copyright collectives, might suggest that a situation of anticommons might be transitory, if at all (References to be added)[7]. In economic terms, inefficiencies occur because each agent acts separately and any one agent must necessarily seek and secure each right-holder's permission, which at the margin (in the case of full complementary goods[8]) could result in non-use of the resource [Buchanan, 2000 #3]. Yet, this is a reality. Pharmaceutical companies have joined with together with the Wellcome Trust, the UK-based non-governmental partner to the Human Genome Project, to form a consortium for the identification of SNPs[9] and keep them in the public domain; a goal that would not only defeat possibilities of securing patent claims on SNPs, but it would also reduce for consortium members the transaction costs in using SNPs [Eisenberg, 2001 #14].

<closing statement>

### Knowledge as a local (quasi) public good

Early work mainly in public finance differentiated goods into two groups, public and private, based on two key properties – excludability and rivalry [Samuelson, 1954 #17; Samuelson, 1955 #16][10]:

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[7] Merges and Nelson (1990) discuss the experience with patent litigation in the automobile industry following the broad patent granted to Selden. The patent had amongst its claim the use of a light gasoline-powered internal combustion engine with a range of possible embodiments. The Association of Licensed Automobile Manufacturers, established to collect royalties and control competition in the industry, developed a procedure for automatic cross licensing of patents; thus allowing other manufacturers to develop and exploit the invention.

[8] An example of full complementary goods is left and right shoes. If right and left shoes were produced by separate agents and sold separately, it is possible for a situation to arise where individuals are 'barefoot in the park'.

[9] SNPs are single nucleotide polymorphisms, i.e. single base points within the genome at which DNA sequences of individuals differ. The information is said to be useful for either searching for genes relevant in particular diseases and/or in developing predictive diagnostic kits.

[10] Kaul et al. (1999) draw our attention to 18th century scholarship (e.g. David Hume and Adam Smith) that discussed the problems faced in providing the 'common good'.

- Excludability: This reflects the possibilities of, and ease in, excluding an individual from enjoying the benefits of a good; thus linked to the appropriability conditions faced by the producer of the said good. A non-excludable good means that everyone can enjoy/access the good meaning that the competition will drive the price down to zero.

- Rivalry[11]: This relates to the distribution of benefits between consumers of the good and whether an individuals consumption of the good rivals similar consumption by other individuals. In economic terms, a good is non-rivalrous if it involves zero marginal cost in providing the benefits to an additional individual.

Following Arrow's (1962) seminal contribution on the economic analysis of information, where the three properties of uncertainty in production, indivisibility in consumption and inappropriability of returns were identified, the dominant approach is to classify information as a public good. More importantly, knowledge and information are narrowly equated with each other, denying their separate and systematically different properties, such that the public good status of information is automatically extended to encompass knowledge[12]. Moreover, knowledge is characterised as a commodity that is homogenous, widely transmittable, fluidly exchanged and essentially inappropriable. This characterisation of knowledge is the shared and binding vision (in Kuhn's sense of the term[13]) within a broad range of allied disciplines in law and economics [Rangnekar, 2000 #5, pp22-27].

To be clear, there are 'free' or 'public' characteristics to knowledge, at least to the extent that some components are codified into transmittable information. More importantly, evolutionary economists draw attention to these spillovers as 'untraded interdependencies': "technological complementarities, 'synergies', and flow of stimuli and constraints which do not necessarily correspond to commodity flows" [Dosi, 1988 #25, p226]. A good example of this untraded interdependency is the manner in which bicycle production appropriated technological knowledge from the production of

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[11] In some legal literature this property is termed 'subtractability' (e.g. Ostrom and Hess, 2001).

[12] This narrow equivalence between knowledge and information has been traced in the works of 19th century economists (see von Tunzelmann, 1995).

[13] This vision forms a set of principles that are fundamental and paradigmatic, in that they exist "prior to, [and are] more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them" (Kuhn, 1970, p46).

