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PRIVATISING THE PRODUCTION OF KNOWLEDGE: PROMISE AND PITFALLS FOR AGRICULTURAL RESEARCH AND EXTENSION

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In the absence of some form of government intervention, knowledge is a classic public good which will be under-produced because of lack of price excludability. Government intervention may take the form of establishing intellectual property rights, or other means of shielding knowledge-based innovations from imitation or copying. Such intervention offers the prospect of 'privatising' the production of knowledge in the sense that a certain level of private knowledge production may become profitable if producers can appropriate at least part of the benefits of R&D.

However, publicly funded R&D or extension still can 'crowd out' private knowledge production by charging lower prices. The principal finding of this study is that such 'crowding out' behaviour may be efficient in the sense of being potentially Pareto superior even if it is at the expense of public funding for so called 'orphan' areas of knowledge production which are privately unprofitable. The reason why conventional conclusions about privatisation and 'crowding out' of private goods need not apply to rural research and extension is that private goods are both rival in consumption and price excludable, while knowledge is intrinsically non rival in consumption even if it can be made price excludable.

Introduction

Profound changes have been imposed on the Australian rural research system during the past decade. To quote from Foley (1992, p.xiii):

> CSIRO has been restructured and largely refocussed, the university research community is presently in the process of being restructured and refocussed and Primary Industries R&D Corporations (current funding $167m) have emerged as a significant funding force (in some areas they are dominant) in rural research. State Departments of Agriculture . . . have also seen a significant reduction of resources and an attendant shift in research priorities. In more recent times there has been the emergence of Cooperative Research Centres (CRCs).

Less dramatic, but arguably more significant in the long run has been the gradual extension in scope of intellectual property rights to cover more and more types of knowledge production.[1] While this process has been ongoing for decades,[2] the most noteworthy developments for Australia have been the relatively recent introduction of Plant Variety Rights (PVR) legislation in 1986, as well as the extension of patent protection to new life forms in the case law of some countries. Moreover, if the current Uruguay round of the GATT ever reaches a successful conclusion, it is likely to incorporate the adoption by the rest of the world of a much more extensive system of intellectual property rights than currently exists.

There also have been a number of government initiatives to encourage private sector research and development (R&D), such as the 150% tax concession for eligible expenditure, the Industry R&D Grants scheme, and the Management Investment Company Scheme to increase the availability of venture capital to develop Australian research results. In addition, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Department of Primary Industry and Energy (DPIE) research bureau were given external funding targets which have encouraged them to modify their *modus operandi*. Similarly, the funding squeeze on institutions of higher education has induced many of them to establish semi-commercial consulting or technology transfer offices in an attempt to capitalise on their expertise and intellectual property.

At least some of the above changes can be characterised as a move to privatise[3] agricultural research and extension, in the sense that they require, or at least encourage funding bodies and/or public research agencies to appropriate research benefits from end users rather than relying on public revenue. Examples of such changes include the PVR legislation and the legal powers (provided through incorporation) of the new R&D corporations to enter joint venture activities, to apply for and take out patents in their own right, to otherwise manage intellectual property, and to charge for services and information. The agenda behind some of these changes is revealed in the following quote from Kerin and Cook (1989) :

[1] This has been an integral part of the bio-technology revolution, and has been accompanied by a small but steady expansion of private agricultural research at the expense of the public research system. See Persley (1991) Lindner (1991), and Huffman and Evenson (1991).

[2] For example, there are a number of international agreements such as the International Convention for the Protection of Industrial Property (Paris Convention, 1883), which has been amended on a number of occasions, as was the International Convention for the Protection of New Varieties of Plants in 1978. In the USA, examples include the Plant Patent Act (1930) and the Plant Variety Protection Act (1970). Legislation to establish Plant Breeder Rights also was introduced in several countries in Europe in the 1960s.

[3] While the term privatisation often refers to the sale of a publicly owned institution to the private sector, in this paper it will be used in a more generic way to describe any policy which makes appropriating of research benefits easier, and so makes private funding of rural research and extension more attractive.

> Corporations . . . will be able to acquire funds for research over and above those provided from government and industry levies by entering into patents and generating income from royalties and licenses for successful R&D they have sponsored.

Most of this paper will be devoted to an exploration of selected aspects of this process of privatisation of public sector R&D. In particular, the suggestion that this privatisation process should lessen the crowding out of private sector R&D by public institutions will be discussed. Crowding out of private producers by a public producer can occur if the latter can undercut prices charged by the former owing to subsidies from consolidated revenue or other public sources. On the other hand, if public organisations have to charge end-users of intellectual property in order to appropriate the benefits from rural R&D, then their ability to crowd out potential private providers will most likely be diminished. As a consequence, the balance between public and private sector R&D is likely to be altered.

In the next Section, privatisation of public sector R&D is discussed in more detail, together with some of the debate about the desirability or otherwise of crowding out private sector R&D. A welfare analytic framework is developed in Section 3 to provide a basis for the more rigorous treatment in Section 4 of some of the issues raised above. Limits on the capacity of holders of intellectual property rights to appropriate all or even most of the benefits generated by use of their intellectual property are discussed in Section 4, which is followed in the next section by a brief review of available empirical evidence on actual benefit appropriation. The paper concludes with a discussion of the key issues and findings.

Privatisation of Public Knowledge Production

Historically, most rural research and extension in Australia has been carried out by government organisations, and has been funded mainly by direct subvention from consolidated revenue. In this respect, the system closely resembled the US Land Grant System, although the division of responsibilities between the university sector and government organisations differs markedly between these two countries.

The traditional mission of public R&D organisations in both countries was to lay the foundations for innovations by carrying out basic research, to further develop promising ideas into useable innovations with applied R&D, and finally to promote their adoption by private producers by means of public extension activities. For some innovations, the transfer to the private sector took place at an earlier stage in the research process, and further refinement of the innovation often was carried by business enterprises and/or by final users. When public research organisations developed new technologies, they did not seek to exploit them commercially, and research management decisions took little regard of the potential for innovations to generate private revenues. In fact, the output of most research was put in the public domain as a matter of course, and was free to end users. It is a moot point whether opportunities for commercial exploitation of intellectual property were not pursued because lack of property rights would have made it difficult to exploit most innovations even if the institutions had wished to do so.

