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Intellectual Property Institutions for Plant Breeding

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INTELLECTUAL PROPERTY INSTITUTIONS FOR PLANT BREEDING[1]

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Abstract - Intellectual property rights for crop plant material should in principle increase social welfare by increasing private research investments to a level closer to the social optimum. In the US, plant patents were first introduced in 1930 by legislation that applied only to asexually reproduced plants. This was followed in 1970 by the weaker plant breeders' rights legislation (PBR) for sexually reproduced plants. Judicial decisions in 1980 and 1985, however, extended much stronger utility patent protection to plant materials. Here we examine theoretical welfare implications of weak PBR vs strong utility patents in a North-South context of technology transfer in agriculture and in the particular case of durable crop traits. The results suggest that PBR owners could obtain only 20% of the royalties that would be available to them with patent protection, PBR institutions may thus be too weak in general to stimulate socially optimal levels of new plant technology in the North. On the other hand, consumers would obtain three times the benefits under PBR as compared to patents. PBR may provide sufficient incentive to stimulate technology transfers to the South and might be the preferred IP institution.

Keywords: Plant breeders rights, patents, North-South, durable traits, Coase.
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1. Introduction

The fundamental welfare economics argument for intellectual property (IP) is that inventions and discoveries have the properties of a public good, and therefore the amount produced will be too small relative to the social optimum. Hence the development of systems that assign property rights to inventors and enforce those rights. The objectives of this paper are to review the simple welfare analytics of IP, trace its development in the US as related to plant breeding, and discuss welfare differences that might be expected from two IP institutions for plant technology, plant breeders rights (PBR) and common utility patents, within a North-South context.

2. The Welfare Economics Argument for IP in Plant Breeding[3]

Any knowledge in existence has the characteristics of a public good: once created, it has high exclusion costs to prevent others from using the good; the marginal cost of making it available to additional persons is negligible; and it is non-rival in consumption. The economic theory of public goods suggests that the market will produce too little knowledge[4]. Intellectual property rights reduce exclusion costs, allow the discoverer to appropriate some of the external benefits and thereby induce an increase the amount of knowledge the market will produce. But once known, that knowledge is still non-rival in consumption, and a social loss is incurred to the extent that others *are* excluded from using it, given that there is no social cost for the excluded to use it, while the benefits are positive. Without the appropriability conferred by IP, the market will create a socially suboptimal amount of new knowledge; but with IP, the diffusion of that knowledge will be restricted to a socially suboptimal level. IP institutions must balance these losses.

[3] This section borrows from Perrin (1994).

[4] For a full development of such theories, see Cornes and Sandler, Ch. 6.

It is useful to characterize a bit of new knowledge, particularly plant genetic knowledge, in terms of the profit increments that it ultimately permits. The present value of the future stream of one such profit increment is a measure of the value of the knowledge in a particular application. This value will vary among potential adopters, for example across the range of agro-climatic conditions to which an advance in plant genetics is applicable. The schedule of such applications ranked from high to low value is a demand schedule for the use of the knowledge. We can refer to it as the derived demand for diffusion of that innovation. Such a schedule is shown in Figure 1, with the most valuable application having value Oa and the total number of applications with any value at all being d_m. If the marginal cost of diffusing the knowledge is close to zero, as is generally assumed, then once the innovation is known, it is socially optimal to achieve complete diffusion to all d_m uses. The maximum social welfare benefit (MSWB) of this bit of knowledge for the current period is thus the consumers' surplus measured by the entire triangle Oad_m

IP and diffusion

If property rights to the knowledge can be perfectly bestowed and costlessly enforced, the owner will have an incentive to maximize profit by setting a royalty fee equal to p*. This would result in diffusion to d* applications, exactly half of the socially optimal level of diffusion given a linear DDD curve as in Figure 1. The realized social benefit will be reduced to amount Oabd*, which in this linear DDD case is exactly 3/4 of the maximum social benefit attainable by diffusion to d_m. The innovator will realize earnings Op*bd*, which is half of MSWB, while the users of the innovation will realize p*ab, just 1/4 of MSWB.

The static analysis so far illustrates the source of some of the opposition to intellectual property rights. Potential consumers of a particular bit of knowledge will be restricted from using it, and those who do use it will be required to share the benefits with the knowledge owner. The monopolistic restriction on diffusion is socially inefficient, once the bit of knowledge is

created, and the amount of waste due to this monopoly pricing equals ¼ MSWB in the linear case.

