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Access Issues for Plant Breeders in an Increasingly Privatized World

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**Contributed Paper presented to the 47th Annual Conference
of the Australian Agricultural and Resource Economics Society**

at

Fremantle,

February 12-14, 2003

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Key Words

Privatisation, plant breeding, access, enabling technologies, competition policy, excludable public goods.

Abstract

There is a growing trend to widespread privatisation of crop breeding, and there are grounds for expecting this trend to continue and even to accelerate. Possible consequences for Australian grain growers and the national interest of much greater private sector involvement in plant breeding are explored.

Growing privatisation and commercialisation of plant breeding will lead to increased competition between plant breeders. While this increased competition has been at least partly driven by the potential for value creation, it also is likely to enhance value creation from plant breeding so long as there is adequate continuing investment in the capacity for plant breeding, and more particularly in productivity enhancing enabling technology.

In the event of monopoly provision of such enabling technology, an important policy issue will be access to what might be termed essential plant breeding infrastructure. For any access regime to essential infrastructure, the core issue is to select terms and conditions for access that promote full and efficient competition in upstream and downstream markets (e.g. plant breeding) while preserving the incentive for adequate levels of investment in the ongoing development, maintenance, and provision of such essential infrastructure.

A key, perhaps pivotal issue will be pricing policy and practice. Because EPBI has the public good characteristic of being non-rival in use, price discovery by market processes can not be expected to produce the desired outcome. Moreover, even if an access regime mandated that EPBI be made available to all plant breeders at a uniform price, the imbalance in market power between the monopoly provider of EPBI and plant breeders seeking access would almost inevitably result in both under-production of EPBI, and in under-utilisation of any produced EPBI due to price rationing. Such outcomes would severely undermine the competitive position of Australian grain growers in international markets.

Results from the literature on what are called excludable public goods are used to analyse the impact on the incentive for adequate investment in EPBI under an access regime mandating uniform pricing.

1. Introduction

Economic outcomes in the “plant breeding industry” are being driven by interactions between advances in scientific knowledge, changes in the legal framework for intellectual property rights, and competitive forces in the market. While extended property rights have created the foundation for new markets, the opportunities arising from scientific discoveries have provided powerful incentives for firms to enter these markets and invest in plant breeding. The competitive forces unleashed by these developments are likely to transform the production of new plant varieties.

This potential for modern plant breeding to create value in the supply chain is one of the driving forces behind the increasing privatisation of plant breeding. In conjunction with an enhanced ability for plant breeding organisations to appropriate a sizeable share of the benefits from improved varieties; it is inevitable that crop breeding in Australia faces a transition from a system dominated by public plant breeding programs to one in which private plant breeding plays a much more important role. Moreover, even if public and/or grower funded plant breeding programs survive for some crops, they also will be under pressure to operate more commercially and at least recover the costs of the breeding program (as distinct from costs of seed multiplication) by charging growers more for newly released varieties.

As a result, there will be increasing commercialization of breeding programs, and much more widespread application of intellectual property rights to both germplasm and to breeding technologies. These changes are discussed in more detail below, including the underlying reasons and the policy issues that need to be addressed to ensure that the potential benefits to society are realised.

2. The Trend to Privatisation

Historically most plant breeding in Australia was conducted by “public” research organisations that were financed mainly from government revenue. The supporting research in agronomy, plant pathology, entomology, biometry, plant nutrition, plant physiology, and other cognate disciplines also was publicly financed. Improved varieties were freely released to producers at nominal costs that at best only partially recovered the costs of breeding, let alone making any contribution to funding the cost of supporting research.

While there has been a gradual substitution of collective industry derived funding for government funding for several decades, until recently plant breeding has continued to be conducted mainly in state government Departments of Agriculture, with selected universities and CSIRO also playing a role in some areas.

There are now clear indications of a growing trend in Australia to privatisation of plant breeding for many crops. Many public systems are rapidly being overshadowed by private alternatives in which both new enabling technologies and improved cultivars are routinely protected by intellectual property rights.

In this paper, the term privatised plant breeding is used to include any plant breeding program that is conducted on a “for profit” basis, or even on a “full cost recovery” basis. It includes plant breeding by profit making firms as well as other organisations that seek to finance the plant breeding operations by selling seed, or otherwise appropriating some of the benefits generated from growing improved varieties. Such appropriation methods include charging seed royalties, technology use fees, “end point royalties”, and “Closed Loop Marketing Agreements” (CLMA).

Public plant breeding includes most other types of program, including publicly funded plant breeding conducted by universities or government agencies, or even contracted out to private institutions. It also includes plant breeding programs funded collectively by industry so long as new cultivars from the breeding program are available to all farmers, and so long as there is no significant charge for the intellectual capital embodied in these varieties.

3. Evidence for Emerging Trends

In a number of other countries, there has been a stronger tradition of private plant breeding for many years. For instance, in Europe private companies played an important role in the development of modern plant breeding. There also has been a strong private plant breeding sector in the U.S. since at least the development of hybrid corn. Furthermore, as noted by Heisey, Srinivasan, and Thirtle (2002), it continues to expand at the expense of the public system:

“Real inflation-adjusted investment in public-sector plant breeding in the U.S. rose until the 1980s but began to stagnate during the mid-1990s, followed by a decline. In contrast, from the mid- 1960s to the mid-1990s, real private-sector investment in plant breeding grew at a remarkable 7 percent annually. Comprising only one-sixth of the public-sector total in the 1960s, private-sector plant breeding surpassed public investment by the mid-1990s.”

“the area of the U.S. planted to field corn is dominated by hybrids developed in the private sector. Private sector hybrids also dominate in the Union and in Canada.”

The rapid privatisation of canola breeding in Canada provides a further indicator of the possible future for other public plant breeding programs, and has been comprehensively documented and analysed by Phillips (1999). The following brief overview of selected highlights was summarised from his recent report.