The traditional system of public provision of rural research and extension described above has been justified on the grounds that research produces knowledge, and knowledge *per se* is a classic public good in the sense that it is both non-rival in consumption, and non-price excludable. Because it is impossible to exclude non-payers from using produced knowledge, potential knowledge creators will not be able to appropriate the consequential benefits, and so will not have an adequate incentive to invest in research. However, there are caveats to this argument. For instance, some types of knowledge can be embodied in products or factors of production which are intrinsically difficult or costly to imitate. A notable example is knowledge from plant breeding research embodied in new varieties of hybrid corn which can not be reproduced without knowledge of and access to the parent lines.

According to Parker and Zilberman (1992), innovations also can be 'shielded' (i.e. protected from copying or imitation) even when they cannot be embodied in some tangible object. Patents or other forms of intellectual property rights provide the most obvious means for doing so, but firms in highly competitive industries often rely more on secrecy to protect process innovations which they can exploit themselves. Lindner (1991) has argued that the domain of intellectual property rights has been expanding over time, so creating new incentives for private sector R&D.

To the extent that the potential to appropriate research benefits increases more or less monotonically as one progresses from the basic end of the research spectrum to the applied end, the argument for public funding is stronger for basic research than for applied, and is even weaker for extension. As a corollary, it has been argued (see below) that R&D should be left to the private sector wherever and whenever appropriation of research benefits is feasible, and that publicly funded R&D should concentrate on the so called 'orphan' research areas which are not commercially attractive.

In some countries, there has been a trend away from the 'pure' public model described above for some time now. Australia is a case in point. While the level of expenditure from all sources on rural R&D has remained reasonably constant over the past two decades,[4] collective funding by industry has gradually been displacing public funding as the principal form of resourcing for rural research and extension. Over the period from 1976 to 1988, Evans, Swinbank and Williams (1989) found that rural industry research funds had grown from a minor proportion of rural research funding in 1976 to 10 per cent in 1981, 25 per cent in 1988, and is projected to grow to 31 per cent in 1991/92.

[4] Approximately 2.5 % of GVP, which approximates to the level of aggregate R&D relative to GDP in comparable OECD countries.

The underlying causes of these shifts in the balance of funding sources include, but are by no means limited to the restructuring of rural R&D described in the introduction. Taken together, such changes have resulted in a sharp shift to a much more commercial *modus operandi* of the national R&D effort. Lindsay (1992) notes the early attempts by the Australian Meat and Livestock Research and Development Corporation (AMLRDC) to capture research benefits in order to fund further R&D, and that most of the other corporations are following suit by introducing legal research contracts based on the possibility of patenting. Hence, it seems likely that there will be an evolutionary trend toward greater use of the powers provided through incorporation, including joint venture activities, royalties from patenting rights, foundation funding and corporate sponsorship.

At the same time, a number of public research organisations, including CSIRO and many Universities, have been attempting to appropriate some of the benefits from commercially valuable technologies developed in their research programmes. In part, this is simply a response to a funding crisis brought on by cut-backs in government financial support, and in part it no doubt reflects altered opportunities brought about by changes to the law regarding intellectual property rights. However, it also is partly a response to pressure from industry funding bodies for an increasing stake in intellectual property rights to technologies generated by research programmes funded by them.

Across Australia, State Departments of Agriculture also have been experiencing significant change, brought on mainly by substantial reductions in their appropriation funding. In some States, such as Victoria and Tasmania, the funding squeeze has been so severe that staff salary budgets swallowed almost all funding from internal sources, leaving the operational costs of research and extension to be dependent on external sources. The way in which the Victorian Department has adjusted its extension activities has been documented by Watson *et al.* (1992). Of particular concern was the practice of devoting scarce publicly funded extension resources to activities with the potential to generate revenue rather than to activities which would not be undertaken by the private sector under any circumstances.

Also noteworthy is the fact that similar changes have been taking place in a number of other countries. Fundamental and spectacular changes have been wrought on agricultural administration in New Zealand in recent years, and significant changes also have occurred in the UK (see Dancey, 1993). With the advent of biotechnology, industry in the US has increased its contribution to basic research dramatically. This has taken place through increased in-house research, increased consulting arrangements, and through the creation of industry consortia at universities. Meanwhile government funding for public sector rural research and extension continues to shrink.

Tight government budgets, a slow economy, and increased global economic competition have been cited as reasons why government agencies have looked to a more commercial approach to rural research and extension as a means to stimulate both short-term economic growth and long-term competitiveness.[5] Many of these changes also have been justified as being necessary for better economic performance. It is claimed that science and technology are vital if we are to make more efficient use of our productive capacity, including in particular our human skills, capital, technology and natural resources.[6] Cynics might note that coincidentally, the shift in funding incidence from the public purse to private sources has coincided with many of the above institutional changes.

However, the concern in this paper is not with the underlying motivation for the changes, but rather with the desirability of certain outcomes of the commercialisation of rural research and extension. In Australia the White Paper by Kerin and Cook (1989, p.5) probably provides the best guide to the principles on which commercialisation of R&D is being based, which are:

> The government believes that portfolio R&D should be administered by agencies with an active interest in both sides of the revenue equation:
>
> - They should be as actively involved in raising funds as in spending them.
> - They should be active in demonstrating the value of their work to industry, so that industry will appreciate the benefits of more funding.
> - They should commercialise their research output, so that they can raise more revenue to plough back into industry R&D.
> - Some projects should be undertaken with particular industry partners, in order to obtain a higher return per dollar spent.
> - Subject to certain constraints, they should be free to promote the international commercialisation of the Australian R&D industry — the bigger and more efficient our R&D industry, the greater will be its capacity to enhance the performance of Australia's primary industries and energy sector.