Divergence of private and social optimum rates of knowledge creation

It is fanciful but still useful to conceptualize a set of potential knowledge projects that would create many different innovations at a given point in time. The knowledge produced by any one of these projects has associated with it a unique derived demand for diffusion and a unique MSWB defined as the area under the diffusion curve in Figure 1, less the cost of producing the knowledge. One way to organize these latent knowledge projects is to rank them by potential net social benefit, resulting in the *marginal net social benefit of knowledge* schedule, MSB(K), shown as line DK_S in Figure 2. The social optimum rate of knowledge creation, number of new innovations, is K_S[5] In the absence of IP, the inventor of any one of these innovations would have a limited ability to directly appropriate benefits, as compared to the total number of potential applications arrayed in Figure 1. We can array these private benefits as the *marginal private benefit of knowledge*, MPB(K), shown as line AK_P in Figure 2, which must lie below the marginal social benefit curve.

In the absence of IP, the amount of knowledge that would be generated would be just K_P, less than the social optimum K_S. The total net *private* benefit generated by these innovations is represented by area OAK_P. In the absence of IP each innovation produced will be fully diffused, to d_m in Figure 1, and thus the total social benefits include the spillover benefits represented by area $ADEK_P$ in Figure 2. Since knowledge is non-rival in consumption, the total marginal social benefit of a bit of knowledge is the vertical summation of the marginal private benefits for the discoverer and all other potential users.

[5] A dynamic analysis might demonstrate an even higher level of K_S if the inventions are necessary for economic growth.

Private and social gains from establishing IP

With IP, neither K_p nor K_S will be the equilibrium level of knowledge creation. To conceptualize the solution under IP, return to Figure 1 and note that the rent earned by the creator of this bit of knowledge is equal to area Op*bd*. Call this rent "royalty benefits" to distinguish it from the level of private benefits that would accrue in the absence of IP. These royalty benefits will be some fraction of the potential social benefit. (This fraction is exactly ½ of MSWB in the linear DDD case shown in Figure 1.) The *marginal net royalty benefit* (MRB(K) in Figure 2) of incremental amounts of knowledge under IP is thus higher than the net private benefit without IPRs, but it is less than the potential social benefit, MSB. The equilibrium rate of knowledge creation will be K_i, somewhere between the rate under no property rights and the socially optimum rate. The *marginal net social benefits under intellectual property rights*, MSBI(K), will lie below the potential marginal social benefits MSB, since diffusion of each innovation will be restricted to d* rather than d_m.

