The Australian Journal of Agricultural and Resource Economics, 48:2, pp. 301–321

Privatised provision of essential plant breeding infrastructure*

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As private plant breeding replaces public programs, the efficient provision and utilisation of key enabling technologies for crop breeding, which are largely knowledge based and provide the foundation for variety improvement, might be at risk. Typically, such inputs are non-rival in use and are therefore termed essential plant breeding infrastructure (EPBI). Specific threats include the possibility of wasteful duplication in production, under-production, under-utilisation of produced EPBI because of price rationing, and anticompetitive outcomes in plant breeding and downstream markets. The likely level of under-investment in hypothetical molecular-marker technology by a profit-maximising monopoly producer, charging uniform prices for access, is analysed using results from the published literature on excludable public goods.

1. Introduction

Interactions between advances in scientific knowledge, changes in the legal framework for intellectual property rights, and competitive forces in the market are driving economic outcomes in the 'plant breeding industry'. Opportunities to create value in the supply chain arising from scientific discoveries provide powerful incentives for firms to invest in plant breeding. More or less concurrently, the capacity to appropriate a sizeable share of the benefits from the intellectual capital embedded in improved varieties has been enhanced by significant extensions to intellectual property rights.

* Precursors to this paper were presented to the 47th Annual Conference of the Australian Agricultural and Resource Economics Society in February, 2003 and to the 7th International Conference of The International Consortium on Agricultural Biotechnology Research (ICABR) on '*Productivity, Public Goods and Public Policy: Agricultural Biotechnology Potentials*' in Ravello (Italy), 30 June–3 July, 2003. The author is grateful to John Freebairn, Mike Perry, and Mick Poole for helpful comments on those papers, and to two anonymous referees for suggestions about how to improve earlier drafts. Remaining problems are the responsibility of the author.

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Together, these developments have unleashed competitive forces that are likely to transform the production of new plant varieties. For many broadacre crops in Australia, a transition is well underway from a crop breeding system dominated by public 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 to recover at least some of the costs of the breeding program (as distinct from costs of seed multiplication) by charging growers more for newly released varieties.

A more commercially orientated and competitive system of crop breeding will bring many benefits to grain growers, but there also will be challenges that need to be addressed if potential greater gains in crop productivity are to be realised.[1] The topic of the present paper is the possible impact of a more privatised crop breeding system on the efficient provision of breeding technologies, and related 'knowledge rich' inputs to plant breeding, that provide the crucial foundation for ongoing variety improvement. For convenience, such inputs will be referred to as key enabling technologies.

Effectively, most key enabling technologies are non-rival in use by competing plant breeders because they are largely knowledge based. Where knowledge is embedded in a tangible technology, the use of which requires consumables that are rival in use, the knowledge component of such technology is still non-rival in use. In effect, the knowledge component enables a capacity to practice the technology that is unlimited, and hence non-rival in use. For reasons to be discussed in following text, this capacity to practice key enabling technologies will be referred to as essential plant breeding infrastructure (EPBI).

In the past, most key enabling technologies for plant breeding have been non-proprietary as provision has been predominantly publicly funded. Consequently, they have been non-excludable as well as largely non-rival in use, which are the two attributes that distinguish true public goods.

Arguably, these admirable arrangements are unlikely to survive the privatisation of the plant breeding industry. Current funding sources for the provision and further development of key enabling technologies are already under threat. As a result, public agencies might abandon such activity to the private sector, and/or might seek to recover some or all of the cost by charging plant breeders for access to these technologies. This is likely to hasten an emerging trend toward greater application of intellectual property rights to breeding technologies as well as to germplasm, and to the commercialisation and possible privatisation of their production.

[1] See Phillips (1999), Lindner (1999, 2002, 2003a, 2003b) and Heisey *et al.* (2002), for details.

If key enabling technologies are proprietary or otherwise price excludable, then they belong to a class of goods variously referred to as joint goods, 'club goods', or simply excludable public goods. The stimulus to inventive activity provided by the patent system demonstrates that private provision of excludable public goods has some potential advantages vis-à-vis public provision of pure public goods. However, there also are threats to the efficient provision and utilisation of EPBI that need to be addressed if the potential benefits from some form of privatised provision of key enabling technologies are to be fully realised.