A possibly naive interpretation of this approach to commercialisation is that the 'user-pays' principle should be extended to rural research and extension. An extreme version would be that because R&D needs to be more market oriented, it should be treated as a private good and 'expected' to generate its own revenue so that it is fully exposed to market pressures. Watson *et al.* (1992) in a review of rural extension in Victoria canvassed the idea of fee for service, and concluded that a necessary condition for government provision of extension services should be 'a deficiency in private provision . . . in the absence of Government action to correct that deficiency'.

[5] See Parker and Zilberman (1992).
[6] See Kerin and Cook (1989, p.1).

There are of course other ways to implement the 'user-pays' principle, such as the widely used practice of industry levies to fund R&D in public research agencies. Moreover, the main thrust of commercialisation of rural research funding in Australia arguably has been to shift the emphasis from basic research to applied research and extension, and to make research priorities more sensitive to 'demand pull' considerations, and less sensitive to 'science push' forces. Many of the steps implemented in an attempt to achieve these changes have been controversial,[7] even among those who accept that there is a need to make rural research and extension more relevant and more closely tied to industry if it is to become more competitive, but other aspects of the government's approach to commercialising R&D have received less attention, perhaps less than they deserve.

Indeed, there is a suggestion in some of the literature[8] that another agenda item being pursued in the commercialisation process is the redress of a perceived problem of 'crowding out' of private sector R&D by publicly funded research. The argument that public funding should not 'crowd out' potential private sector involvement in rural research and extension, but should be restricted to those areas of clear-cut market failure (in the sense of a lack of incentive for private sector investment) is a theme that has been raised in a number of different situations. For instance, in the context of future directions for international research efforts to exploit the potential of the biotechnology revolution, Barker (1990, p. 304) states that the public sector should ask the question: 'What important technological goals should be pursued because they will not be undertaken by the private sector?' The most common response in the literature to this question is that where strong intellectual property rights exist, the public sector R&D should focus on the so called 'orphan' commodities which are commercially unattractive to private R&D firms. In other words, where adequate financial incentives exist for private investment in R&D, they should not be 'crowded out' by public funding which makes innovations available at no cost, or at least at 'subsidised prices'.

To sum up, a key question which needs to be addressed in the context of the commercialisation of rural research and extension is whether government agencies should fund 'profitable' research or extension, or only invest in 'orphan' areas? Alternatively, can 'crowding out' of private sector rural research and extension by public funding ever be efficient? This is the main topic to be addressed in the remainder of the paper.

[7] For instance, the grounds for the shift away from basic research in favour of more funding for applied R&D and extension has been attacked by Lindsay (1992) for allegedly being based on the false perception that we have plenty of research results, and it is only our inability to sell them to farmers that is preventing large scale adoption.

[8] Watson *et al.* (1992).

Welfare Analytics of Ideal Knowledge Production

The welfare effects of knowledge production when funded from public and private sector sources need to be analysed first. Questions which need to be answered include the extent to which the benefits of new knowledge production might be appropriated under a free market system even if it incorporated ideal intellectual property rights. Will under-production of knowledge still be something to be concerned about? If so, what are the determinants of the relative magnitudes of the welfare losses from under-production of knowledge *vis-a-vis* those from under-utilisation of produced knowledge?

In the remainder of this paper, rural research and extension will be treated as a mechanistic and deterministic process with continuously divisible knowledge as the only output. Of course, this is a gross oversimplification. In practice knowledge production is a highly stochastic process which also may be subject to substantial indivisibilities, but these complications will be ignored here in order to maintain some semblance of analytical tractability.

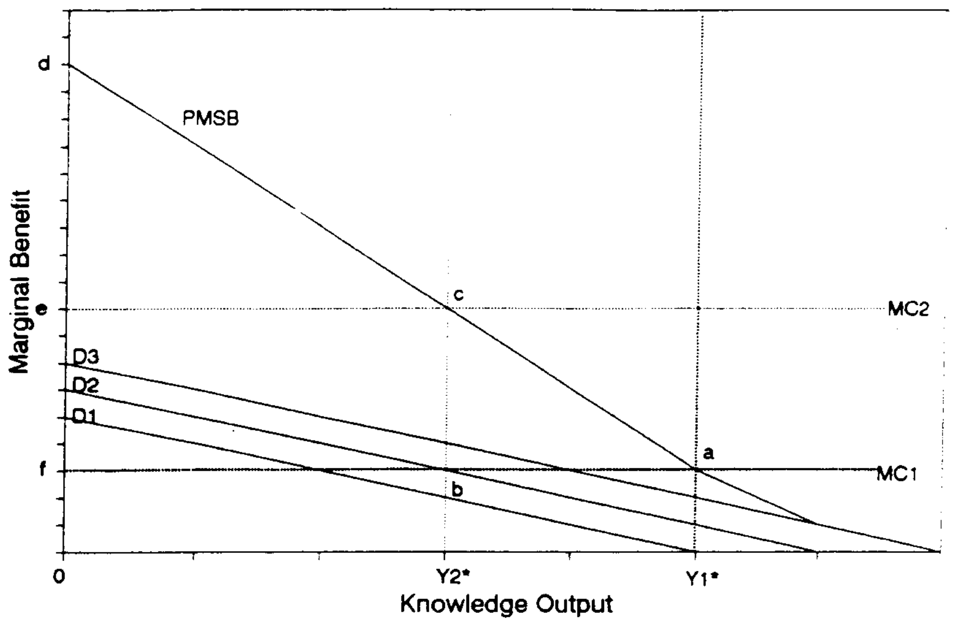
From an analytic perspective, what is involved in effectively privatising knowledge production is the transformation of production of a pure public good into one which is referred to in a branch of the public finance literature as a price excludable public good, or more simply a joint good.[9] This way of viewing the problem highlights the fact that while effective privatisation of knowledge production overcomes the 'problem' of non-price excludability, it has no impact at all on the other critical non-rival property of knowledge produced by rural research and extension. Direct comparison of these two alternatives is difficult because positive economic theory does not provide any definitive predictions about the level of investment in knowledge production by a publicly funded research system. Hence, the approach adopted below is to define the optimal net social surplus which would be generated in an ideal first-best world as a benchmark, and to assess the efficiency losses associated with various alternative public and private sector R&D systems against this benchmark.