As recently as 1982, there were only six canola cultivars actively grown in the world, and all were bred by public sector institutions in Canada. The plant breeding program used largely non-proprietary technologies, and all seeds produced and sold were in the public domain. The rate of development of new varieties was also relatively slow, with an average of one new variety every two years, and the average lifespan of a cultivar was about 10 years.

Between 1982 and 1997, a number of new proprietary technologies replaced the publicly developed breeding methods and more than 125 new varieties were introduced. By 1996, private companies developed more than 75% of the new varieties, while public institutions only developed about one quarter of the seed sold in Canada. The average active lifespan of a cultivar declined to about three years by 1997.

In Australia, the situation differs from crop to crop. For some crops such as lupins, there is virtually no private sector involvement in plant breeding, and little evidence of any interest in future investment. Plant breeding for Canola is an example of a mixed system with both public and private plant breeders, and with a trend to more private plant breeding and fewer public plant breeding programs.

Wheat breeding is heading in the same direction. Currently there are at least two private plant breeding firms, namely Grain Biotechnology Australia, and Longreach. The latter reportedly will invest \$14m in wheat breeding over the next 5 years¹, and is a joint venture between AWB Ltd. and Syngenta which has wheat breeding programs in UK, France, US, Canada and NZ. This

¹ The Australian, 9/3/2002 –

At the same time, GRDC has signalled its intent to consolidate and to corporatise the wheat breeding programs that it supports. Specifically, GRDC will replace its support for Australia's eight existing and mainly state-based breeding programs with support for three new commercially focussed wheat breeding programs. These will be Sunprime, Australian Grain Technologies, and Enterprise Grains Australia, which is a joint venture between GRDC, the WA Department of Agriculture, NSW Agriculture and the Queensland Department of Primary Industries.

4. Reasons for Privatisation of Plant Breeding

Plant breeding can be conceptualised as an investment that develops improved varieties with the potential to generate future benefits in the form of improved crop productivity, reduced costs of production, and/or higher returns. Potential value from improved cultivars will be realised only if and when farmers adopt these cultivars in their cropping systems, AND when consumers willingly purchase the food or other crop products in a competitive market. Growers will only adopt these new varieties if they provide real financial benefits that exceed the costs of adoption, including any additional costs of acquiring the improved variety. Similarly, consumers will only knowingly purchase food from these new varieties if by so doing they derive a net benefit in the form of enhanced attributes and/or lower prices relative to available alternatives.

Arguably the most important reason for the growing trend to privatisation of plant breeding has been significant changes in the ability of plant breeders to appropriate at least some of the benefits from improved grain varieties that otherwise would be captured by growers. Specifically, the incentive for firms to invest in plant breeding depends on the ability to exclude grain growers, as well as competing plant breeders, from commercial exploitation of a breeder's varieties unless they pay to do so.

For some crops such as corn, the development of hybrid technology provided genetic copy protection that enabled plant breeders to capture much of the value from heterosis as well as other superior traits. For other crops, it has been the expanding scope of intellectual property rights that has enabled the capture of some of the value created by plant breeding.

So while the application of science to plant breeding has generated much of the recent potential for value creation in the grain supply chain, it has been extensions to the legal framework for intellectual property rights that have made possible private capture of enough of the value created by plant breeding to provide the private sector with an incentive to invest more in plant breeding. The most significant of these intellectual property rights are patents and Plant Breeder's Rights. In recent decades, both court decisions and legislative changes have expanded the scope and impact of these two types of intellectual property right appreciably.

Complementing these developments in the institutional framework have been scientific discoveries that have led to greater potential for value creation by improvements in plant breeding methods. Apart from hybrid technology, other recent advances include new technologies that improve the efficiency of all plant breeding, including both conventional and transgenic plant breeding. Such techniques include double haploidy, plant regeneration systems, molecular based hybrid technologies, and marker assisted selection. Use of these techniques in conventional plant breeding is already reducing the time lags from initial crosses to release of new varieties. Potentially beneficial outcomes from the application of these technologies to plant breeding include one or more of the following:

- cheaper² development of improved crop varieties.
- faster/earlier development of improved crop varieties.
- development of superior³ improved crop varieties, that are more productive, produce better quality grain, or both.

In addition, there has been the more controversial development of transgenic technologies used to produce GMO's. Potential beneficial outcomes from transgenic technologies include:

- development of improved crop cultivars with novel⁴ agronomic/input traits that enable lower average costs of production.
- development of improved crop cultivars with novel quality-enhanced traits for which consumers are willing to pay a price premium.

On the other side of the coin, publicly funded rural research has been under pressure for at least the last two decades. In part, this has been due to a growing perception that grain growers have been the primary beneficiaries of the traditional plant breeding programs. Historically these programs have been funded mainly from consolidated revenue. To some extent, this concern has been addressed by the relatively recent evolution of the GRDC and similar bodies that rely heavily on collective industry funding to support much of their investments, but the fact remains that a significant part of plant breeding programs is still publicly funded.

Governments also now demand greater accountability at the same time that they reduce funding for agricultural research and extension. As a result, many "public" institutions are under pressure to become at least partially self-funding, and are starting to charge for selected goods and services. Public research institutions also seek to patent and/or commercialise discoveries made in the course of government funded research, or pursue opportunities to license technologies to the private sector.

Public plant breeding programs have not been immune to government pressure to generate revenue from their activities. Like private business, their capacity to capture a high proportion of the net benefits of new varieties depends on:

- a legal basis to establish ownership of the intellectual property embodied in the variety,
- the capacity to exclude potential users who are not willing to pay the nominated price,
- the costs of monitoring and enforcing compliance,
- the capacity for price discrimination.

Pricing practice by public institutions is still evolving. If they start charging significant fees at levels approaching full cost recovery, and exclude farmers unwilling to pay these fees from access to new varieties, then they cease to be public plant breeding organisations within the meaning of the term in this paper.

² i.e. relative to varieties with equivalent characteristics to those currently being produced by conventional plant breeding methods.

³ i.e. In this context, these are varieties that have superior performance to those that could be bred economically by conventional plant breeding methods.

⁴ i.e. traits that could not have been incorporated economically into improved varieties by conventional plant breeding methods.