As private plant breeding replaces public programs, there are at least four identifiable threats to the efficient provision and utilisation of EPBI. First, is the possibility of wasteful duplication in their production as private plant breeding firms strive for competitive advantage in the market place. Second, is the risk that the incentives for private investment will be inadequate for it to substitute fully for the likely withdrawal of public funding. Third, increasingly prevalent attempts to maintain the incentive for adequate investment in the development of key enabling technologies by protecting and charging for their use will almost inevitably result in inefficient underutilisation of EPBI as a result of price exclusion. Finally, monopoly provision of enabling technologies may result in anti-competitive outcomes in downstream markets unless there are access regimes to ensure that the potential benefits from competition among plant breeders are fully realised.

A number of examples of key enabling technologies for plant breeding are reviewed in the next section, together with some of the causal changes behind the emerging trend to privatisation in the plant breeding industry. This is followed by a discussion of the policy issues that need to be addressed to ensure that the potential benefits to grain growers from these trends are realised. An analysis of the likely level of under-production of EPBI by a profit maximising monopoly provider constrained to charging a uniform price for access to EPBI precedes the concluding section.

2. Key enabling technologies and the trend to privatisation of plant breeding

Historically, most crop breeding in Australia was conducted by 'public' research organisations that were financed mainly from government revenue. Publicly financed agencies, including state government Departments of Agriculture, universities and CSIRO, also carried out supporting research in agronomy, plant pathology, entomology, biometry, plant nutrition, plant physiology and cognate disciplines. These programs produced enabling knowledge and technology for plant breeding that has underpinned much of the productivity growth of modern plant breeding, and provided the foundation for ongoing variety improvement and consequent productivity gains in crop production.

Prime examples of enabling technologies of long standing are the collection and conservation of germplasm, including both land-race and elite breeding lines, marker assisted selection, and hybrid technology. Results of prebreeding research in such diverse fields as agronomy, biometry, entomology, plant pathology and quarantine, plant physiology, product chemistry, and quantitative genetics, have led to greater potential for value creation by improvements in plant breeding methods.

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. New plant breeding methods such as dihaploidy, plant regeneration systems such as 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 have 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.

Use of these techniques in conventional plant breeding is already reducing the time lags from initial crosses to release of new varieties, reducing the cost of development of improved crop varieties, and enabling the development of superior 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 genetically modified organisms (GMO). Examples include agrobacterium-mediated transformation, positive and negative selection systems for detecting transgenic plants, and polymerase chain reaction (PCR). Potential beneficial outcomes from transgenic technologies include:

- development of improved crop cultivars with novel agronomic/input traits that enable lower average costs of production.[2]
- development of improved crop cultivars with novel quality-enhanced traits for which consumers are willing to pay a price premium.

Because key enabling technologies provide the foundation for ongoing variety improvement and consequent productivity gains in crop production, future private investment in crop breeding will be threatened unless there is sufficient continuing investment in further development of these productivity enhancing enabling technologies.

[2] Namely, traits that could not have been incorporated economically into improved varieties by conventional plant breeding methods.

Whether by accident or by design, traditional arrangements for funding, provision and access to these key enabling technologies treated them as public goods. Public agencies that developed them did not seek to register any proprietary interest in them. Nor did they charge for access to them, and all plant breeding programs had open access to any key enabling technologies so produced. In addition, no attempt was made to recover the costs of production by charging growers for the intellectual capital embedded in newly released varieties.[3] Therefore, historically these key enabling technologies were both non-rival in use, and non-price excludable, the two essential attributes of true public goods.

Other sources of funding, most notably collective industry funding have gradually substituted for a significant proportion of government funding over the past decade or so. Although, at least until recently, both plant breeding and the development of key enabling technologies have continued to be conducted primarily by the same public agencies. Furthermore, where national industry organisations such as the Grains Research and Development Corporation (GRDC) collectively funded the development of enabling technologies for plant breeding, they implemented a system of national coordination to control, if not eliminate, any tendency for duplication, and to ensure that all plant breeding programs continued to enjoy free and open access to these technologies.