To illustrate the benchmark case, an hypothetical world comprising only three potential consumers of research or extension output is depicted in Figure 1. The horizontal axis measures the amount of knowledge produced, with units of knowledge being defined so that the marginal cost of producing each unit is constant. Since each unit of knowledge can represent a distinct and unique output of the R&D process, units of knowledge are rank ordered on the horizontal axis by level of potential marginal social benefit (PMSB) as defined below. The marginal cost of production, as well as the marginal benefit of consumption, both individually and in aggregate, are measured on the vertical axis. Note that while

[9] See Brennan and Walsh (1981,1985) and Burns and Walsh (1981).

knowledge is often embodied in some tangible product which has associated, but conceptually distinct supply and demand curves, Figure 1 involves a high degree of abstraction because it only depicts the costs of production and demand for disembodied knowledge.[10]

FIGURE 1
Optimal Knowledge Production



Each potential user is assumed to have a linear demand for knowledge function,[11] denoted by D1, D2, and D3 respectively. It is assumed that once produced, knowledge is completely non-rival in use and so can be disseminated among potential users and utilised by them at zero marginal social cost. Because of this non-rival characteristic of knowledge, the potential marginal social benefit curve available to society from full utilisation of each unit of knowledge produced is obtained by vertically summing the individual demand curves, and is denoted by PMSB to distinguish it from the marginal social benefit actually realised given incomplete knowledge utilisation.

[10] Or for the knowledge component when it is embodied in a tangible product such as a seed for a new plant variety, computer spreadsheet, etc.

[11] These functions are defined to measure marginal willingness to pay for knowledge given that the marginal cost of utilisation is zero. For process innovations, this assumption is consistent with, *inter alia*, variations on 'all-or-nothing' pricing schemes. However, these individual knowledge demand functions will overstate willingness to pay when the price charged to use the knowledge is related to scale of production of final output, or to level of input use.

Given constant marginal costs of producing knowledge, as denoted by the horizontal lines MC1 and MC2, the corresponding optimal levels of knowledge to produce are represented in Figure 1 by Y1* and Y2*. If the optimal amount of knowledge is produced, but then made available without cost to potential users by some undefined but costless mechanism, net social surplus will be equal to the area below the PMSB curve and above the marginal cost of knowledge production. The areas *adf* and *cde* depict potential net social surplus associated with MC1 and MC2 respectively.

As is well known, for all of the potential benefits to be realised from producing any defined level of knowledge, it is necessary that each user be charged only for the marginal cost of reproduction, which for simplicity is assumed to be zero. Hence, all three users will, given the individual demand curves illustrated in Figure 1, consume the total amount of knowledge produced. Note that for MC2, demand by all three individuals will be rationed by limited supply, in the sense that they would prefer to consume more than Y2* at zero price. This idealised case will be used below as a norm against which to assess the relative magnitudes of efficiency losses associated with alternative forms of organisation and funding.

Welfare Analytics of Private Knowledge Production

If rural research and extension were left exclusively to the private sector, the level of investment in knowledge production would be determined by the opportunity for producers to appropriate at least some of the potential benefits to society from its utilisation. Clearly, the ability of producers to exclude potential users who are unwilling to pay the asking price will be the pivotal determinant of capacity to appropriate, and in most cases, existence or absence of intellectual property rights will be crucial. Exceptions do exist though, and hybrid corn is widely cited as a case where knowledge producers successfully appropriate significant research benefits in the absence of intellectual property rights. Conversely, software producers are prone to complain bitterly about the impact of piracy on their ability to appropriate R&D benefits.

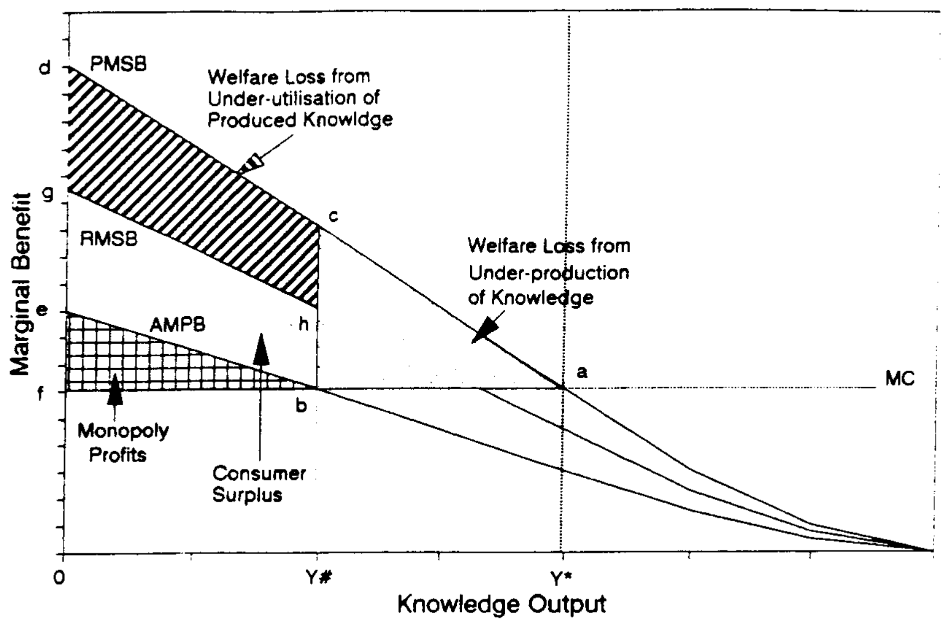
Whatever the circumstances of individual cases, it is clear that for any given unit of knowledge, potential marginal social benefit represents an upper bound on the incremental return which a private producer could hope to appropriate. Moreover, for reasons to be discussed below, the proportion of potential benefits actually appropriated by private producers typically will be markedly less than unity even when strong intellectual property rights exist. Consequently, the level of investment in knowledge production will almost certainly be sub-optimal so long as the system of intellectual property rights is designed to avoid the 'common pool' problem.[12] In addition, if some potential users are excluded by price

[12] See Wright (1983) for ways in which this might be achieved, and for a discussion of the practical difficulties of doing so. The implications of the 'common pool' problem for level of private investment in knowledge creation are discussed further below.

from fully utilising produced knowledge, then realised social benefits will be less than potential social benefits.