Finally, agronomic practice by grain growers has become increasingly sophisticated and much more tactical. In particular, many growers now make decisions about which varieties to grow each season on the basis of the latest possible information about the climatic outlook and other seasonal indicators, such as soil moisture levels as well as weed and disease threats. Consequently they are less likely to use seed saved from the previous harvest, and more likely to purchase new seed of the desired variety from a seed merchant. This change in farming practice will increase the size of the seed market, and improve the economics of private plant breeding.

5. Value Creation and Value Capture for Enabling Technologies

Inevitably the growing privatisation and commercialisation of plant breeding in the Australian grains industry will lead to increased competition between plant breeders. While the potential for value creation has been at least partly responsible for this increased competition, more competition among plant breeders also is likely to enhance value creation provided that there is continuing and sufficient investment in the underlying capacity for plant breeding. Of particular importance is continuing investment in productivity enhancing enabling technology.

While adequate provision of enabling technologies is one cause for concern, efficient utilisation is another. As these enabling technologies are quasi public goods in the sense that they are non-rival in use, efficient utilisation involves the much maligned concept of the “level playing field”. If the institutional, policy, or legal framework confers advantages on some firms relative to others, competition may not generate desirable outcomes if the favoured firms are not the most efficient. Conversely, if all firms compete on a “level playing field”, then only the most efficient should survive.

As noted above, the potential exists for new varieties to create value by lowering the cost of producing and delivering grain and grain products to consumers; and/or by enabling the production of superior grain products for which consumers are willing to pay higher prices. This potential for value creation will be realised when new varieties from the breeding program are released and adopted by grain growers, and the resulting products are purchased and consumed by end-users.

However, much of this potential for value creation rests on a foundation of enabling technologies. Examples of long standing enabling technologies include the collection and conservation of germplasm, including both land-race and elite breeding lines, and results of pre-breeding research in such diverse fields as agronomy; biometry; entomology; quantitative genetics, plant pathology; plant physiology; plant quarantine; and product chemistry.

More recently, the application of modern science, and in particular of molecular biology and information technology, to plant breeding has dramatically increased the potential to create extra value in the grain supply chain. As noted above, new plant breeding methods such as di-haploidy, embryo rescue, and rapid breeding cycles have sped up the development of new varieties and reduced breeding costs. Furthermore, information and database systems together with molecular marker technology has enabled breeders to be much more selective and effective at identifying desirable traits in germplasm collections and incorporating these traits into elite lines, while transformation technologies have significantly expanded the range of traits that plant breeders can access.

The rest of this paper addresses concerns about the provision and utilisation of essential enabling technologies for plant breeding. These key inputs provide the foundation for ongoing long-term variety improvement and consequent productivity gains. They also share a key attribute with public goods in that they are non-rival in use by plant breeders. Given this property, competitive provision by more than one supplier would involve wasteful duplication in the production of essential plant breeding infrastructure. Therefore, the first best solution would involve some form of cooperative behaviour to ensure adequate provision of these key enabling technologies by a sole producer.

Traditionally, such inputs to plant breeding were non-proprietary, provision was publicly funded, and access by public plant breeding programs was both open and free of any charges. In return, no attempt was made to recover the costs of the breeding program (as distinct from costs of seed multiplication) by charging either plant breeders or growers for the intellectual property embodied in newly released varieties. Given that there is zero opportunity cost to the use of non-rival goods once produced, this institutional structure would represent a first best benchmark against which to assess the performance of alternative arrangements provided that public funding incurred no social cost.

Nevertheless, for reasons already discussed, less rather than more public funds are likely to be available for investment in these enabling technologies, as well as in plant breeding *per se*. If as a result there is no compensating funding from other sources, eventually innovation in plant breeding methods and consequent returns to private investment in plant breeding are likely to stall.

Traditionally, the main alternative source to government funding has been collectively financed industry bodies. For instance, in Australia the needs of the grains industry are likely to be met by continued collective funding by grain growers through the Grains Research and Development Corporation (GRDC). Joint ventures involving collective funding by plant breeding companies are another possible source of compensating funding. A concrete example of the latter alternative is the formation of global consortia of private and public plant breeding organisations to develop molecular marker technology. Alternatively, an increasing proportion may need to come from individual private providers.

For each of the above alternatives, it is likely that continued funding will be forthcoming only if commercial returns from “private” provision are sufficiently attractive to maintain ongoing investment. This will depend on the extent to which market forces and intellectual property rights enable providers to capture at least part of the value created from enabling technologies. Irrespective of the funding source for the investment, there will be concern about the efficient utilisation of these enabling technologies so long as there is a lack of competition in their provision. In particular, there will be concerns that charging for use of enabling technology in order to recoup the investment costs incurred to produce them will result in inefficient under utilisation.

There are obvious parallels here to National Competition Policy (NCP) principles governing access to essential infrastructure. The aim of National Competition Policy (NCP) is to facilitate effective competition where competition between suppliers of goods and services result in lower prices, a wider range of products, and/or better service for consumers, but also to accommodate situations where competition does not have that effect, or where it conflicts with social objectives.

In industries such as telecommunications, air and rail transport, and electricity transmission, it is recognised in NCP that competition may not be feasible or desirable in the provision of some essential infrastructure, and that the shared use of such ‘bottleneck’ or ‘essential’ infrastructure facilities may be necessary to facilitate efficient competition in downstream markets that use such infrastructure. Access regulation that aims to promote competition in markets that use the services of ‘essential’ infrastructure while preserving incentives to develop and maintain those facilities have been developed to address concerns about denial of access and/or monopoly pricing of access.

Hence a case can be made that as plant breeding becomes increasingly privatised, equivalent access regimes will need to be developed for those enabling technologies that effectively are essential plant breeding infrastructure (EPBI). Unless some rational access regime is established, much of the potential benefits from scientific discoveries underpinning modern plant breeding may not be fully realised. In common with NCP access regimes, the aim should be to promote full and efficient competition between plant breeders, while preserving adequate incentives for investment in the ongoing development, maintenance, and provision of essential plant breeding infrastructure.