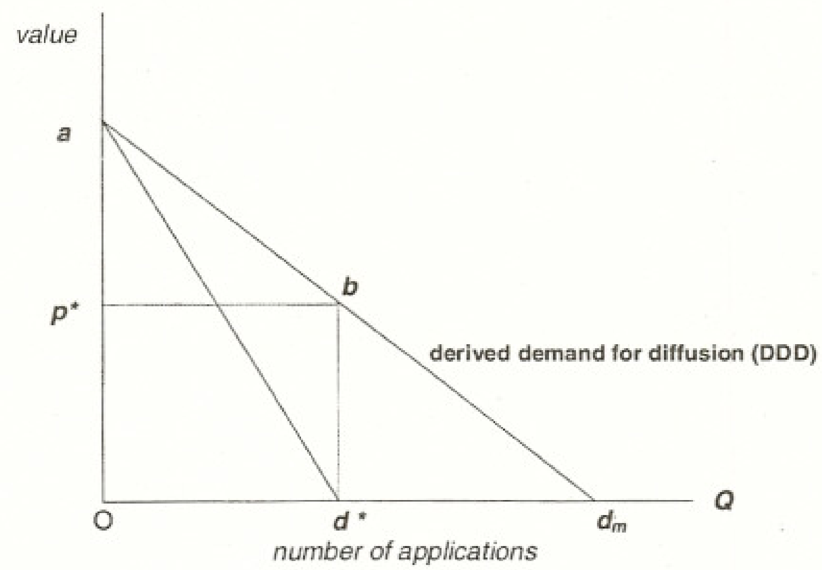

Figure 1 - Derived demand for diffusion

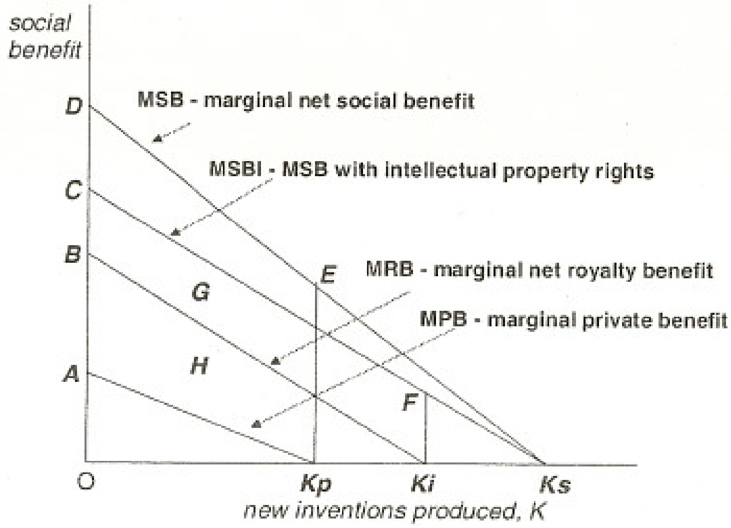

Figure 2 - Welfare effects of property rights

Under IP, then, consumers gain area $BCFK_i$ from new knowledge, while the innovators gain OBK_i. IP thus causes an unambiguous increase in net benefits to innovators (an obvious conclusion without any analysis at all.) But the IP impact on social welfare is ambiguous even though the rate of knowledge creation moves closer to the social optimum. This is because with the more limited diffusion under IP, area $OCFK_i$ could be larger or smaller than area $ODEK_p$. IP may either increase or decrease consumer benefits (area $BCFK_i$ with IP, versus area $ADEK_p$ without.) Consumers and society as a whole are more likely to gain from IP as marginal private benefits MPB become small compared to marginal social benefits MSB, causing K_p to be small relative to K_s and K_i. This is the case that is usually offered in support of government research in agriculture.

Next we briefly describe the development of IP, as applicable to plant biotechnology, in the US. then demonstrate the weakness of PBR as a form of property rights, relative to common utility patents. Finally, we will turn to a North-South context to demonstrate that weaker IP institutions in the South may be preferable to stronger ones.

3. Evolution of IPRs Institutions Related to Plant Breeding in the U.S.A.

1790 – the first patent act

The U.S. Constitution empowers Congress "to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." (Art. I Sec. 8.) The first patent act pursuant to this provision was passed in 1790, but by convention its benefits were not extended to living things. This patent act was superceded by current law, which was enacted in the patent act of 1952.

1930 – Plant Patent Act

The 1930 PPA provided some relatively brief amendments to Title 35 of the U.S. Code, that extended to asexually reproduced (budding and grafting) plant varieties the same patent opportunities given industry through the patent process. The limitation of rights to to the category of just asexually reproduced plants greatly restricted potential effects of the bill, but apparently it was widely felt that patent rights could not practically be extended to sexually reproduced plant material. Testimony in hearings asserted that sexual reproduction would not replicate the parent variety and that enforcement difficulties would arise from this and from difficulties in identifying varieties and monitoring commercial transactions in grain that might be used as seed.

1960's – UPOV

In Europe several countries had established plant breeders' rights (PBRs) by 1960, but the provisions varied greatly (see Committee on Transactions in Seeds, Ch. 3). It was the intent of the Paris Convention of 1961 (which established the International Union for the Protection of Varieties

of Plants, or UPOV) to introduce some uniformity among these provisions as countries established and modified systems of plant breeders' rights. Provisions of the Convention were quite general, permitting member states to specify more extensive rights. It provides for reciprocal rights for breeders of one member state in each of the other member states, and specified that the breeder's permission is not required to use a variety in plant breeding. (The Paris Convention has been amended a number of times, and currently there are 64 signatory nations, including the US.)

In the US, in 1968 an amendment was offered to the PPA to extend patent rights to sexually produced varieties. By this time, however, a presidential commission on the patent system had rejected the patent system as a proper vehicle for plant variety protection, and the amendment died in committee pending further study of an appropriate means of protection. The 1970 Plant Variety Protection Act was the result of these further explorations.

1970 – Plant Variety Protection Act

The PVPA established in the US the relatively weak IP institution, plant breeders rights, for sexually-reproduced plant varieties. Amendments to the Act have brought its provisions into harmony with UPOV, of which the US became a member in 1981. The basic right conferred is the right to exclude others from selling, reproducing, importing or exporting the protected variety for a period of 20 years. The weakness of PVP (and PBRs in general) relative to utility patents derives from the significant exceptions to excludability. It is not an infringement of these rights for one to: a) save seed for use on the producer's farm, or b) use and reproduce a protected variety for plant breeding or other bona fide research.

To be eligible for PVP, a variety must have three properties: a) distinctness in some identifiable characteristics from all prior varieties of public knowledge; b) uniformity in the sense that any variations are describable, predictable and commercially acceptable, and c) stability when sexually reproduced, in terms of retaining distinctive characteristics.

While some dispute the significance of the social benefits of PVPA, studies by Perrin, et al (1983), Butler and Marion (1985), and Alston and Venner (2002) establish plausible evidence for increases the numbers of and productivity of varieties of various commercial crops in the US. The PVP Office continues to process and grant hundreds of PVP certificates each year.