As indicated above, while effective privatisation converts knowledge from a good which is not price excludable to one that is partly or wholly price excludable, knowledge remains non-rival in use whether privatised or not. Figure 2 adapted from Perrin (1991) illustrates this case of private knowledge production. The level of knowledge produced by a private supplier will be determined by the point of intersection of the marginal cost of the knowledge production and the appropriated marginal private benefit (AMPB) function. In Figure 2, this level of knowledge is depicted as Y#, which is less than the optimal level of production, denoted by Y*. Thus there will be a welfare loss associated with the under-production of knowledge, which in Figure 2 is depicted by the shaded area *abc*.

FIGURE 2
Private Knowledge Production



In addition, if a price is charged to utilise knowledge, some potential users will be excluded, either partially or completely, from utilising the optimal amount of produced knowledge. As a result, each unit of knowledge will not be fully utilised, and consequently the realised marginal social benefit (RMSB) from each unit of knowledge will be less than the potential social benefit (PMSB). Hence, there will be an additional welfare loss from under-utilisation of knowledge, depicted by the shaded area *cdgh*. Aggregate realised net benefits from producing Y# of knowledge are measured by the area *bhgf*, of which *bef* is monopoly profits appropriated by the producer. The difference between these two areas is *bhge*, which represents consumer surplus accruing to knowledge users.

Total deadweight loss relative to the first-best benchmark case equals the sum of the areas representing efficiency losses from under-production of knowledge, and under-utilisation of produced knowledge (i.e. area *abc* plus area *cdgh*). This sum can be divided by the area representing maximum possible net social surplus to arrive at a value for proportional efficiency loss ((*abc*+*cdgh*)/*adf*).

Figure 2 also can be used to gain some insights into the 'crowding out' issue outlined above. Take a hypothetical situation in which a public research agency had sufficient funds to produce Y# of knowledge, or (Y*-Y#), but not both. In the absence of shielded innovations,[13] it could not charge for research results, and on efficiency grounds should produce Y# of knowledge. The net social benefit (NSB) is represented by the area *bcdf*, although the gain to users is *Y#cd0* as they pay nothing for the knowledge that they use.

On the other hand, several options are available if research produces shielded innovations which make benefit appropriation as represented by the AMPB schedule feasible. For a non-commercial public R&D organisation which is not commercialised (i.e. does not charge for produced knowledge), maximising the net social benefit generated by its activities still requires production of Y# of knowledge even though this involves 'crowding out'. Note that in a world of imperfect knowledge, it still might be necessary for this organisation to shield its intellectual property by legal or other means in order to prevent private firms from exploiting its innovations for commercial gain.[14]

If this same organisation were to pursue a policy of not 'crowding out' private sector R&D, this would permit private production of Y# of knowledge, with associated net social benefit equal to *bhgf*. The non-commercialised public R&D organisation could then concentrate on 'orphan' research areas, and produce (Y*-Y#) of knowledge. So long as users were not charged anything to use it, net social benefits would be represented by the area *abc*. Hence aggregate net social benefit from this option is (*bhgf*+*abc*), which may or may not exceed the net social benefit (*bcdf*) from the first option.

A further option for a commercialised public R&D organisation would be to 'crowd out' private sector R&D by providing Y# on a cost recovery basis, and to employ its public funding to provide (Y*-Y#) at no charge to users. So long as private and public sector R&D were equally efficient, and so long as fees for using Y# were set on a non-profit basis, the public R&D organisation should be able to charge lower fees than any private competitor. Consequently, the welfare loss from under-utilisation of Y# of knowledge would be somewhat lower than the area *cdgh* depicted in Figure 2, and net social benefit would be correspondingly larger than *bhgf*. Hence, this third commercialised option is demonstrably superior

[13] This assumption implies that APMB is everywhere less than MC.

[14] In this paper, any costs of this form of shielding are assumed to be trivial.

to the second option examined above, but whether it is also superior to the first option clearly remains an empirical question, the answer to which hinges on the relative positions of the PMSB, RMSB, AMPB, and MC curves.

It can be shown (Lindner, 1992) that the situation depicted in Figure 2 is a special case dependent on particulars about both the demand (for knowledge) distribution, and about the pricing practice of the knowledge provider. Furthermore, it is unlikely to be independent of the characteristics of the type of knowledge under consideration. In general, the key determinants of proportional efficiency loss, given a particular set of individual knowledge demand functions (the demand distribution in Burns and Walsh terminology) and a particular marginal cost function, will be the relation between appropriated marginal private benefits and potential marginal social benefits on the one hand, and between realised marginal social benefits and potential marginal social benefits on the other. The first of these issues is discussed in the next section.

Benefit Appropriation Under Intellectual Property Rights

The ability to appropriate benefits has two dimensions. The first is the ability to exclude potential users from utilising those bits of produced knowledge for which they do not pay. The second is the ability of the knowledge producer to exercise price discrimination. It is well known that privatising the production of public goods would not involve any efficiency losses if the producer is able to practise first-degree price discrimination, and is able to exclude from use all those unwilling to pay the asking price.