There is provision in Part IIIA of the Trade Practices Act 1974 for a third party to gain access to an eligible infrastructure service by having a service declared. However, such provisions are unlikely to be needed for plant breeding for the Australian grains industry. GRDC, as the key provider of EPBI, is cognisant of the problem, and likely to develop an undertaking as provided for in the TPA that specifies terms and conditions for access by all plant breeders.

In such an undertaking, two key issues will be the grounds (if any) for denial of access, and pricing policy. There are at least two possible cases where denial of access, or discriminatory pricing, may be contemplated.

One would be to deny access to, or charge higher prices for EPBI to large multi-national “life science” firms. A possible ground for doing so would be that these multi-national firms have access to other sources of EPBI from which Australian plant breeding firms are excluded, and therefore would have an unfair competitive advantage if they also had access to GRDC funded essential plant breeding infrastructure. Whether this would be in the interests of Australia, the grains industry at large, and/or growers is moot, and deserves further investigation.

Another possible ground would be that GRDC has, and plans to continue to invest in selected new and Australian owned plant breeding firms. Fears have been expressed that they may decide to “protect” such investments by limiting other plant breeders access to GRDC funded EPBI. *Prima facie*, denying access or discriminatory pricing for this reason would seem to be an example of exploiting market power in order to benefit owned or related entities in upstream or downstream markets, and so contrary to NCP principles. Specifically, it would inhibit rigorous competition in the downstream plant breeding market. Nevertheless there may be grounds based on the potential impact on Australia’s trading position for treating plant breeding firms owned by overseas interests differently to domestically owned firms.

6. Monopoly Provision of Enabling Technologies given Uniform Pricing

In the remainder of this paper, such concerns will be put aside in order to investigate monopoly provision of EPBI when the producer is obliged to provide access to all plant breeders **at a uniform price**. This scenario involves some fascinating pricing policy issues that deserve study even if essential plant breeding infrastructure funded by Australian grain growers is made available at non-commercial prices to all plant breeders.

As is well known, goods that are both non-rival in use and non-price excludable are known as public goods. It has been argued above that while essential plant breeding infrastructure is non-rival in use, it can be price excludable. Such goods are variously referred to in the literature as joint goods, club goods, price excludable public goods, or simply excludable public goods.

Molecular markers for a valuable polygenic trait are a good example of essential plant breeding infrastructure that is an excludable public good. They are one of the key inputs for more productive plant breeding; and *prima facie*, are non-rival in use by plant breeders⁵. Thus production by more than one producer would involve wasteful duplication, and monopoly provision is likely to be economically efficient.

At the same time, intellectual property created by the invention of new molecular markers can be protected as a trade secret, or by seeking patent rights. Hence, even though there are instances where they are made freely available, at least partial price excludability is feasible. Limits on the capacity for price exclusion are likely to depend on the costs of imitation by competitors, the costs of detection of imitation, and once detected, the costs of enforcing property rights against imitators. Consequently they provide a tangible and comprehensible case study with which to explore the likely consequences of adopting an access regime based on non-discriminatory pricing.

Clearly there will be an imbalance in market power between a monopoly provider of molecular marker technology and third-party plant breeders seeking access, so the potential exists for excessive pricing that would be detrimental to Australian grain growers in international markets. On the other hand, if the eventual aim is to provide a basis for privatisation of production of molecular markers, the uniform price charged will need to be high enough to maintain the incentive for ongoing provision of the optimal level of this EPBI. In an ideal world, a monopoly provider could maximise revenue by practicing first degree price discrimination, and appropriating all of the benefits generated by essential plant breeding infrastructure. Specifically, each user would be charged their individual marginal willingness to pay for each molecular marker. While such an outcome might be regarded as inequitable, it would be efficient for at least the autarky case. In practice, the extent to which perfect price discrimination can be practised will be constrained by imperfect knowledge, transaction costs, and arbitrage opportunities for users or third parties. Furthermore, the application of competition policy principles is likely to require a monopoly provider of essential plant breeding infrastructure to charge the same price to all potential users.

⁵ Produced output from molecular marker programs can include disembodied knowledge about, *inter alia*, how to produce relevant primers for individual markers, estimates of genetic distance between breeding lines that might be used as parents for breeding hybrids, and QTL maps to assist in selecting for polygenic traits of interest. Use of these produced units of knowledge by one plant breeder does not prevent use by any number of other plant breeders.

In the remainder of this paper, it will be assumed that a monopoly supplier must comply with a uniform pricing strategy that requires all potential customers to be charged the same price for each and every molecular marker produced. Given this constraint, in order to maximise profits, a monopoly provider will need to at least:

- i) minimise costs of production, and
- ii) appropriate as much of the potential aggregate net benefit as possible. Even if complete price excludability is feasible and costless, maximising the appropriation of benefits will involve:
 - a) selecting what is known as the Optimal Uniform Price (OUP), defined as the uniform price that maximises revenue at each level of production, and
 - b) choosing the optimal level of output to produce given the marginal revenue function associated with OUP.

Relying on market processes to determine the price can not be expected to produce the desired outcome. In fact, from the literature on excludable public goods, it is clear that providers of such goods have considerable latitude in setting prices, including uniform prices.

Some of the consequences of various pricing strategies used by a monopoly provider of excludable public goods have been analysed, *inter alia*, by Brennan and Walsh (1981,1985), and Burns and Walsh (1981). The remainder of this paper draws on some of their results. A key finding was that, in contrast to markets for private goods, the frequency distribution of individual demand functions is of critical importance in determining returns to producers of joint goods. Consequently, the firms' pricing practice needs to take into account when analysing the supply of joint goods.