1980 – Chakrabarty decision

A.M. Chakrabarty, working for general Electric Company, engineered a bacterium to have the capacity to break down crude oil, for the purpose of helping to clean up oil spills. The Patent Office declined to issue a patent, but in a split decision in 1980, the US Supreme Court decided that the bacterium was patentable, despite the fact that it was living material. This decision opened the way to widespread patenting of various aspects of plants and other living things, at the same time as breakthroughs in the life sciences were being widely discovered and exploited.

1985 – ex parte Hibberd

The Patent and Trademark Office Board of Appeal ruled in 1985 that maize plants with a high tryptophan level could be patented under the basic section 101 of the patent code. This decision ushered in new debates about the appropriate scope of such patent claims, and these and similar issues are yet to be settled. But from Hibberd onward, new, man-made plant characteristics and materials became patentable under the basic utility patent institution.

4. Welfare Impacts of Patents versus Plant Breeders' Rights

Individual crop traits, such as the color of the grain, were at one time sold together with other traits as a package in the germplasm matrix of the individual varieties or hybrids that farmers planted. That has changed – scientists are now able to transfer traits previously unknown in a crop species into existing varieties and hybrids, and the owners of these traits can price them separately from the seeds themselves. Some crop traits have been marketed by biotechnology firms to seed companies, who in turn incorporate them into their existing commercial lines for sale to farmers, but price them separately. In other cases the price of the traits are implicitly included in the seed price.

Intellectual Property Rights and Durable Crop Traits.[6]

If a crop trait is incorporated into a traditional self-reproducing variety, that trait can be considered to be a durable input because the farmer can save seed from the crop for re-use in a new production cycle. On the other hand, if the trait is incorporated into a hybrid or is combined with some type of genetic use restriction technology, or GURT, it is not a durable input because seeds from the harvested crop will not faithfully reproduce the parent crop. Furthermore, if the trait is patented, the owner may impose a technology agreement on the sale of the variety in which the farmer agrees not to replant the seed, thus converting the trait from a durable to an input that is no longer legally a durable.

The distinction between a durable trait and a non-durable trait is significant because of Coase's conjecture that sellers of durable goods may not earn any profit at all, as opposed to the normal monopoly rent that could be extracted from a non-durable good.

[6] This section borrows from Perrin and Fulginiti (2006).

Against this background, we now turn to the theoretical issue of how a trait might be priced under alternative IP institutions, and the resultant distributions of welfare. We will assume perfect and costless enforcement of these IP rights so as to focus on differences inherent in the institutional rights themselves.

Welfare benchmark: maximum social welfare benefit (MSWB) of a trait

We measure welfare here in terms of traditional consumer and producer surplus - areas between the price line and the demand curve and the supply curve, respectively. The demand curve for the current services of a crop trait is derived from the harvest-time payoffs of the trait across heterogeneous plots of land. This payoff can be due either to a reduction of unit production cost or added crop value, or both. If the density of plot valuations is uniform, the market demand curve at the beginning of the season for a single year, corresponding to the derived demand for diffusion curve in Figure 1, will be $v = \delta(1-Q)$, where v represents value and $\delta = 1/(1+i)$. Here the highest-value application is indexed at a=1, and the potential units of application are indexed by Q=[0,1]. For one year of crop trait the potential benefits, the area under the demand curve, thus equals $\delta/2$.

Assume that the trait will persist in producing this value each year for T calendar years from the date of its introduction, at which point its utility is exhausted. The maximum social welfare benefit (MSWB) of the trait is the present value of the fully-adopted flow of benefits, or $V_0(T)=k_0(T)(1-Q)$, where $k_0(T)=[1-(1+i)^{-T}]/i$, the present value of a unit annuity starting at time t=1, one year from release, and continuing through time $t=T$.

We can thus express the maximum social welfare benefit from the trait (present value of social surplus) as

$$\text{Maximum Present Value of Social Welfare Benefit (MSWB)} = \frac{k_0(T)}{2}. \quad (1)$$

Welfare distribution from a trait protected by a patent

If the trait owner holds a patent, his optimal strategy will be to invoke a non-reuse technology agreement and charge an annual royalty $p^* = \delta/2$ per unit, selling to $Q = 1/2$ applications. Equivalently, he would be willing to sell the trait as a durable for $P^* = k_0(T)/2$. Either way, producer surplus would be the normal monopoly profit of MSWB/2, consumer surplus would be MSWB/4, for total welfare benefit equal to three-fourths of MSWB. The missing one fourth of potential benefits is the monopoly welfare loss due to excluding half of the potential beneficiaries from using the trait.