In practice, there are likely to be limits both to the ability of the producer to exclude all potential users from all units of knowledge for which they do not pay, and to practise perfect price discrimination. 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 the costs of enforcing property rights against imitators, once detected. For instance, according to Butler and Marion (1985), in the USA appropriability from new varieties lasts about 2-3 years on average because the market subsequently subsumes a new variety with other new varieties of similar characteristics. Issues relating to the design of intellectual property rights, and to enforcement of those rights, are the subject matter of a rapidly expanding body of legal as well as economic literature, and go well beyond the scope of this paper.

However, even if costs of price exclusion were zero or negligible, practical limitations faced by firms trying to practise perfect price discrimination would frustrate attempts to appropriate all potential social benefits from rural research and extension. In general, restrictive trade practices legislation will limit the scope for firms to practise first-degree price discrimination between customers. The 'first sale'and 'exhaustion' doctrines embedded in copyright and patent legislation also prevent knowledge producers from imposing resale conditions, and so further limit their ability to engage in price discrimination. Nevertheless, lower order forms of price discrimination are often feasible for certain types of knowledge, and examples of discriminatory pricing practices are not difficult to find. For instance, licensing fees for new manufacturing processes commonly vary with the scale of production, while professional journals are prone to charge different fees to libraries from those charged to individual subscribers.

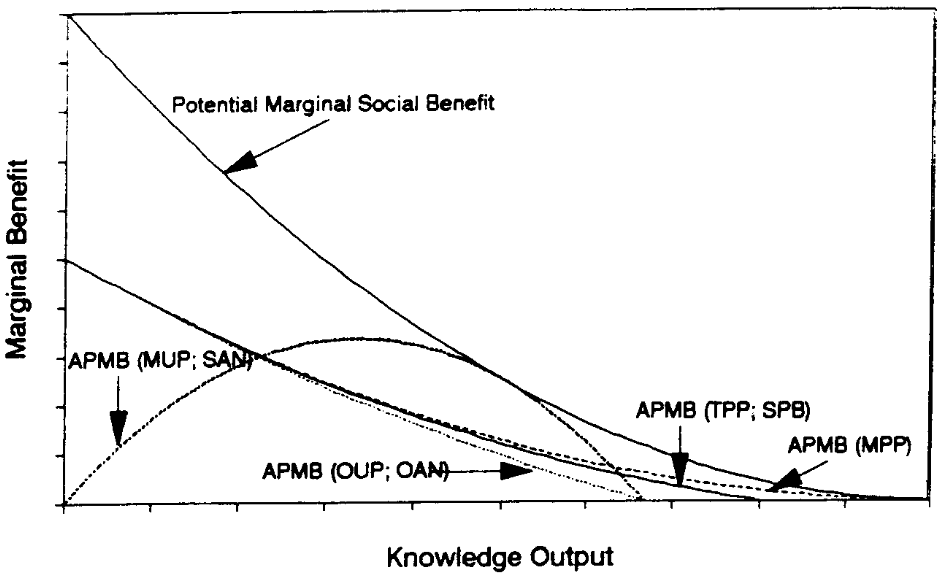
It is difficult though to generalise about the ability of firms to practise one or other form of price discrimination. The nature of the knowledge being produced may be crucial, in part because of its influence on the method by which it will be transferred for use, and in part because it could influence the firm's capacity to prevent secondary trade in their products. The capacity to embody knowledge in an innovation so that it can be produced in exclusive units is often thought to be necessary for both price excludability and price discrimination. However, as Parker and Zilberman (1992) point out, of greater importance is whether the innovation can be shielded in the sense that it cannot be inexpensively reproduced by others in the market place. If shielding is feasible, then it might be possible to implement discriminatory usage charges via some form of licensing arrangement even when it is not possible to embody the knowledge in an innovation. The structure of the market also is likely to be instrumental in the ultimate adoption of a specific pricing practices.

Because of the complexity of the forces influencing the ability of the firm to charge different prices to different users, and/or to discriminate between users on the basis of degree of utilisation of knowledge, the implications of selected alternative pricing practices will be discussed below. Analysis of the market provision of joint goods is complicated by the variety of different pricing practices which might be employed by a producer to appropriate some of the potential social surplus generated by utilisation of its output. Unlike the supply of private goods where, given market structure, price and output determination are essentially synonymous, a range of pricing practices might be possible for any given level of production. Thus the firm must first determine the optimal pricing practice, and only then select the privately optimal level of output for that pricing practice.

Some sense of the possible importance of pricing practices can be gauged from Figure 3 which illustrates[15] the effect on appropriable marginal revenue of the following seven pricing practices identified by Burns and Walsh (1981) in their study of the monopoly supply of joint goods, Maximum Uniform Pricing (MUP), Optimal Uniform Pricing (OUP), Simple All or Nothing Charging (SAN), Optimal All or Nothing Charging (OAN), Optimal Two-Part Pricing (TPP), Separate Pricing of Bundles (SPB), Optimal Multipart Pricing (MPP).

[15] Reproduced in slightly modified form from Burns and Walsh, (1981).

FIGURE 3
Joint Good Pricing
(Potential MSB and Appropriable PMB



A few examples of how existing types of knowledge are marketed might be instructive in assessing the relevance of these different pricing practices to privatised knowledge production. Many types of knowledge can be embodied in factors of production. Examples drawn from agriculture include: the creation by biological research of genes with novel characteristics which can be embodied in new plant variety seeds; biochemical research results embodied in new pesticides;[16] mechanical engineering discoveries embodied in new farm equipment; and the mathematical algorithms and other features embodied in 'managerial software' such as computer spreadsheets.