To quote Burns and Walsh (1981, pp 168-169):

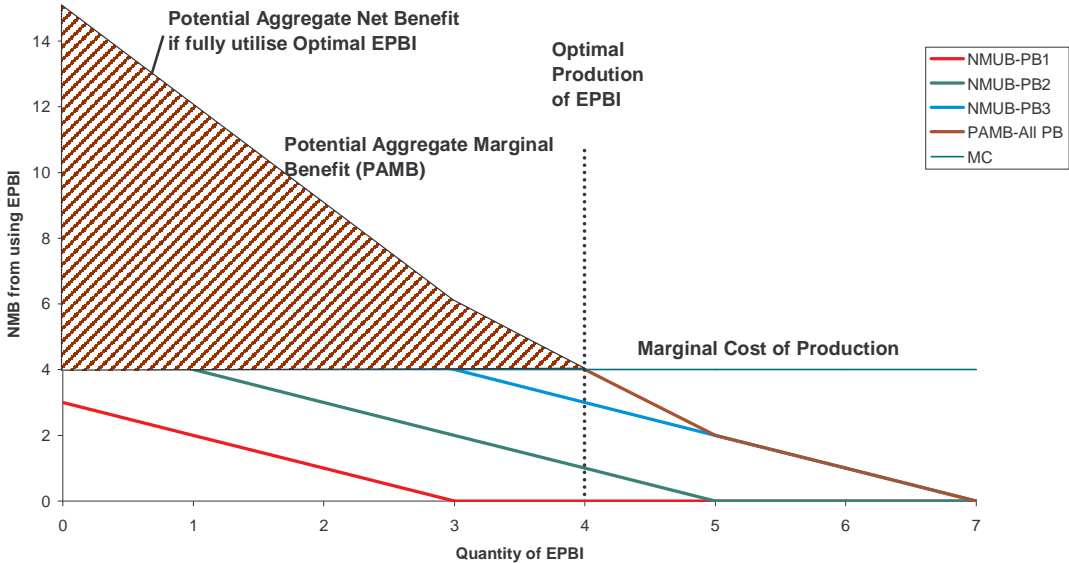
“for monopoly production of price-excludable public goods, information on aggregate demand is inadequate even under uniform per-unit pricing. Since each production unit can be fully and equally consumed by all individuals, output need never exceed that required to satisfy the highest demand individual at any price. Moreover, the per-unit price faced by each individual can be less than the marginal production cost since many units are jointly consumed, but this would necessitate the rationing of some high-demand individuals by output rather than by price. Consequently, not only does the conventional aggregate demand curve not define the relationship between price and output for joint goods, in general it need not even define the relationship between price and aggregate consumption. Operationally, the producer of a joint good will be concerned to identify the maximum revenue obtainable from (various) given output levels, and this critically depends on the composition of demand. Specifically, he will be interested in the number of individuals who would purchase (at least) a certain quantity when confronted with a particular (revenue maximising) price, since this determines his marginal revenue. This construct we term the “distribution of demand”, or, more succinctly, the demand distribution.”

For any given plant breeder, the “value in use” of each molecular marker will be different because the genetic distance between the loci of each marker and the genes of interest are different. Consequently for each breeder the net⁶ marginal user benefit (NMUB) will be a declining function of the number of molecular markers used. Furthermore, the willingness to pay for any particular marker is likely to differ between breeders because of differences in market size, expertise of the plant breeder in marker technology, etc...

Figure 1 below illustrates the demand distribution for a hypothetical case where three plant breeding firms are the only potential customers for seven molecular markers that could be used to select for a valuable polygenic trait. The horizontal axis measures the number of selectable molecular markers produced by the sole supplier, as well as the number used by each plant breeder, while the vertical axis measures marginal user benefit, both individually and in aggregate.

The demand functions for each of the three plant breeding firms⁷ are depicted as a set of separate linear demand curves *D1*, *D2*, and *D3*, which represent the net marginal user benefit (NMUB) for each individual plant breeder for each of the seven molecular markers. It is assumed that knowledge about these molecular markers, once produced, can be disseminated among potential users and utilized by them at zero net marginal social cost. Hence the potential combined marginal user benefit potentially available from full utilization of each molecular marker produced is obtained by vertically summing the individual demand curves for all users. This curve is denoted the potential aggregate marginal benefit (PAMB) function because it assumes that there will be full utilisation of produced output.

FIGURE 1 - OPTIMAL PROVISION OF EPBI



⁶ The direct variable costs of using molecular markers in a plant breeding program are significant, and need to be subtracted from the benefits of doing so to arrive at the net marginal user benefit from the essential plant breeding infrastructure knowledge that is non-rival in use.

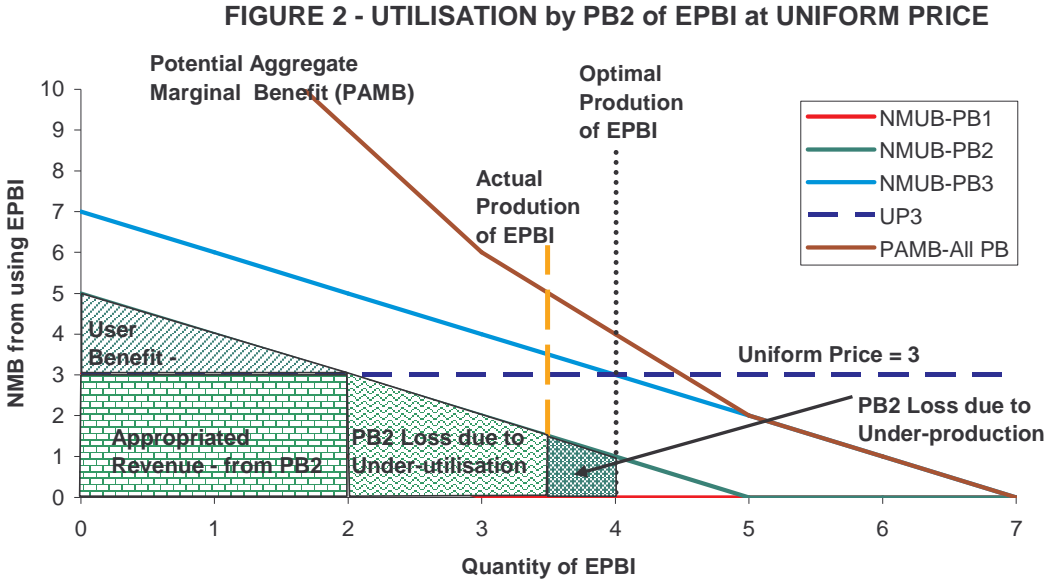
⁷ These functions are defined to measure marginal willingness to pay for each unit of knowledge given that the net marginal cost of utilisation is zero.