shotgun barrels [Dosi, 1988 #8]. Some of these flows (through patent documents, changing personnel, shared R&D activities, etc.) also occur within a technological sector; thus making a clear demarcation of the firm's knowledge borders difficult. However, the fact that there is freely available information does in no way imply that adoption and utilisation is a free lunch. This distinction has been historically recognised [Marx, 1887 [1954] #26, pp386-87]. More recent scholarship draws attention to the importance of developmental costs associated in using the 'free' components of public domain information [Rosenberg, 1982 #27; Rosenberg, 1992 #10]. This has analytically been recognised through conceptualising a dual role for R&D: it is conducted to produce new products/processes (the traditional conceptualisation) and generate novel information [Cohen, 1989 #29]. The latter role is understood as a process of building in-house competency to identify, assimilate and exploit externally generated knowledge. In contrast to conventional thinking, Cohen and Levinthal (op. cit.) argue that a looser appropriability regime, that which enhances intra-industry spillovers, will encourage equilibrium industry R&D investments. Recognising these points, it is suggested that only for those with the capacity to integrate disparate pieces of knowledge, mobilise and invest in resources and complementary assets that knowledge can be considered a non-rival and non-excludable [Callon, 1994 #33]. Thus, table 1 categorises knowledge as a club good, it being non-rivalrous for members of the club. To be fair, some economists within this persuasion recognise that knowledge exhibits limited and incomplete excludability, making it an impure public good [Stiglitz, 1999 #24; Romer, 1990 #23] and would as such place it in the 'club good' category.

TABLE 1

**Types of Goods**

| | *Rivalrous* | *Nonrivalrous* |
|---|---|---|
| *Excludable* | **Private goods**<br>Personal computers<br>Cake, bread | **Toll or club goods, networks**<br>Leisure clubs<br>Silicon valley (i.e. science parks make the good, i.e. knowledge, nonrivalrous within the club)<br>Day-care centres |
| *Nonexcludable* | **Common-pool resources**<br>Public libraries<br>Geostationary orbits<br>Irrigation systems (i.e. goods subject to some congestion and depletion; but accessible to all) | **Pure public good**<br>Sunset and (some) scenic spots<br>Some global commons (e.g. the ozone layer) |

*Note:* Public goods encompass the three shaded boxes.
*Source:* Based on Ostrom and Hess (2001) and Kaul et al. (1999).

A range of other factors that relate to the learning and innovation process and the appropriation strategies of firms also undermine the presumed public good*ness* of knowledge. For instance, learning processes exhibit tacit and local dimensions that cannot be easily or entirely reduced to transmittable codes. Further, learning occurs through a variety of processes beyond and outside the formalism of R&D, which includes 'learning by doing', 'learning by using' and 'learning as a joint-product of producing and using artefacts' [Metcalfe, 1995 #36; Arrow, 1962 #35; Rosenberg, 1982 #27]. Then there are wider institutional dimensions of the innovation process, such as cumulativeness and path-dependency, that restrict access to and diffusion of knowledge [Arthur, 1989 #42; David, 1985 #41]. Here, bibliometric studies note the presence of geographically dispersed but strongly clustered centres of knowledge creation and the different mechanisms used by firms to 'connect' with these localised clusters [Narin, 1997 #37; Cockburn, 1998 #38; Zucker and Darby, dt?]. Public policy, such as the creation of science parks/corridors, enables such connection. However, it is the case that knowledge, in such instances, remains a local public good to members of the park. Recognising these attributes of the innovation/learning process, evolutionary economist have long suggested that technologically-dominated firms cannot adopt the techniques of the dominating firm as they simply do not know how to (e.g. Freeman, 1982; Nelson and Winter, 1982; Dosi, 1988; Dosi, Pavitt and Soete, 1990). To be clear, this 'inability' has little to do with legal protection in that technological leads and lags may well persist in a world without legal appropriation. Thus, in a world where legal means of appropriating knowledge and related resources have been dramatically strengthened, technological leads and lags may very well be deeper and more persistent.

## Implications for agricultural research

To restate the question: does the provision of IPRs (e.g. patents and plant variety rights) on plant varieties, genes used in plant breeding and on the processes and research tools used to create plant varieties generate a situation in which the innovation process is stalled, delayed or denied? Following Merges and Nelson (1990), we note that the impact of IPRs on innovation is sectorally differentiated, being substantially determined by the mode of technical advance and the relationship between resources and research tools. Merges and Nelson (1990) have identified four modes of technical advance:

- Discrete: These tend to be 'stand-alone' developments that are mainly derived through the inventor's insight and the invention itself does not generate techno-economic opportunities for subsequent development. Examples include the safety razor, ball-point pens and the toy industry.

- Cumulative technologies: Here, technological advance builds on and interacts with other technologies and develops with a range of research tools and resources (i.e. multi-component). Examples include automobiles, aircrafts, electrical light systems and semiconductors.

- Chemical processes: The chemical industry is considered quite unique in terms of its specific features as they are a mix of discrete and cumulative technological advance models. In addition, there are complex and uncertain elements to the innovation process.