Coase's conjecture regarding the pricing of durables

Coase conjectured that monopoly rents for a durable good might be driven to zero due to the following guessing game played by seller and buyers. Potential buyers know the price will fall in the future because the seller has an incentive for intertemporal price discrimination, *i.e.,* to sell at a high price to the most willing buyers during the first period, then sell additional units at a lower price to additional buyers in the next period. But buyers are aware of this strategy, and thus have an incentive to delay their purchase to the next period after the price has fallen. The seller, not able to sell the quantity intended, is forced to reduce the first period price. But buyers recognize that unless that reduced price is close to marginal cost, the seller still has an opportunity for intertemporal price discrimination, and they will continue to wait. Their waiting game may force the price to the level of marginal costs immediately, with the result that the monopolist earns no profit at all.

Welfare distribution from a durable trait protected by PBR

Plant Breeders Rights do not allow the trait owner to exclude farmers from saving seed to plant the following year, so PBR-protected traits are durable goods (unless protected by some type of GURT.) The seed market

is to some extent protected from the Coasian re-pricing collapse because of the biological one-year interval between pricing periods. Given this one-year interval, just how fast might the price of a trait fall, given the game-like market structure posed by Coase? We trace through the logic of this game as follows.

The seller must choose a time path for prices that acknowledges and is consistent with the strategy of far-sighted buyers[7]. To be explicit, for buyers to be willing to buy at time *t* rather than wait, the present value of buying now must be equal to or greater than the present value of waiting until the following year. For the *marginal* buyer at time *t*, indexed by Q_t, the present values of buying now and waiting must be equal, so

$$\begin{aligned} &V_t(Q_t) - P_t = \delta\left[V_{t+1}(Q_t) - P_{t+1}\right], \text{ or} \\ &k_t(1-Q_t) - P_t = \delta\left[k_{t+1}(1-Q_t) - P_{t+1}\right], \text{ or, given that } (k_t - \delta k_{t+1}) = \delta, \\ &Q_t = 1 - \frac{1}{\delta}P_t + P_{t+1}. \end{aligned} \tag{2}$$

To determine the optimal time path for prices subject to this condition, we use backward induction. At the time of final trait sales, *t=(T-1)*, the owner's problem is

$$\max_{P_{T-1}}\left\{P_{T-1}\left(Q_{T-1} - Q_{T-2}\right) = P_{T-1}\left(\frac{P_{T-2}}{\delta} - \frac{1+\delta}{\delta}P_{T-1}\right)\right\},$$

which solves as (3)

$$P_{T-1} = P_{T-2} / 2\left(1+\delta\right).$$

[7] If the seller can credibly commit that the price will remain constant in the future, at $P^* = V_d(T)/2$, normal monopoly rent can be achieved, but the durables pricing literature illustrates the great difficulty of establishing this credibility (see, for example, Orbach).

For $t<(T\text{-}1)$, price is constrained by the relationship in equation , and the problem is

$$\max_{P_t}\left\{P_t\left(Q_t - Q_t\right) = P_t\left(\frac{P_{t-1}}{\delta} - \frac{1+\delta}{\delta}P_t + P_{t+1}\right)\right\},$$

which solves as

$$P_t = \left(P_{t-1} + \delta P_{t+1}\right)/\,2\left(1+\delta\right), \text{ which can be written} \qquad (4)$$

$$P_t = \ 2\left(1+\delta\right)P_{t+1} - \delta P_{t+2}.$$

In principle, one might use and recursively to express every P_t in terms of $P_{T\text{-}1}$, so that one could then choose $P_{T\text{-}1}$ to maximize the present value of revenues. However, this analytical approach proved to be too intractable for a life longer than about five years, so we have instead used a search procedure. Using and the last expression in , we numerically evaluate every P_t in terms of the subsequent two prices (one subsequent price in the case of $P_{T\text{-}2}$). We then obtained the optimum value of final price $P_{T\text{-}1}$ by numerical search.

The optimal price path for T=10 and i=.05 yields the initial price P_0=0.82; *i.e.* the price is set at 82% of the value of the benefit for one year on the highest-valued application. This is a very low price, as compared to the optimal rental rate for one year, which is about p^*=0.5 . The optimal price path declines rapidly to less than .01 by t=4, as shown by the dashed line in Figure 3. This price path was not very sensitive to the choice of T and i [8], as indicated in the figure. Here the implications of the Coase conjecture are evident: the time path of price starts low and falls rapidly. Trait owner welfare is only 11% of MSWB, rather than the normal monopoly rent equal

[8] For T=5, i=.05: P_0=.81and price fell below .01 at T=4. For T=10, i=.20: P_0=.70 and price fell below .01 at T=4. For T=5,i=.20: P_0=.70 and price fell below .01 at T=4.

to 50% of MSWB. Consumers, on the other hand, very quickly achieve full adoption (Figure 4), and they achieve a welfare gain equal to 84% of MSWB. Total social welfare benefit reaches 95% of its maximum value. The price of the durable is not forced to zero immediately because prices are updated only once per year rather than continuously.