For simplicity, assume constant marginal costs of producing molecular marker knowledge, as denoted by the horizontal line MC. As illustrated in Figure 1, it is socially optimal to produce four molecular markers. If these four molecular markers are produced and made available without cost to all plant breeders by some undefined but costless mechanism, potential aggregate net benefit will be equal to the shaded area below the potential aggregate marginal benefit (PAMB) curve and above the marginal cost of production. This area depicts the maximum potential net social surplus achievable given full utilisation of the optimal level of four molecular markers. This idealized set of circumstances will be used below as a benchmark against which to assess the impact of an access regime involving a mandated pricing strategy based on competition policy principles, to private provision of essential plant breeding infrastructure.

Note that in the case illustrated in Figure 1, even if the enabling marker technology is provided free, plant breeder 1 will only use three molecular markers because the direct cost of using the 4th available marker would exceed the gross benefit of doing so. On the other hand, use by breeders 2 and 3 will be constrained by availability of produced markers as the NMUB of the 4th molecular marker is greater than zero. Hence full utilisation does not necessarily involve all breeders using all available markers.

In general, there will be incomplete utilization of produced output when plant breeders are charged a uniform price to obtain access to molecular markers. Hence the PAMB function will overestimate realized aggregate marginal benefit (RAMB), which is defined as the sum of marginal benefits from actual utilisation. Recall that actual use may be rationed either by price or by availability when a uniform price is charged for access to molecular markers.

Given a uniform price, and given that a sub-optimal number of molecular markers are produced; the aggregate net benefit that can be appropriated from plant breeder 2 is illustrated in Figure 2. Realised benefit is the area under the individual demand curve for plant breeder 2 up to the amount of molecular markers actually used at the uniform price. Due to being obliged to charge a uniform price for all units of output, the monopoly provider will only be able to appropriate part of this area. Specifically revenue will equal the product of uniform price by amount of molecular markers used⁸, leaving the area labelled “User Benefit” as a net benefit for plant breeder 2.



⁸ The area labelled “Appropriated Revenue – from PB2”,

Note that plant breeder 2 will underutilise molecular markers so long as price rationing results in actual utilisation being less than produced molecular markers. In Figure 2, this loss is depicted by the area labelled “PB2 Loss due to Under-utilisation”. Furthermore, to the extent that plant breeder 2 would have used more molecular markers than the produced amount if they were *freely* available, there will be a loss of potential welfare due solely to “under-production”. Such a loss, which is depicted in Figure 2 by the area labelled “PB2 Loss due to Under-production”, is part of the social deadweight loss of privatising molecular marker production, even though it is not a loss of potentially appropriable benefits.

As drawn in Figure 2, the maximum willingness-to-pay by plant breeder 1⁹ just equals the uniform price. Consequently, PB1 is totally excluded by price from using any molecular markers, and the monopolist will earn no revenue from this plant breeder. Conversely, plant breeder 3 will be rationed solely by availability, and will use all produced molecular markers, so revenue will equal the product of total produced quantity by the uniform price. Total revenue from uniform pricing is obtained by summing over the realised benefit appropriated from all plant breeders.

The magnitude of each area identified above will not only be different for each plant breeder, but will depend on both the quantum of molecular markers produced, and on the uniform price charged. Conditional on the latter two variables, aggregate revenue, user benefit not appropriated, and welfare losses due to under-utilisation and to under-production can be obtained by summing over the separate measures for all users.

To proceed more formally with an analysis of the monopoly provision and pricing of a joint good like molecular markers, the same set of simplifying assumptions used by Burns and Walsh (1981) are adopted here. The starting point is the specification of the demand distribution, defined as “the number of individuals, n^{10} , who would each consume at least q units of output if the joint good was made available at a per-unit price of p .”

Specifically, let the demand distribution be denoted as $n=n(p,q)$;

where $dn/dp < 0$; and $dn/dq < 0$.

Alternatively the inverse function is $p=p(n,q)$ which denotes maximum willingness to pay by user n for incremental unit of output q .

The limits of this demand distribution can be specified by the parameters: N , P , and Q , defined as follows:

N denotes total number of potential users,

Q denotes quantity demanded at price zero by the most demanding user, and also denotes maximum possible production.

P denotes maximum willingness-to-pay by the most demanding user,

In order to ensure mathematical tractability, Burns and Walsh (1981) further assumed that the individual demand curves that make up this demand distribution are linear, and have identical slopes¹¹. Lastly it is assumed that:

- n is uniformly distributed on the interval $U(0, \dots, N)$ ¹². and

Given these assumptions:

⁹ i.e. the intersection of the demand curve for PB1 With the vertical axis.

¹⁰ See Burns and Walsh (1981, p.169). Note that the variable, n , refers only to the number of users who would consume *all* of the available amount of the joint good, and does not include those users who would consume only part of q at the defined price, p .

¹¹ Note that this assumption ensures that individual demand curves in the demand distribution do not intersect. Eliminating the possibility of intersecting individual demand curves makes the analysis much more tractable.