These traditional, and in many ways ideal arrangements are changing for a number of reasons. There has been reduced public funding for many purposes, including rural research, for at least a decade or two. For rural research, this has partly been a result of a growing perception that grain growers have been the primary beneficiaries of these R&D programs. As a result, many 'public' institutions are under pressure to become at least partially self-funding, and are now charging for selected goods and services.

Research institutions are not immune to these pressures, and many public R&D organisations are under pressure to commercialise discoveries, and to convert some of their operations to a 'cost recovery', or even 'for profit' basis. Patenting or otherwise protecting inventions are now common practice, as is the pursuit of opportunities to license technologies to the private sector.

The capacity to use intellectual property rights to register propriety interests in key enabling technologies as a basis for commercialisation has expanded appreciably. The most significant intellectual property rights for plant breeding are patents and Plant Breeder's Rights. In recent decades,

[3] Typically, producers paid a nominal fee for improved varieties, which were made freely available. Any fee in excess of the costs of seed multiplication recovered little if any of the costs of breeding, and contributed nothing toward the cost of supporting research.

court judgements, legislative changes, and new or revised international agreements have expanded the domain and scope of patents and plant breeders' rights.

These extensions to the legal framework for intellectual property rights have made it possible for firms to capture more of the value created by key enabling technologies and plant breeding, thereby providing an incentive for private investment in their development. In turn, this has contributed to the trend to privatisation of crop breeding in Australia.

3. Policy challenges for privatised provision of essential plant breeding infrastructure

In the emerging world of competitive plant breeding, there are a number of possible threats to the future level of investment in the creation of these key enabling technologies, and to their efficient production and utilisation. 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 there is no compensating funding from other sources, it is inevitable that development of new enabling technologies and innovation in plant breeding methods will decline.

One alternative in a world of privatised plant breeding would be for each plant breeding firm to fund the production of key enabling technologies for its own use. Arguably, this would be the worst possible outcome for two reasons. So long as the production technology for essential plant breeding infrastructure is fixed,[4] production by competing plant breeder of inputs that are non-rival in use would involve wasteful duplication. In addition, the level produced and utilised by any given firm would be suboptimal because the value in use to any one firm would be a fraction of aggregate value in use for all firms combined.

Subject to the above caveat, there is a *prima facie* case for some form of collective funding and monopoly provision of key enabling technologies by a sole producer. Cooperative behaviour and shared funding by plant breeding firms is one possibility. An actual example is the development of molecular marker technology for canola breeding by Agriculture and Agri-Food Canada that is funded by a global consortium of private and public plant breeders. The provider charges an 'up front' subscription fee to each consortium member, who contribute equally to the overall cost of development. In return, consortium members have exclusive access to the

[4] As the race to sequence the human genome demonstrated, competition and consequent duplication might be beneficial if it enables the invention of more efficient methods of production.

technology and can make unlimited use of it without further payment. 'Free riding' by non-members is prevented by legally binding confidentiality clauses in the consortium agreement.

The consortium agreement treats the molecular marker technology as a classic club good. In return for payment of a uniform 'all or nothing' fee, exclusive access is available to club members, but subsequent usage is not rationed by price. However, the 'all or nothing' price can ration utilisation by potential users who are unwilling to pay for entry to the club.

Another potential problem with such arrangements is the transaction costs involved in their establishment. Potential members differ markedly in their capacity to benefit from the molecular marker technology and, henceforth, in their willingness to pay for access to it. There are also likely to be differences about many matters of detail, such as which types of molecular markers to develop, how many molecular markers to produce, what limits, if any, are to be put on use by consortium members and ownership rights.

In Australia, collective funding by grain growers through bodies, such as GRDC, is an alternative source of funding for essential plant breeding infrastructure that could continue to meet the needs of the grains industry. For this club, membership is compulsory for all producers of mandate grains, although the cost of membership is linked to the level of grain production.

While potential benefits are likely to be correlated with grain production levels, for any given technology there will be significant regional and crop related differences in potential benefits, as well as differences between individual farmers in their ability to benefit from any given technology. In addition, there will be intertemporal differences between past, present and future grain growers. Perhaps for these reasons, there is increasing pressure for GRDC to commercialise those enabling technologies in which it invests, and to recoup at least part of the cost of its investment by way of user fees. Another possible problem to be discussed below is a potential conflict of interest when GRDC invests in the development of key enabling technologies as well as in some but not all plant breeding firms that are likely users of such technology.