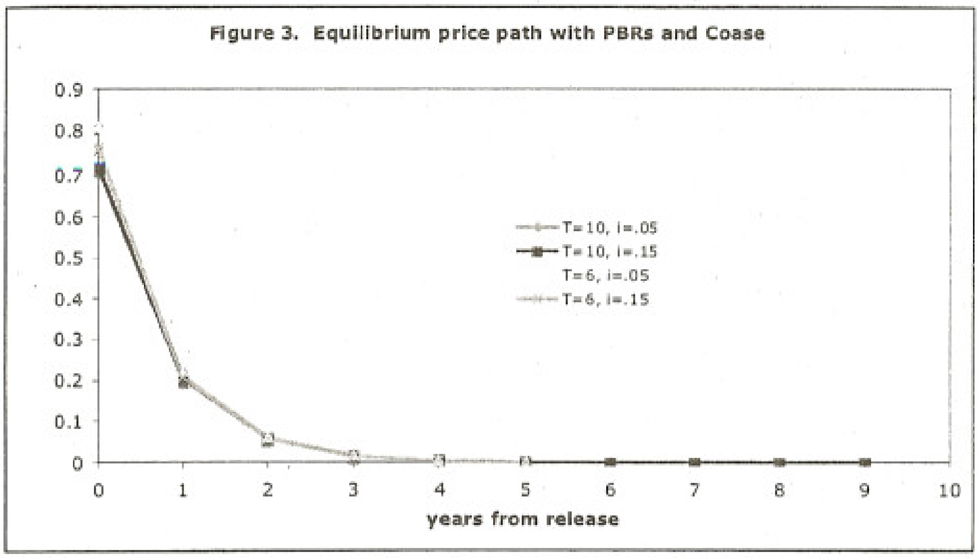

Figure 3

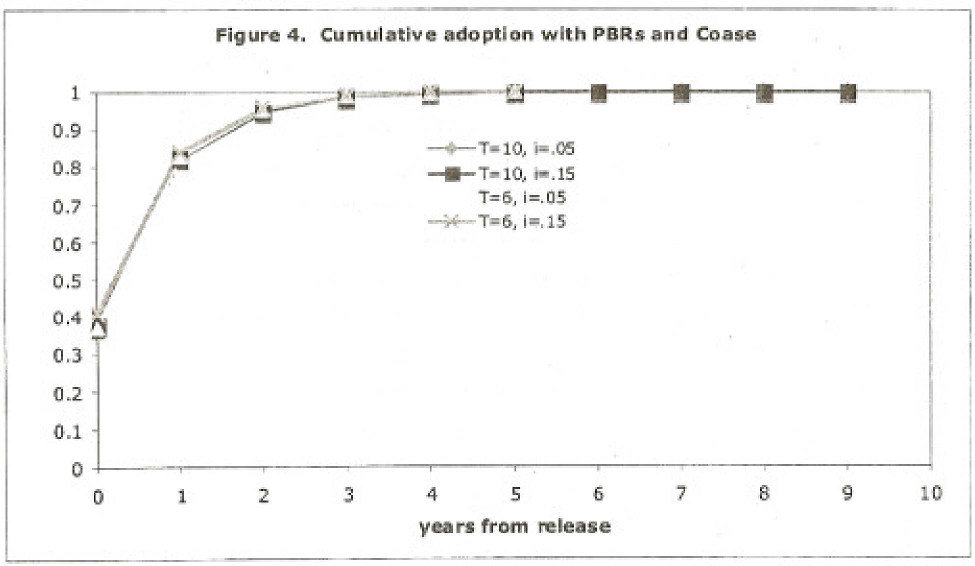

Figure 4

This analysis suggests that the Coase conjecture might indeed drastically reduce rents to trait owners, relative to what could be realized with a patent, even though such rents would not be driven to zero. They are thus a very weak form of IP. One might conclude from this that the biotechnology industry would eschew PBR in favor of patents, but this has not been the case. However is certainly true that in the US, where monitoring and enforcement costs are relatively low, patents are pursued on virtually all crop traits of any significance. But it costs a firm millions of dollars to establish a patent on a trait, whereas PBR can be obtained for mere thousands of dollars. PBR thus provide some protection with minimal outlay of funds and time, even though patent protection might be pursued simultaneously. Another incentive for continued use of PBR is that they are valid in a number of countries that do not acknowledge patents on crop traits. Yet another possible reason for their continued use is that PBR protection can be obtained on varieties that have crop traits that for some reason are not patentable.