Note that for the first two types of knowledge, the price paid by farmers for the knowledge component will be incorporated into the price of the factor embodying the knowledge. Consequently, the amount of benefit appropriated from each user will be directly proportional to the level of factor use. This has two consequences: it distorts factor price ratios, thus leading to efficiency losses similar to those caused by selective taxes on factor use; and it introduces some degree of price discrimination between users of the same amount of knowledge. For the alternative polar case of neutral embodied technology, such as computer software, monitoring the extent of usage is likely to be prohibitively costly if not impractical. This suggests that firms will employ some form of 'all or nothing' pricing, in the sense that the price paid for the intellectual property involved is likely

[16] Or other types of agro-chemicals.

to be totally independent of degree of input utilisation or scale of output.[17] If different products embodying different levels of knowledge[18] are produced, then price discrimination between different units of produced knowledge[19] (but not between different users of the same level of knowledge) might be feasible and desirable for the producer. Alternatively, if all of the produced knowledge is embodied in a single product, then no dimension of price discrimination will be feasible, and optimal 'all or nothing'(OAN) pricing will maximise firm profits.

On the other hand, there are certain types of knowledge which can not be embodied in a saleable product, or for which alternative means of appropriating user benefits are preferred by the holder of the intellectual property right. For instance, the knowledge producer might choose to license users in a manner that permits the price charged for the knowledge to be related directly to the scale of final output produced using the innovation. To the extent that willingness to pay for the knowledge is correlated with scale of production, this form of pricing will permit at least some degree of price discrimination between users, thereby increasing the potential to appropriate a higher proportion of total realised social surplus.[20] However, this pricing practice will cause some loss of welfare due to under-utilisation of produced knowledge and consequent less than optimal higher marginal costs and production of final output by innovation users. By comparison, 'all or nothing' pricing of knowledge does not ameliorate the reduction in the marginal cost of production of final output from innovation adoption, so the potential exists in a competitive world for produced knowledge to be fully utilised. It follows that no single assumption about pricing practice will encompass all types of knowledge discussed above. Hence, separate analyses will be required for different types of knowledge production in any definitive study of commercialisation of rural research and extension.

The key conclusion to be drawn from Figure 3 is that total price excludability is necessary but not sufficient to solve the under-investment problem. It can be seen that with one fortuitous exception, appropriable private marginal benefits are everywhere less than potential marginal social benefits for all pricing schemes analysed by Burns and Walsh. Furthermore, while the single exception is theoretically possible, it is extremely unlikely to be observed in practice because in terms of revenue maximisation the two pricing schemes involved, MUP and SAN, are

[17] Knowledge embodied in plant and equipment is likely to be intermediate between the first two examples and the last.

[18] For instance, computer spreadsheets differ in the number and quality of features that they offer. Such differences can be treated as reflecting different levels of knowledge, among which users can choose on the basis of price.

[19] MPP in Burns and Walsh (1981) terminology.

[20] It will be demonstrated below that the magnitude of total realised social surplus also is likely to be sensitive to the degree of price discrimination practised by the knowledge producer.

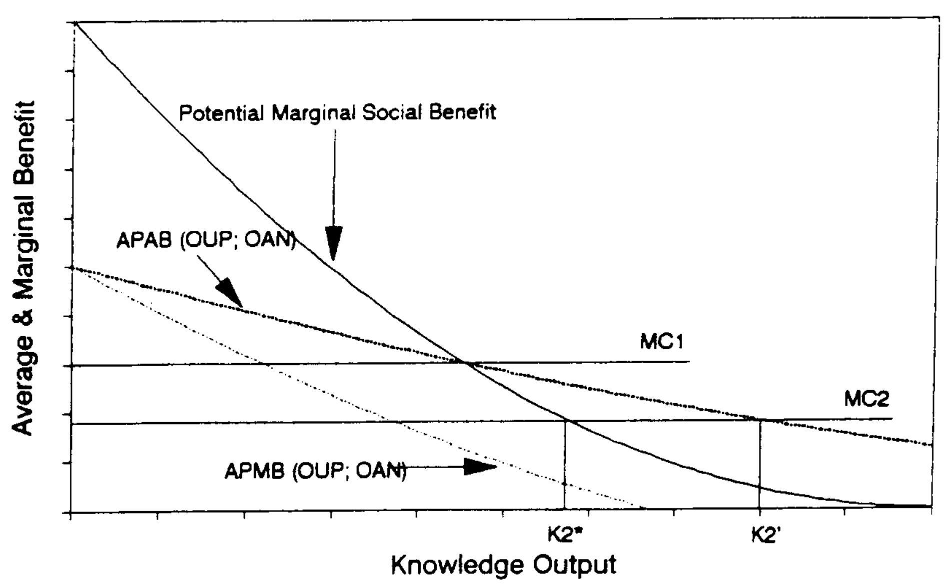
everywhere inferior to OUP and OAN respectively. Therefore, even if perfect intellectual property rights could be designed and implemented, complete privatisation of rural research and extension would still incur deadweight efficiency losses owing both to under-investment in the production of knowledge and to under-utilisation of such knowledge as is produced.

The Common Pool Problem

However, the conclusions reached above may be negated because of what is referred to in the literature as the 'common pool' problem. The 'common pool' problem arises if the intellectual property right regime is based on a 'winner-take-all' principle (as is the patent law in some countries). Such a system is likely to induce 'patent races' which result, *ex ante*, in dissipation of expected monopoly profits. In other words, in the quest for exclusive rights to monopoly profits, private producers of knowledge continue to expand production beyond the socially optimal level, and up to the point of equality between marginal cost of production and appropriable average private benefits (AAPB) rather than equality with appropriable marginal private benefits (AMPB). This possibility has received considerable attention in the literature.