Private provision by a profit maximising producer is yet another alternative. How much value is captured will depend on the extent to which market forces and intellectual property rights enable providers to appropriate part of the value created from enabling technologies by charging for the right to access the technology. It is likely that continued funding for future production will be forthcoming only if the returns from 'private' provision are sufficiently attractive to maintain ongoing investment.

While a suitable funding source, sufficient provision, and minimum wasteful duplication in production are all causes for concern, efficient utilisation of key enabling technologies is another. Of particular concern is the possibility of significant deadweight losses in efficiency from under-utilisation. Under-utilisation is an inevitable consequence of charging for access unless the producer can practice first-degree price discrimination, and thereby appropriate all of the benefits generated by using the technology. If the technology is under-utilised, a further consequence will be an inadequate incentive to invest in the optimal level of production. The possible degree of under-production of essential plant breeding infrastructure by a profit maximising monopoly provider is analysed in the next section.

To ensure efficient utilisation, and to reap all of the benefits from more competition, all competing plant breeding firms need to have access to key enabling technologies on equal terms and conditions. If utilisation by some firms is advantaged relative to others because of commercial practice, or by the institutional, policy, or legal framework; then competition among plant breeders might not generate optimal outcomes. Conversely, if all firms compete on a 'level playing field', then only the most efficient should survive.

There are obvious parallels here to National Competition Policy (NCP) principles governing access to essential infrastructure (Productivity Commission 1999, 2001). The aim of NCP is to facilitate effective competition in those situations where competition between suppliers of goods and services will result in lower prices, a wider range of products, and/or better service for consumers. Where competition can be shown to not have these effects, or where it endangers other social objectives, there are provisions to permit non-competitive production.

Because the capacity of physical infrastructure also can be non-rival in use so long as available capacity exceeds the demand for it, competition might not be feasible or desirable in its provision. For instance, monopoly provision of essential infrastructure is accepted in industries such as telecommunications, air and rail transport, and electricity transmission.

However, shared use of such 'bottleneck' or 'essential' infrastructure facilities might 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.

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 EPBI. Unless some rational access regime is established, some of the potential benefits from scientific discoveries underpinning modern plant breeding might 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 (TPA) 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. As the key provider of EPBI for crop breeding, GRDC 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 or discriminatory pricing. One would be to deny access to, or charge higher prices for EPBI to large multinational 'life science' firms. A possible ground for doing so would be that these multinational 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.

4. Monopoly provision of EPBI given uniform pricing

The rest of the present paper is devoted to an analysis of the provision of EPBI when a monopoly producer either chooses, or is obliged to provide all plant breeders with access to essential plant breeding infrastructure on the same terms and conditions. An ideal system of publicly funded and produced essential plant breeding infrastructure that are freely and openly provided to all plant breeders will be used as a first best benchmark, against which to assess the performance of alternative arrangements. This assumes that the opportunity cost of public funding would be the same as the opportunity cost of private funding, that best practice production technology is known, and that an ideal public system can correctly identify the optimal level of provision for each key enabling technology. Whether the historical system outlined above satisfied these conditions will not be investigated in the present paper.

Molecular markers that could be used to generate a linkage map for a valuable polygenic trait are a good example of essential plant breeding infrastructure that could be an excludable public good.[5] They are one of the key inputs for more productive plant breeding; and *prima facie*, are non-rival in use by plant breeders.[6] Therefore, 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. Henceforth, at least partial price excludability is usually feasible even though there are numerous instances where they have been made freely available. 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, molecular markers provide a tangible and comprehensible case study with which to analyse some of the likely consequences of adopting an access regime based on non-discriminatory pricing.

In principle, a monopoly provider could maximise revenue by practising 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 at least for 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

[5] Molecular markers can be defined as segments of a plant's DNA that exhibit polymorphism in relevant breeding populations (i.e., genotypic variation between individual members of the population). By means of linkage studies, they can be statistically correlated with particular allele(s) of the gene(s) of interest. One or more such genes can determine traits of economic value, so the presence of particular molecular markers can be used to infer that a plant does or does not possess a particular genotype.