- Science-based: These are technologies where advance is mainly driven by current/recent developments in science; thus providing a close relationship between R&D and science. Examples include biotechnology, medical diagnostic equipment and nuclear.

It is not the explicit purpose of this paper to present a techno-economic characterisation of either plant breeding (the sector) or seeds (the product). The following summary points are made.

Plant breeding is an activity that involves the controlled pollination of a population to produce a desired recombination of the traits in a new cultivar (commercial variety that is genetically homogenous and distinct from existing plants of the same species)[14]. As an activity it sits hesitatingly between different scientific disciplines and commercial activities (see figure 1 in the appendix). Not only does it depend upon a number of different disciplines, but it is also contingent on a range of activities. Some of these activities like germplasm collection, documentation and maintenance provides the raw materials (genetic information and variation) to breeders. Others like varietal maintenance, seed multiplication and distribution are important for delivering the products (new varieties) to consumers (farmers). Broadly, the following elements must be mobilised for plant breeding.

[14] Naturally, by focussing on cultivars we are automatically restricting the boundaries of plant breeding.

- Resources: genes, genetic resources, land, laboratories, gene banks, *in situ* and *ex situ* collections, etc.

- Research tools: transformation mechanisms, promoters, genetic markers, varietal testing techniques, diagnostic probes, etc.

- Knowledge and information: documentation and characterisation of genetic resources, expertise to use research tools, 'eye of the breeder', etc.

In terms of Merges and Nelson (1990), we suggest that plant breeding is quite unique. To begin with, plant breeding is *cumulative* (new varieties build on previous generations), *networked* (varieties work in an environment built by inputs) and *science-based* (Mendelian genetics and biotechnology). However, cumulativeness in plant breeding is very remarkable. Here note the fact that a popular rice variety of the Green Revolution era, IR-72, had twenty-two landraces in its pedigree apart from numerous other cultivars. More compelling is the case of VEERY, the wheat variety developed by CIMMYT in 1977, which was the result of 3,170 crosses among 51 parental lines. Even commercially bred varieties have complex pedigrees and parentages; though they tend to largely depend on previously released cultivars rather than on landraces[15]. The dependence on science or rather the role of science (to avoid a mistaken linearity in the innovation process), in plant breeding has been greatly enhanced with the development and use of new research tools. The latter are invariably protected by IPRs. Thus, for example, the development of *GoldenRice*™, a type of rice that has been genetically engineered to produce elevated levels of carotene (metabolised by humans into Vitamin A) is allegedly protected by some 70 patents owned by 31 different organisations.

We draw attention to four particular trends in IPRs and the organisation of research that are relevant to our subject.

- <u>Patenting genes and biological material</u>: With advances in genetic engineering the distinction between a discovery and an invention has been blurred, suggesting that the prior existence of a natural substance does not

[15] This puts even greater pressure on maintaining a research exemption clause and permissive provisions for commercialising the results in IPRs. Thus, not surprisingly, even the 1991 revision to the International Convention for the Protection of New Varieties of Plants (UPOV) did not eliminate the research exemption clause even while it restricted provisions for commercialising derived varieties.

automatically preclude the possible patenting of an isolated and purified form of the natural product. At the heart of this practice is the interpretation of novelty as ‘not previously available to the public’ (reference to be added, Correa? Barton?), which with growing harmonisation across key jurisdictions raise pertinent questions In the case of genes, patents are often granted for the (mere) isolation of a gene and identification of its function (e.g. US). Claims in patents map out the techno-economic territory that will constitute the property right of the patentee. In the case of genes this could and does involve a protein, a vector incorporating the identified sequence and potentially an organism; thus, enabling the patentee to acquire control over the diverse use of the gene (Lewontin, Barton, Correa). A case in point are the patents involving *Bacillus Thuringensis*.

- <u>Patenting of plant varieties</u>: Plant varieties are largely protected under a *sui generis* system that grants plant breeder rights within the framework of UPOV. Yet, some countries, notably the US and Australia, also grant patents in plant varieties. The two systems differ significantly in terms of the standards of protection (e.g. the novelty test) and in the scope of protection. Briefly, there are very limited, if at all, provisions for research use of patented subject matter. Thus, some commentators argue that in principle a patentee could prohibit the experimental use (e.g. multiplication and crossing) for breeding purposes of a patented plant variety.

- <u>Broad scope patents</u>: The skilful writing of a patent application, in particular the manner in which prior art is acknowledged and claims enlisted, allow the patentee to widen the techno-economic territory under their control (see Merges and Nelson, 1990). Such broad patents, some granted in the US (details to be added), include a gene, the vector or carrier that enables the transformation, and potentially the whole organism and/or <u>all</u> crops incorporating the gene (CIPR, 2002, p64).