Have markets for PBR-protected traits reflected the price decline predicted by this adaptation of Coase's conjecture? That is a question that has not been addressed empirically, primarily because of the difficulty of acquiring data on price of traits, per se, in countries that rely on PBR rather than patents.

It is clear that the relatively weak protection offered by PBR allows for wider diffusion of crop trait than would patents, but concomitantly they provide less incentive to achieve the socially optimal level of research described earlier in this paper. Patents would appear to be preferable except for two arguments. First, if we consider the welfare of two peoples separately instead of jointly, it may be optimal for one country to free-ride on plant technology created in another country, while the limited opportunity for royalties provides sufficient incentive for the transfer of technology if not its discovery. Second, biotechnology research requires a wide variety of processes and products that are patented, and the difficulty and expense of arranging the appropriate portfolio of licenses is alleged to unduly restrict innovation (these and other arguments for the reform of US patent institutions have been detailed by Jaffe and Lerner.)

5. Welfare impacts of IP for biotechnology in a North-South context[9]

The strength of intellectual property rights among third-world countries has become an important policy issue since the inclusion of TRIPs (trade-related intellectual property) as part of the fabric of the World Trade Organization. IP issues had traditionally been addressed through the World Intellectual Property Organization, but U.S. frustration with attempts to strengthen existing international treaties led to the adoption of a clause (Clause 301) in the 1988 trade act that allowed trade retaliation against countries that inadequately protect intellectual property rights. U.S. self-interest in the issue was reflected in the U.S. Trade Commission (1988) estimate, widely discounted, that U.S. export losses due to intellectual property right infringements were then $60 billion per year and growing.

However, the U.S. also argued that strong intellectual property rights within developing countries would be in the self-interest of those countries themselves because of the stimulating effect of IP on development, even though the most direct effect would be a transfer of royalty payments away from the less-developed countries. Many developing countries seem to reject this proposition, only adopting stronger IP due to retaliation threats under WTO.

The potential welfare gains to developing countries (the "South") from stronger IP has been the subject of a number of theoretical analyses over the past two decades. Virtually all of these studies posit a set of innovating firms and customers in the North with only customers in South. These studies almost uniformly conclude that the South would lose from strengthening their own IP.

The South has an incentive to free ride on plant biotechnology innovations in the North if those innovations are appropriate for the South's

[9] This section borrows from Perrin (1999).

agro-climatic and socio-economic circumstances. But the South also has an incentive to establish IP so as to enhance technology transfer from the North and to encourage innovations uniquely appropriate to the South. To consider this dilemma more fully, arrange the payoffs from the set of latent innovations on the continuum shown in Figure 5, rather than as a marginal return to knowledge as in Figure 2. In figure 5, the SBN curve arrays the net social benefit to the North from a set of knowledge projects, K. The most desirable innovation is located at the middle of the SBN curve, with height OD, rather than at the inception of the MSB curve in Figure 2. Under some form of IP, the innovating firm's Northern royalties are represented by curve RBN. The number of innovations is as earlier, Ki , all those for which royalties (net of research costs) are positive. As argued above, under IP the diffusion of each innovation will be restricted, so the the social benefit in the North of each innovation under IP (SBIN) will be less than the potential benefit. The area between the SBN cuve and the SBIN curve represents the social benefits lost due to restricted diffusion under IP, and the areas under the tails of the SBN curve (outside the range of Ki) represent social benefits lost due to lack of adequate incentives for invention.

Let the distribution of potential social benefits of innovation in the South be represented as SBS, in Figure 5. Diwan and Rodrik suggest that benefits in the South can be conveniently calibrated relative to those in the North as SBS = γSBN(K-ó), where γ indicates the relative size of the South, and ó represents a horizontal shift measuring the congruity of the payoffs, the "appropriateness" of innovations, for the two sets of agroclimatic and social circumstances. Thus if σ=0, Northern technology would be fully appropriate to the South, since the order of ranking of the innovations by benefits is the same no matter which country is considered. The parameter γ adjusts for the relative size of the South by shifting the height of SBS relative to SBN.