[6] 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.

users or third parties. Furthermore, and most importantly in the context of this article, the application of competition policy principles gives clear guidance to a monopoly provider such as GRDC that all potential users should be charged the same price to access molecular marker technology.

In the remainder of the present paper, it will be assumed that a monopoly supplier charges all potential customers the same uniform price for each and every molecular marker produced. It is clear from the literature on excludable public goods that providers of such goods have considerable latitude in setting prices even if they are committed to charging uniform prices. Moreover, market pressures cannot be relied on to determine a unique price. In order to maximise profits given the constraint of uniform pricing, a monopoly provider will need to at least:

- minimise costs of production,
- 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:

- selecting what is known as the optimal uniform price (OUP), defined as the uniform price that maximises revenue at each level of production,
- choosing the optimal level of output to produce given the marginal revenue function associated with OUP.

Note that this pricing behaviour might not be first best. It is however, a plausible pricing policy for a monopolist seeking to maximise revenue subject to the constraint of conforming to competition policy principles.

Some of the consequences of a range of pricing strategies that might be used by a monopoly provider of excludable public goods have been analysed, *inter alia*, by Brennan and Walsh *et al.* (1981, 1985) and Burns and Walsh (1981). The analysis below 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 the demand distribution 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. As 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 net 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.[7]

Figure 1 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 ordering of molecular markers along the horizontal axis is determined by their 'quality', as measured by their net benefit to plant breeders.

The demand functions for each of the three plant breeding firms are depicted as a set of separate linear demand curves NMUB-PB1, NMUB-PB2, and NMUB-PB3, which represent the NMUB for each individual

[7] 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 knowledge component of the molecular marker that constitutes the essential plant breeding infrastructure and is non-rival in use.

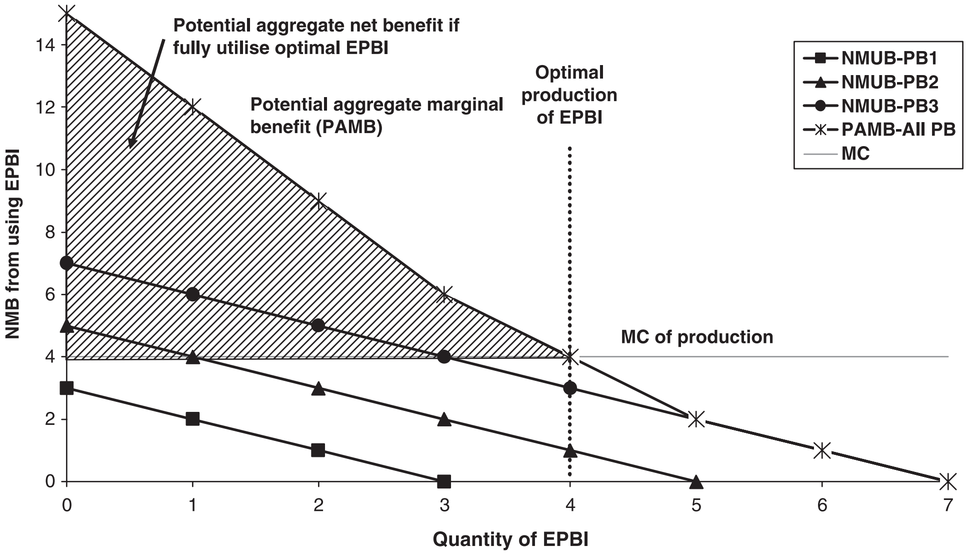

Figure 1 Optimal provision of essential plant breeding infrastructure (EPBI). NMUB, net marginal user benefit; MC, marginal cost; PB, plant breeder.

plant breeder.[8] Once produced, knowledge about these molecular markers can be disseminated among potential users and used at zero net marginal social cost. Henceforth, the combined marginal user benefit potentially available from full use 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 use of produced output.

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 made available without cost to all plant breeders by some undefined but costless mechanism, potential aggregate net benefit (PANB) will be equal to the shaded area below the 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 idealised outcome will serve as a benchmark against which to assess the impact of private provision of essential plant breeding infrastructure and an access regime based on competition policy principles.