- <u>The ‘privatisation’ of the public sector</u>: With the passage of the Bayh-Dole Act, 1980 in the US, public institutions were able to seek IPRs on the results of publicly funded research. Between 1993 and 1997 universities were issued 10,050 patents and 2,214 new companies were formed based on protected academic intellectual property following the Bayh-Dole Act (Oehmke et al., 2000). Critiques of the consequences of this Act have raised questions about accountability, research orientation of public institutions and curtailed access to key technologies. Ironically, this 'privatisation' of a public institution is being emulated in some developing countries. For example, India's Plant Variety Protection and Farmers' Right Act allows public sector breeders to seek rights in their varieties.

We now speculate on the implications of these trends. Our discussion proceeds along three policy-related issues: access and consolidation within the industry, transaction costs and uncertainty, and orphan crops/regions and research capacity.

<u>Access:</u> By their very nature of being a 'right to prohibit' certain acts/transactions, patents will limit access and allow the patentee to control the diffusion of the protected subject matter. In an informal survey conducted amongst public sector breeders in the US (covering 25 universities, 41 crops and involving 86 respondents), Price (1999) found that 48% experienced difficulties in obtaining genetic material, 45% indicated that this interfered with their research activity, and 28% felt that it hampered their ability to release new varieties. With patent laws not incorporating a research exemption clause comparable to the one existing PBRs law, it is felt that follow-on research is hampered. The extent of this potential threat is not easily discernible. However, evidence of US-patents involving the major cereals is large and growing rapidly (Falcon and Fowler, 2002, table 1 to be inserted here). This has dynamic consequences on the ability of competing inventors (public and private) in developing the technology (cf. Merges and Nelson, 1990). Given the network/cumulative properties of plant breeding, we express apprehension about the implications of limited access to genetic resources and enabling technologies. Here, Tansey's (2002, p20) views following a study commissioned by the Global Forum on Agricultural Research: a "scenario in which all germplasm exchange falls under bilateral agreements entails excessively high transaction costs" and only a few industrial crops that originate in a few countries (e.g. soybean) might a bilateral approach be acceptable. To be clear, patents on genes and biological material do not prohibit the use of organisms that naturally exhibit the gene; however, the use of the gene (in its isolated form) in breeding programmes will infringe the patent. More disturbing are the implications arising from proprietary control over enabling technologies, the research tools that allow manipulation of genes and govern their function, use and transfer into other organisms. Evidence of the use of proprietary agri-biotech technologies in the public sector (national and international) has been documented (cf. ISNAR studies). The evidence is mixed and suggests that partnerships and material transfer agreements appear to work. However, it also shows

that potential problems in disseminating research products (e.g. new varieties) are imminent.

The comments noted here must be placed in a wider context of consolidation within the seed industry, or what is nowadays termed the ‘life sciences’ industry. Falcon and Fowler (2002) document the changing complexion of the industry, which they characterise as the second-wave of consolidation, following an earlier era of acquisition in the 1970s-80s. In the US, for example, between 1995 and 1998, approximately 68 seed companies were acquired (Pingali and Taxler, 2002). Part of the drive towards consolidation is for the larger companies to acquire IP owned by smaller biotech-startups: 75% of the Bt patents (in 1999) owned by top five life science companies were obtained following acquisition of smaller companies (CIPR, 2002, p65).

Uncertainty and transaction costs: Standards and practices in the patenting of genetic material and allied enabling technologies are rapidly changing; thus placing a high premium on practitioners maintaining awareness of IP-matters. In this respect the ISNAR studies shed useful insights into the potential problems facing public sector researchers. Not only, is there a possibility of ‘inadvertent infringement’; but many respondents expressed incomplete information about possible restrictions on dissemination of research results (reference and data to be added). Another dimension of uncertainty arises from a lack of clarity on the borders of patented subject matter. Overlapping patents is one manifestation of this uncertainty, which complicates the activity of breeders (cf. Barton). The CIPR Report (2002, pp64-5) draws attention to the complex legal battles involving Bt, where several hundred patents allegedly exist. These issues come to a head when we recognise the strong science-base and cumulative nature of plant breeding, where ‘knowledge and information’ are both the inputs and the outputs of the process. Here, the views of Merges and Nelson (1990, p916) are noteworthy,

> Ultimately it is important to bear in mind that every potential inventor is also a potential infringer. Thus a ‘strengthening’ of property rights will not always increase incentives to invent; it may do so for some pioneers, but it will also greatly increase an improver’s chances of becoming enmeshed in litigation.