¹² Note that this is equivalent to assuming that maximum willingness-to-pay by the n the user, $p(n)$, is uniformly distributed on the interval $U(0, \dots, P)$; and $q(n)$, is uniformly distributed on the interval $U(0, \dots, Q)$.

$$p(n, q) = P \cdot \left[\frac{n}{N} - \frac{q}{Q} \right] \quad (1)$$

Derivation of potential aggregate marginal benefits, $PAMB(q)$ for produced output q , is straightforward, and yields:

$$PAMB(q) = \int_{q \cdot N/Q}^N p(n, q) dn = \frac{NP}{2} \left[\frac{q}{Q} - 1 \right]^2 \quad (2)$$

Optimal production of molecular markers in an ideal world, q_{OPT} , is obtained by solving for q when $PAMB(q)$ is equal to the marginal cost of production, μ .

$$q_{OPT} = \left\{ 1 - \sqrt{(2 \cdot \mu / N \cdot P)} \right\} \cdot Q \quad (3)$$

By defining a production cost index, $\psi = \mu / (P \cdot N)$, and substituting this variable into equation and (3) dividing it by Q , a normalised equation can be obtained as follows:

$$q_{OPT}/Q = \left\{ 1 - \sqrt{(2 \cdot \psi)} \right\} \quad (4)$$

As proposed above, this ideal of output can be used as a benchmark against which to compare the monopoly provision of essential plant breeding infrastructure when the monopolist is constrained to charge a uniform price for all produced output.

To derive the total revenue, $TR(qa, pu)$, that the monopolist can appropriate when potential users are charged a per unit uniform price pu , to access any number of molecular markers up to a limit of the amount produced, qa , note that:

When available output equals qa , and uniform price equals pu ,

Users for whom $p(n, 0) < pu$ are totally excluded by price, so the monopolist derives no revenue from this group of potential users.

For $N \cdot (pu/P) < n < N \cdot (pu/P + qa/Q)$, appropriated revenue equals $pu \cdot Q \cdot (n/N - pu/P)$, and

For $n > N \cdot (pu/P + qa/Q)$, appropriated revenue equals $pu \cdot Q$, so total appropriated revenue is given by:

$$TR(qa, pu) = \int_{N \cdot pu/P}^{N \cdot (pu/P + qa/Q)} pu \cdot Q \cdot (n/N - pu/P) dn + \int_{N \cdot (pu/P + qa/Q)}^N pu \cdot qa dn \quad (5)$$

Simplifying (5) yields:

$$TR(qa, pu) = N \cdot pu \cdot qa \cdot \left(\left(1 - \frac{qa}{2 \cdot Q} \right) - \frac{pu}{P} \right) \quad (6)$$

For any given level of production qa , the optimal uniform price, $p_{OUP}(qa)$, is defined as the uniform price that maximises revenue for that level of output. Setting the derivative of (6) with respect to pu equal to zero, and solving for $OUP(qa)$ yields :

$$OUP(qa) = \frac{P}{4} \cdot \left[2 - \frac{qa}{Q} \right] \quad (7)$$

Substituting $OUP(qa)$ from (7) back into (6) for pu yields total revenue for qa given optimal uniform pricing $TR_{OUP}(qa)$:

$$TR_{OUP}(qa) = \frac{N \cdot P \cdot qa}{16} \cdot \left[2 - \frac{qa}{Q} \right]^2 \quad (8)$$

And the equivalent marginal revenue function, $MR_{OUP}(qa)$, for a profit maximising monopolist is:

$$MR_{OUP}(qa) = \frac{N \cdot P}{16} \cdot \left(4 \cdot \left[\frac{qa}{Q} - 1 \right]^2 - \left[\frac{qa}{Q} \right]^2 \right) \quad (9)$$

which is equal to:

$$MR_{OUP}(qa) = \frac{N \cdot P \cdot (2Q - 3qa)(2Q - qa)}{16Q^2} \quad (10)$$

The impact of privatizing the production of essential plant breeding infrastructure, such as molecular markers, on the produced level of output can be assessed by setting the above function equal to marginal cost, μ , and solving for profit maximising output, $q_{OUP}(\mu)$:

$$q_{OUP}(\mu) = \frac{2Q}{3} \left(2 - \frac{\sqrt{(N \cdot P + 12\mu)}}{\sqrt{N \cdot P}} \right) \quad (11)$$

Again this equation can be normalised by substituting ψ for $\mu/(P \cdot N)$, and dividing by Q , as follows:

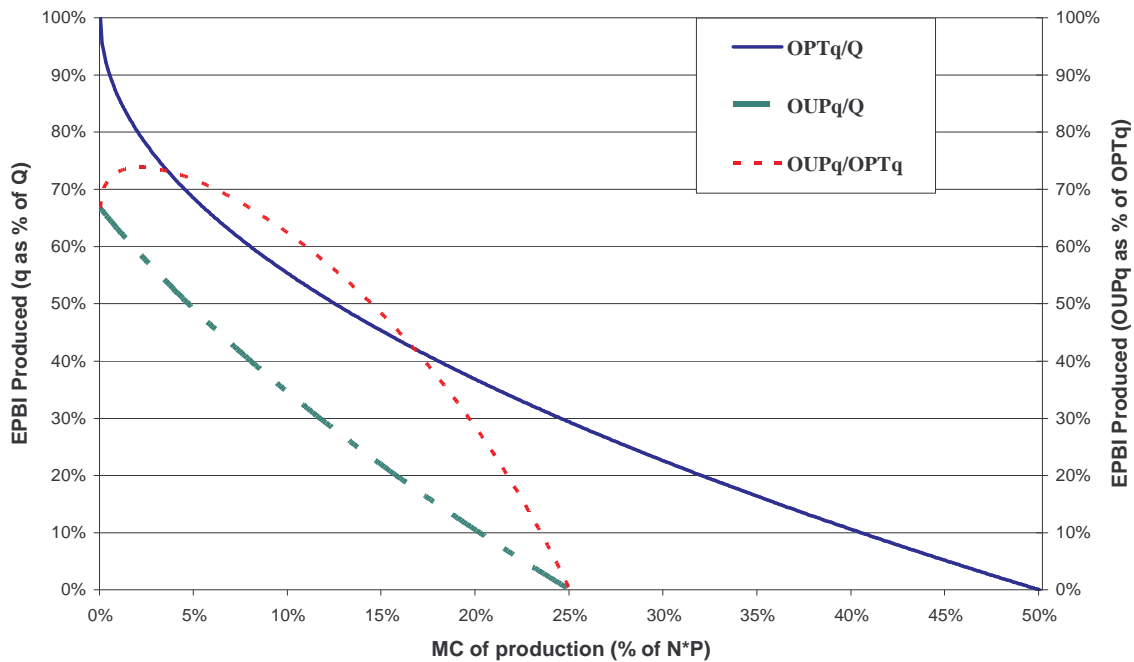
$$q_{OUP}(\mu)/Q = \frac{2}{3} \left(2 - \sqrt{(12 \cdot \psi + 1)} \right) \quad (12)$$

and the ratio of $q_{OUP}(\mu)$ to q_{OPT} is:

$$q_{OUP}(\mu)/q_{OPT} = \frac{2 \cdot (\sqrt{(12 \cdot \psi + 1)} - 2)}{3 \cdot (\sqrt{2 \cdot \psi} - 1)} \quad (13)$$