[8] These functions are defined to measure net marginal willingness to pay for each unit of knowledge given that the net marginal cost of utilisation is zero. If the marginal cost of utilisation is greater than zero, then as noted above it can be deducted from the gross marginal willingness to pay to utilise each molecular marker to obtain the marginal willingness to pay for the knowledge embodied in each molecular marker.

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 fourth available marker would exceed the gross benefit of doing so. In contrast, use by breeders 2 and 3 will be constrained by availability of produced markers as the NMUB of the fourth 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 utilisation of produced output when plant breeders are charged a positive uniform price to obtain access to molecular markers. Hence, the PAMB function will overestimate realised aggregate marginal benefit (RAMB), 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.

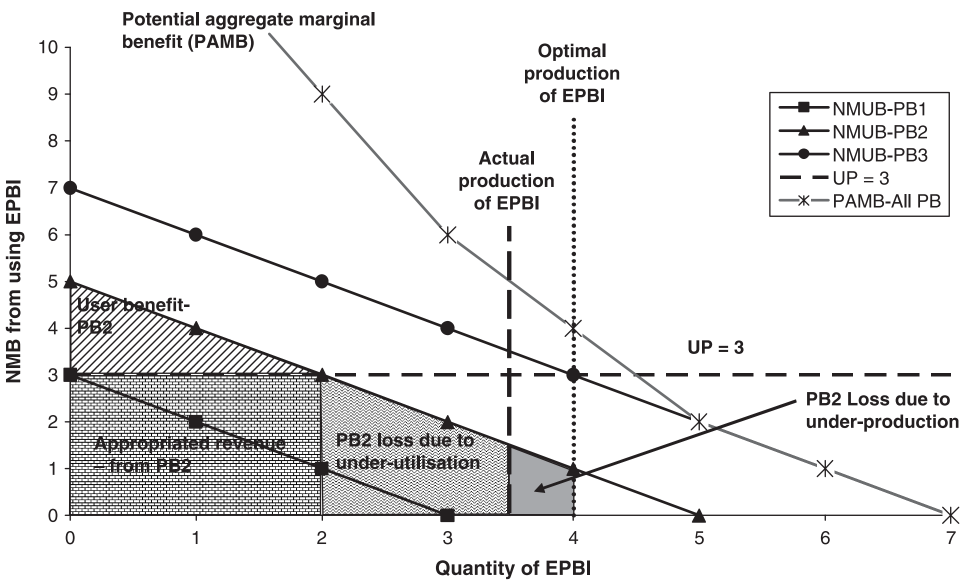

Figure 2 Utilisation by PB2 of essential plant breeding infrastructure (EPBI) at uniform price. NMUB, net marginal user benefit; PB, plant breeder; UP, uniform price.

For reasons to be discussed below, the actual level of EPBI produced by a revenue maximising monopolist will be less than the optimal level. Figure 2 illustrates the aggregate net benefit appropriated from plant breeder 2 given an arbitrary and suboptimal number of produced molecular markers – denoted as actual production of EPBI in figure 2 – for which any given uniform price is charged. Realised benefit is the area under the individual demand curve for plant breeder 2, and up to the amount of molecular markers actually used at the uniform price, in this case 2 units.

As the uniform price is charged 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 used,[9] leaving the area labelled 'User benefit' as a net benefit for plant breeder 2.

Note that plant breeder 2 will under-utilise molecular markers so long as price rationing results in actual utilisation being less than the produced number of molecular markers. In figure 2, this loss is depicted by the area labelled 'PB2 loss as a result of 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 solely because of 'under-production'. Such a loss, which is depicted in figure 2 by the area labelled 'PB2 loss as a result of under-production', is part of the 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 1 just equals the uniform price.[10] Consequently, the uniform price effectively excludes PB1 from using any molecular markers, and the monopolist will earn no revenue from this plant breeder. Conversely, availability of produced molecular markers will ration use by plant breeder 3, so revenue from breeder 3 will equal the product of total produced quantity by the uniform price. Total revenue from uniform pricing is the sum of the benefits 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 as a result of 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, who would each consume at least q units of output if the joint good was made available at a per-unit price of p.[11]

[9] The area labelled 'Appropriated revenue – from PB2'.

[10] That is, the intersection of the demand curve for PB1 with the vertical axis.

[11] 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.