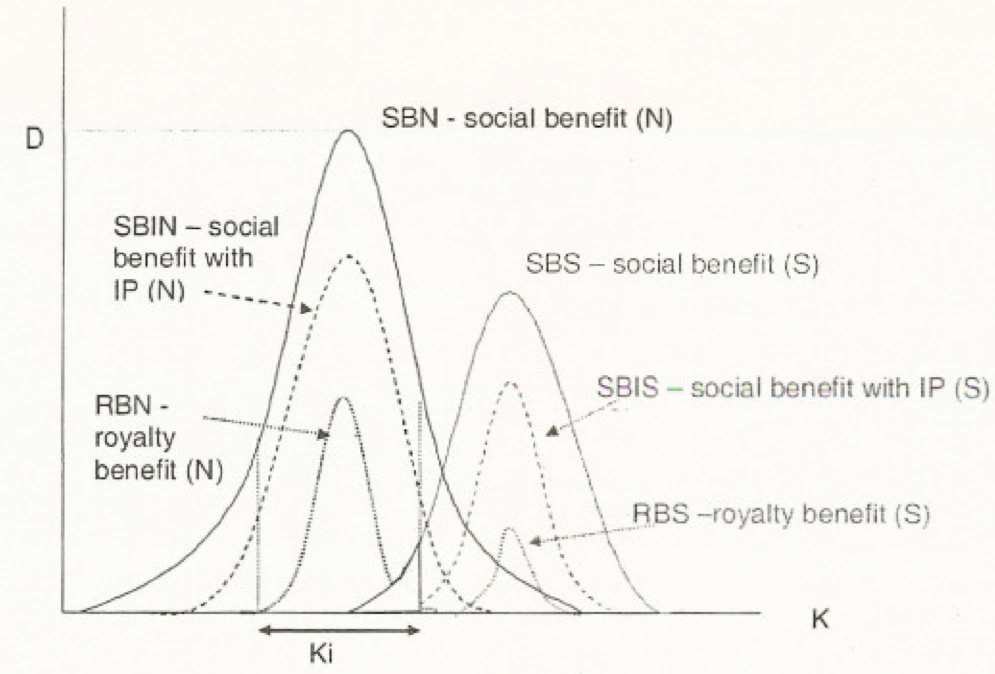

Figure 5 - Appropriate technology in North and South

Suppose the South were to eschew IP in favor of free-riding on innovations in the North. If the South's distribution of benefits were exactly congruent with the North's, then the South would have no incentive to establish IP, and would gain more than the North from the North's innovations because diffusion would not be restricted. As the relative size of the South (ã) decreases, or the shift parameter ó increases, the gains to the South from Northern innovation would diminish. In figure 5, social benefits to the South under the free-riding strategy are limited to the shaded triangle.

If the South chooses IP, the potential royalty earnings from diffusion in the South are represented by the curve RBS stimulating innovations of an amount analogous to Ki. The South's benefits from North-appropriate innovations will be reduced because of royalties paid. But this loss may well be offset by benefits from south-appropriate innovations, represented by the difference between curves SBIS and RBS.

It is evident that it is not necessarily in the South's self-interest to establish strong IP, even though it would tilt the range of innovations toward technology that is more appropriate for South[10]. These analyses suggest two factors that would enhance the payoff of strong IP in the South. First, the greater is the divergence in the distribution of payoffs from various technologies, the less appropriate is Northern technology for the South and the greater is the payoff for strong IP in the South. Second, the larger is the South's domain of application (γ), the greater is its payoff from IP (unless its circumstances are congruent with those of the North.) In the absence of these circumstances, PBRs would be likely the preferred IP institution in the South.

6. Conclusions

IP for crop traits has theoretical advantages because it compensates for the externalities that limit research to levels below the social optimum. In the US as well as many other industrialized countries, crop trait developers have two primary forms of IP protection available – Plant Breeders Rights (in the form of Plant Variety Protection in the US) and common utility patents. In many other countries, only PBR is available, which is a weaker form of protection in that buyers cannot be restricted from re-planting seed. Our theoretical analysis suggests that:

(a) It is not evident that agricultural development in the South would benefit from the stronger version of IP, despite the tendency of strong IP to tilt innovation toward technology that is appropriate for the South. For a given less-developed country, the "appropriate technology" case for weak IPRs decreases with the size of the agricultural sector and decreases with the divergence of its agro-climatic characteristics from those of the North. (b) Because of the problems in the monopoly pricing of durables, PBR

[10] Diwan and Rodrik explore the reaction function of the South, whose property rights strength is â, relative to North's á. In their model as in the case here, optimal â is certainly positive if á=0 because there would otherwise be no innovation at all for South to use.

protection may provide only 20% the level of royalties that would be obtainable with a patent. The weakness of protection provided by PBR is not a serious issue in the US, because virtually all plant traits developed through biotechnology are protected by patents. Many seed firms will also seek PBR protection on varieties that include these traits, presumably because such protection is inexpensive and provides a limited amount of excludability at home but perhaps more abroad. PBR will not provide much incentive for plant research, but would provide some positive incentive for technology transfer, and would result in wider adoption and therefore greater benefit from crop traits once they have been discovered. For some countries in the South, diffusion of technology may be of greater importance than its discovery, and in such a case PBR, despite its theoretical limitations, may be a more appropriate institution for stimulating technology transfer than patents.

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