Note that equations (4), (12), and (13) all depend solely on the production cost index, ($\psi = \mu/(P \cdot N)$), defined as the ratio of the marginal cost of production to the product of two of the three parameters of the demand distribution, N and P . In Figure 3 below, the normalised equations (4) and (12) for optimal output in an ideal world, q_{OPT}/Q , and provision by a profit maximising monopolist constrained to charging a uniform price, $q_{OUP}(\mu)/Q$, respectively, as well as the ratio of the latter to the former, are plotted against the production cost index, $\psi = \mu/(P \cdot Q)$ to illustrate the impact of privatization on production of essential plant breeding infrastructure:

FIGURE 3: OPTIMAL versus MONOPOLY PROVISION of EPBI under OUP



Several points from this Figure are noteworthy. Optimal level of output for molecular markers in an ideal world declines monotonically from Q , which is the quantity demanded at price zero by the most demanding user, and one of the limits of the demand distribution, to zero as the production cost index increases from 0 to 50%.

However, even when the production cost index is zero, the profit maximising level of output for a monopolist constrained to charging a single uniform price for each and every level of output, will be only 67 percent of Q , the limit of the demand distribution. Moreover, it monotonically declines to zero by the time that the production cost index reaches 25%, which is half the value of the production cost index at which it is no longer optimal to produce any level of molecular markers.

Furthermore, the ratio of molecular marker provision by monopolist charging a uniform price to optimal output in an ideal world never exceeds 75% even when the marginal cost of production is relatively inexpensive, and it declines rapidly to 0% by the time that the production cost index reaches 25%. In other words, the degree of under production of essential plant breeding infrastructure caused by privatisation becomes more severe as production costs become relatively more expensive.

7. Conclusions

Much of the previous productivity gains from plant breeding derive from scientific discoveries that have underpinned enabling technologies for plant breeding. Just two examples are pre-breeding research in such diverse fields as biometry and plant pathology. Once produced, most of these enabling technologies are non-rival in use by plant breeders, and consequently can be thought of as essential plant breeding infrastructure (EPBI). Traditionally, such inputs were non-proprietary, provision was publicly funded, and access by public plant breeding programs was both open and free of any charges. As a result, there was no financial impediment to full utilisation of EPBI.

As plant breeding becomes increasingly privatised, future potential productivity gains will depend on overcoming emerging threats to the provision of adequate levels of modern EPBI, such as molecular markers, and on the development of institutional arrangements that ensure, if not full utilisation, then at least levels of utilisation that minimise the loss of potential benefits in downstream markets. In a world where the supply of essential plant breeding infrastructure is being left more and more to commercially driven entities, these two issues of adequate provision, and open access will be interconnected by permitted pricing practices. Because competitive supply would involve wasteful duplication in production of such joint goods, pricing of EPBI by a monopoly provider will be a particularly important policy issue to be addressed if the potential benefits from modern plant breeding are to be fully realised. In common with NCP access regulation, at least part of the aim should be to promote full and efficient competition in upstream and downstream markets, while preserving adequate incentives for investment in the ongoing development, maintenance, and provision of essential plant breeding infrastructure. Some lessons can be learnt from the application of provisions in Part IIIA of the Trade Practices Act 1974 to overcome denial of access to a third party to an eligible infrastructure service.

However, even if denial of access does not prove to be a problem, an essential issue for any access regime will be to determine the impact of pricing practice by a monopoly provider of EPBI on potential losses from under-production due to inadequate incentives for future investment on the one hand, and the opportunity cost of under-utilisation of produced EPBI by plant breeders on the other hand.

A start has been made on this task in this paper by utilising the framework for analysis of pricing of excludable public goods developed, *inter alia*, by Burns and Walsh (1981). Specifically, the impact on level of production of EPBI was analysed when a monopoly provider is constrained by competition policy to charging a single uniform price to all plant breeders for each and every molecular marker produced.

As would be expected, it was demonstrated the monopoly provision would fall far short of theoretical output by a publicly financed and well informed public provider acting to maximise aggregate potential benefits to industry and to society. It also was possible to quantify the possible degree of under-production. For molecular markers that are low cost relative to the parameters of the demand distribution, under-production might be as little as 25%. However, past some very low level of the production cost index, the degree of under-production increased dramatically. Moreover, even though it would be socially desirable to produce some EPBI for values of the production cost index up to 50%, a monopoly provider would not produce any essential plant breeding infrastructure if the production cost index exceeded 25%.

Many questions require further research, including the following.

What is the actual nature of plant breeders' demand distribution for molecular markers, or other essential plant breeding infrastructure?

How sensitive are the above results to the key assumptions that individual demand curves are linear, have the same slope, and are uniformly distributed across the demand distribution range, and that the marginal cost of production is constant?.

What would be the effect on level of production of essential plant breeding infrastructure if differing pricing strategies were employed, such as:

- molecular markers provided to plant breeders on a cost recovery basis, or
- the access regime regulates prices so that monopoly profits do not exceed normal profits, or
- the monopolist must charge a uniform price for any given molecular marker, but can charge different uniform prices for different molecular markers,

- all feasible forms of price discrimination are permitted?

Finally, apart from the impact of different pricing strategies on level of provision of essential plant breeding infrastructure, the magnitude of the loss of potential benefits due to under-production and to under-utilisation also need to be estimated.

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