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, and 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 slopes.[12] Lastly, it is assumed that n is uniformly distributed on the interval $U(0, \ldots, N)$.[13]

Given these assumptions:

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

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

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

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,

$$q\_OPT = \left\{ 1 - \sqrt{(2 \cdot \mu / N \cdot P)} \right\} \cdot Q \tag{3}$$

By defining a capacity production cost index, $\psi = 2 \cdot \mu / (P * N)$, and substituting this variable into equation (3) and dividing it by Q, a normalised equation can be obtained as follows:

$$q\_OPT/Q = \left\{ 1 - \sqrt{\psi} \right\} \tag{4}$$

[12] 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.

[13] 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 $U(0, \ldots, P)$; and $q(n)$, is uniformly distributed on the interval $U(0, \ldots, Q)$.

As proposed, this ideal output q_OPT, can be used as a benchmark against which to compare the monopoly provision of essential plant breeding infrastructure when the monopolist charges a per unit uniform price to access any or all produced output.

To derive 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 users for whom:

- $p(n, 0) < pu$ are totally excluded by price, so the monopolist derives no revenue from this group of potential users,
- $N \cdot (pu/P) < n < N \cdot (pu/P + qa/Q)$, appropriated revenue equals $pu \cdot Q \cdot (n/N\text{-}pu/P)$,
- $n > N \cdot (pu/P + qa/Q)$, appropriated revenue equals $pu \cdot Q$.

Total appropriated revenue can be obtained by summing the product of pu and the relevant quantity of molecular markers used by each group of potential users, as follows:

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

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, $OUP(qa)$, 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, $TR\_OUP\,(qa)$, for qa given optimal uniform pricing:

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

and the equivalent marginal revenue function, $MR\_OUP\,(qa)$ is:

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

which simplifies to:

$$MR\_OUP(qa) = \frac{N \cdot P \cdot (2Q - 3qa)(2Q - qa)}{16Q^2} \tag{10}$$

The impact of privatising the production of essential plant breeding infrastructure 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, $q\_OUP(\mu)$:

$$q\_OUP(\mu) = \frac{2Q}{3}\left(2 - \frac{\sqrt{N \cdot P + 12\mu}}{\sqrt{N \cdot P}}\right) \tag{11}$$

Again, this equation can be normalised by substituting $ø$ for $2 \cdot \mu/(P*N)$, and dividing by Q, as follows:

$$q\_OUP(\mu)/Q = \frac{2}{3}\left(2 - \sqrt{6 \cdot \psi + 1}\right) \tag{12}$$

and the ratio of $q\_OUP(\mu)$ to q_OPT is:

$$q\_OUP(\mu)/q\_OPT = \frac{2 \cdot \left(\sqrt{6 \cdot \psi + 1} - 2\right)}{3 \cdot \left(\sqrt{\psi} - 1\right)} \tag{13}$$

Note that equations (4), (12), and (13) all depend solely on the capacity production cost index ($\psi = 2 \cdot \mu/(P*N)$), 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, normalised equation 4 for optimal output in an ideal world, q_OPT/Q, and normalised equation 12 for monopoly output given uniform pricing, $q\_OUP(\mu)/Q$, as well as the ratio of the latter to the former, are plotted against the capacity production cost index, $\psi = 2 \cdot \mu/(P*Q)$ to illustrate the impact of privatisation on production of essential plant breeding infrastructure.

Note that optimal output for molecular markers 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 capacity production cost index increases from 0 to 1.0.