Orphans and research capacity: There is increasing concern within the international/national agricultural research centres that research capacity to assimilate and utilise novel material and tools is being lost (Anderson, Byerlee, Morris, etc.). This is partly manifested in the strikingly different funding patterns for agricultural research between developed and developing countries: while unevenly distributed, public sector research expenditures were US$11.5bn in developing countries and US$10.2bn in developed; however, only US$0.7bn of a total of US$11.5bn private sector research expenditures were in developing countries (CIPR, 2002, p60). The CGIAR system spends about US$340mn annually, of which US$25mn is slotted for agri-biotech, which does not compare favourably with an estimated US$1.5bn research budget of the top six life science companies (Byerlee and Fischer, 2002). The numbers are indicative of changing competencies. To an extent, these competencies are compromised by a lack of access to new material and enabling technologies (cf. Price, 1999). In a dynamic sense, and recognising the local/tacit and cumulative nature of learning/innovation process (see earlier discussion), it is possible that public sector capabilities in assimilating and exploiting (i.e. absorptive capacity) novel technologies will be compromised in the future. The consequence in the case of plant breeding are grave since it is imperative for key stages of the breeding process to be undertaken in the target area, i.e. plants need to be made adaptable to the conditions in which they will be grown. Pingali and Taxler (2002) note that less than 1% of the existing benefits of biotechnology innovations have accrued to tropical regions. This is not surprising since the crops and the agronomic conditions that dominate agri-biotech research are not relevant for large sections of the tropical world. Yet, they draw disturbing implications from existing evidence, suggesting that there are orphan regions, crops and research areas.

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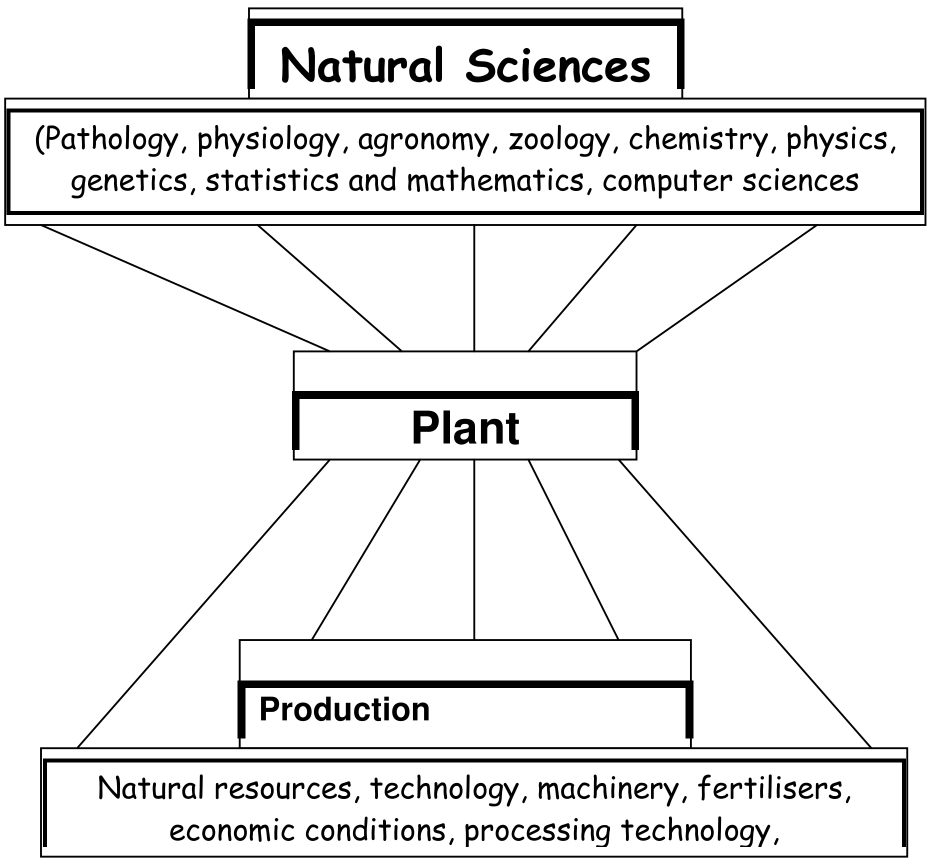
## Appendix

Figure 1: The Location of Plant Breeding




*Source:* Berlan and Lewontin (1986)