FIGURE 4

Impact of Patent Races
Appropriable PMB and PAB for OUP and OAN



In simple terms, the essence of the problem is depicted in Figure 4, which is limited to the case of Optimal Uniform Pricing (or Optimal All or Nothing Charging). Average appropriable private benefits must by definition exceed marginal appropriable private benefits. Consequently, if marginal cost is less than MC1, private level of investment in knowledge creation (where MC=AAPB) will exceed the optimal level of investment (where MC=PMSB). Thus when marginal cost equals MC2, the 'patent race' level of private investment would be K2′ which exceeds the optimal level of investment, K2*. Conversely, if marginal cost exceeds MC1, private investment in knowledge production will be sub-optimal, even if there is a 'common pool' problem. The situation in the real world is further complicated by the fact that intellectual property rights in practise confer less than all-encompassing rights to exploit the intellectual property in perpetuity. As a result, the 'common pool' problem will be ameliorated to greater or lesser extent depending on the detail of the intellectual property rights regime, as well as on the costs of enforcement.

Empirical Evidence

To sum up the findings presented above, not only does theory fail to provide clear guidance about the severity of the potential under-investment problem if R&D were privatised, but it also leaves open the possibility of over-investment in some circumstances. It needs to be added that empirical studies of returns to rural R&D have consistently found very high rates of return. This provides *prima facie* evidence that in the real world, the combined level of investment by both the private and public sectors still falls well short of the optimal investment in knowledge production. A brief review is undertaken below of some of the limited evidence available about the potential for previously public R&D bodies to raise funds by seeking to appropriate research benefits.

Glenn and Lascelles (1992) noted that in the financial statements for CSIRO from 1977-78 to 1990-91, the item 'earned revenue', which presumably includes but is not limited to income from sale of intellectual property, was less than 2% of cash expenditure in the early part of the period, and never exceeded 7.3%. Likewise, Lindsay (1992) notes that despite expenditure of several hundred thousand dollars by the AMLRDC on intellectual property rights in its early years, in the last annual report (1989) to include royalties as a line item, total income reported from this source was a mere $2,382. Universities also have met with mixed success in attempting to exploit their intellectual property. For instance, The University of Western Australia closed its consulting and intellectual property office after it incurred losses of several hundred thousand dollars (not including any of the costs of the research which created the intellectual property).

In the US, Parker and Zilberman (1992) examined university-based technology transfer offices (OTL) and the development of the biotechnology industry in the San Francisco Bay Area and the Boston Area. They suggested that the number and type of invention disclosures can be used to measure the amount of research being performed, the type of research, and the effectiveness of the OTL when working with university faculty, and report estimates that only 60% of all disclosures ever lead to a licensing agreement, while only 25% ever returned any money to the university. Their survey indicated an average of 1 invention disclosure per $2.4 million in research.

Revenues generated by the OTLs as a percentage of total research expenditure ranged from a low of just 0.10% to a high of 9.77%, while on average each OTL generated $1.80 in revenues per $1.00 in OTL expenditures. Parker and Zilberman (1992) also reported estimates that it takes 7 years for an OTL to become self-sufficient (a ratio of 1.0) and that 30% of all OTLs are currently losing money. They go on to state that 20% are making money while the remaining 50% are just breaking even.

Conclusions

According to conventional wisdom, knowledge is a classical public good which will be under-produced because of lack of price excludability. Intellectual property rights, or other means of shielding knowledge-based innovations from imitation or copying, offer the prospect to private producers of appropriating at least part of R&D benefits so that a certain level of private production of knowledge becomes profitable. It has been argued in the literature that publicly funded R&D or extension should not 'crowd out' privately profitable knowledge production by charging lower prices, but instead should be reserved for so called 'orphan' areas of knowledge production which are unprofitable for private producers. The principal finding of this study is that 'crowding out' as defined above, even if at the expense of public production of 'orphan' areas of knowledge production, may be efficient in the sense of being potentially Pareto superior.

Conclusions about privatisation and 'crowding out' of private goods need not apply to rural research and extension because while private goods are both rival in consumption and price excludable, knowledge is intrinsically non-rival in consumption. This fundamental property of knowledge is not altered even if the production of knowledge is effectively privatised by some means or other such as establishing intellectual property rights or other devices for shielding innovations from copying or imitation. The possibility of novel conclusions discussed above are due to this distinguishing characteristic of knowledge.

However, there are a number of caveats and additional considerations which need to be taken into account with regard to the above finding. In particular, the question of the efficiency of private versus public organisations, which is pivotal with regard to privatisation of the production of private goods, is also relevant to the privatisation of the production of knowledge. This is not a topic which has been heavily researched. Apart from one important caveat, there is a suggestion in some of the literature that private sector R&D is, if anything, likely to be more efficient than public sector R&D. The caveat relates to concerns that fundamental scientific knowledge might not be so readily shared in the private sector as is the tradition in the public sector.

This concern also has been expressed by Lindsay (1992) in relation to the operation of the new rural R&D corporations. Notwithstanding the meagre monetary returns earned to date by these organisations from the sale of intellectual property, most corporations already have, or are planning to introduce complex contracts based on the possibility of patenting. These legal contracts may constrain normal scientific interchange of results and ideas, thus reducing efficiency of the research process. In addition, considerable time will most likely be wasted on ensuring compliance with the legal exigencies of these contracts.

Next, a note of caution. Notwithstanding the fact that the case for government funding of basic R&D is stronger than that for applied R&D, and stronger for R&D than for extension, the conclusions about 'crowding out' derived above should not be used to justify shifting the balance between basic and applied research, and between research and extension. With regard to these key questions, there is one further and all important consideration which cannot be overlooked, and that is the cumulative nature of scientific discovery and knowledge creation which underpins all good R&D. Sir Isaac Newton[21] put it most aptly when he said:

> If I have seen further, it is by standing on the shoulders of giants.

The key conclusion of this paper is that economic theory provides no neat answers to the 'crowding out' question, or to the other related issues canvassed above. Like all important empirical issues, much remains to be done on these questions, and much needs to be done before it will be possible to reach definitive conclusions about commercialisation, corporatisation, and privatisation of rural research and extension. In the meantime, government appointed members on the boards of the rural R&D corporations have the responsibility as representatives of a key 'stakeholder' to ensure that the public interest is being served.

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[21] Isaac Newton (1642-1727) letter to Robert Hooke, 5 Feb. 1675.

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