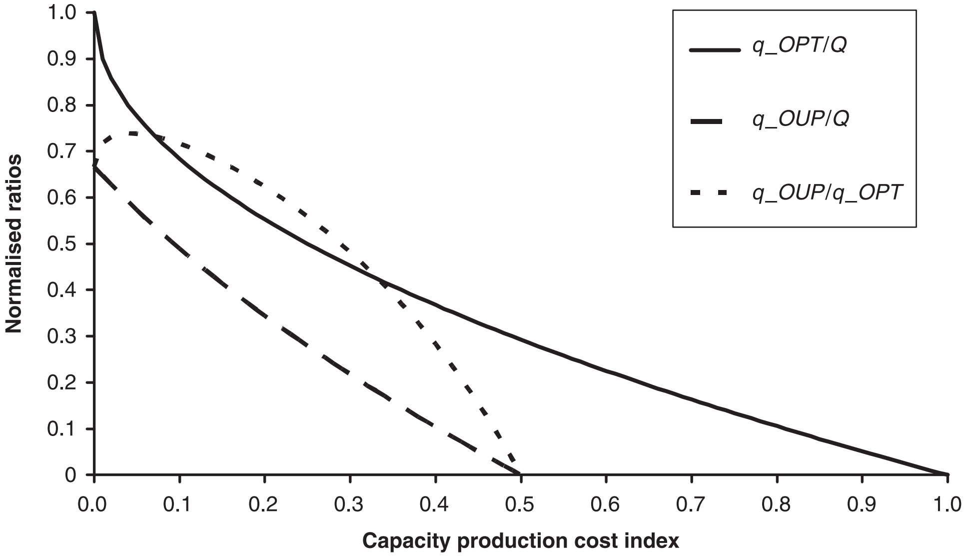

Figure 3 Optimal versus monopoly provision of essential plant breeding infrastructure (EPBI) under optimal uniform price (OUP).

However, the profit maximising level of output for a monopolist constrained to charging a uniform per unit price will be only 67 per cent of *Q* even when the capacity production cost index is zero. Moreover, monopoly output monotonically declines to zero by the time that the capacity production cost index reaches 0.5, which is half of the upper bound of the capacity production cost index.

The ratio of monopoly provision of molecular markers to optimal output in an ideal world never exceeds 75 per cent even when the marginal cost of production is relatively inexpensive, and it declines rapidly to 0 per cent by the time that the capacity production cost index reaches 0.5. 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. Clearly, the values derived above depend on assumptions about the demand distribution, and on the lack of consideration of price discrimination. Further work is planned to investigate how sensitive the results are to these key assumptions.

5. Conclusions

Productivity gains from plant breeding are underpinned by enabling technologies developed from scientific discoveries. Once produced, the knowledge component of enabling technologies are effectively non-rival in use by plant breeders. Consequently, this knowledge component can be thought of as 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, two threats to future productivity gains are the efficient provision of adequate levels of modern EPBI, and under-utilisation of such EPBI as is produced. It is widely recognised that competitive supply of joint goods normally will involve wasteful duplication, but there also are potential problems with monopoly provision of EPBI. In keeping with NCP principles, access to EPBI by competing plant breeders should be open and on equal terms, so as to promote full and efficient competition in downstream markets, while preserving adequate incentives for investment in the ongoing development of EPBI. However, even if denial of access does not prove to be a problem, the impact of profit maximising pricing by a monopoly provider on potential losses from under-production, and on under-utilisation by plant breeders of produced EPBI, are essential issues that need to be considered in the formulation of any access regime. In particular, pricing practices of a private provider are integral to the key issues for any access regime; namely, adequate provision and sufficient utilisation.

The impact on level of production of EPBI was analysed when a monopoly provider chooses, or is constrained to charging a single uniform price to all plant breeders for each and every molecular marker produced. For molecular markers that are low cost relative to the parameters of the demand distribution, under-production might be as little as 25 per cent. However, once the capacity production cost index rises, the degree of under-production increases dramatically. Ideally, EPBI would be produced for values of the cost index up to 1.0, but a monopoly provider would not produce any EPBI if the capacity production cost index exceeded 0.5. This demonstrates that monopoly provision always falls short, and often far short of the optimal output that an ideal and omniscient publicly financed provider would produce.

Many questions require further research, including determination of the nature of plant breeders' demand distribution for molecular markers, and the sensitivity of the above results to this and other key assumptions used in the analysis. For instance, a private provider might employ other pricing strategies that may or may not be uniform, and might include some degree of price discrimination. Alternatively, EPBI could continue to be produced by a collectively funded industry organisation, such as the GRDC, which need not set prices for access to produced EPBI at revenue maximising levels. In fact, the GRDC currently makes EPBI freely available to plant breeders. This leads to more interesting questions concerning the welfare effects on grain growers, and whether they are better or worse off from continuing to fund provision of EPBI through the GRDC. Research into these issues will require a method to quantify the relative magnitude of the loss of potential benefits as a result of under-production, and to under-utilisation, of excludable public goods, including essential plant breeding infrastructure.

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