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An Auction Model of Intellectual Property Protection: Patent Versus Copyright

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ABSTRACT. – In this paper several firms compete for the right to obtain intellectual property protection for a basic idea which has subsequent potential applications. The modelling employs an auction analogy, taking the context to be an n-player all-pay auction, with a reserve. We find that, even taking only firms' own utilities into account, welfare has no interior maximum, so that either maximal, or minimal, protection is optimal. Through examining a simple version of this game, we suggest that software is socially better protected by means of copyright rather than patent.

Modèle de vente publique pour la protection de la propriété intellectuelle : brevet ou copyright ?

RÉSUMÉ. – Nous décrivons la situation où plusieurs sociétés concurrentes cherchent à obtenir la protection de leur propriété intellectuelle pour une idée de base pouvant avoir des applications ultérieures. La modélisation fait appel à un jeu de vente publique à n personnes avec paiement par toutes les personnes, et un prix minimum. Nous observons que, même en ne tenant compte que du degré de satisfaction des sociétés, les biens n'ont pas de maximum intérieur, si bien qu'une protection maximale ou minimale est optimale. Nous proposons que le copyright est préférable au brevet pour la protection des logiciels.

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1 Introduction

There is a very considerable literature on the social welfare effects of patents. Traditionally, following Nordhaus's [1969] pioneering work, it was concerned with determining the optimal length of a patent. More recently, it has become concerned with patent breadth and patent height. Important contributions on patent breadth include KLEMPERER [1990] and GILBERT and SHAPIRO [1990]. Some authors refer to patent height as breadth, though VAN DIJK [1996] for example is strongly of the view that they are different dimensions. Essentially, height is concerned with the standard of novelty for an incremental development. Apart from van DIJK, examples include SCOTCHMER and GREEN [1990] and FERRANDO [1992]. A related concern voiced more recently is that later discoveries may affect the incentive to invest in enabling innovations, and patents on these might curtail activity on further developments – GREEN and SCOTCHMER [1995] and CHANG [1995] are relevant here. Our paper is concerned in part with novelty requirements. However our major focus is on the optimal extent of coverage to be afforded by intellectual property protection.

In practice, intellectual property protection to enable the appropriation of the results of inventive activities takes a variety of forms. Besides patents the other major rights are copyright and trademarks. One rather important distinction may be made between patents and copyright. Arguably patents are capable of providing rather extensive protection whereas copyright provides a much weaker form of protection, since the thing that is copyrighted is normally not proof against, for example, similar ideas expressed in different ways. It is the form, not the thing itself. PHILLIPS and FIRTH [1995] define an "Absolute Monopoly" as "The right of an intellectual property holder to prevent all other persons from using that property within the market place governed by the law which protects it. An example of the absolute monopoly can be found in the rights enjoyed by the holder of a patent for an invention." (p. 13). By contrast "copyright monopoly is only a limited, qualified sort of monopoly..." (p. 129) where "qualified monopoly" is defined as "absolute monopoly subject to one major qualification: [the owner] cannot stop another party 'stripping down' his creation and thus effectively using it as the basis for his own creation" (p. 14). Clearly, the latter allows significant spillowers from a development to accrue to other firms, whereas the former does not.

Thus we may ask whether it is desirable that some inventive activities receive extensive protection via patents whilst others do not, because only copyright is available. Remarkably, it transpires that having such polar alternatives is socially optimal. Hence the major issue becomes one of determining for which sectors of industry particular types of protection are appropriate.

One of the problems in evaluating existing contributions to the literature is that social welfare losses arise from many sources, whereas of course individual papers include only a subset. The early literature incorporated a tradeoff between monopoly power and incentives, but there are other factors.

For example in KLEMPERER [1990], as well as people paying high prices for the patented good, there are losses to those who buy some related, cheaper but less-desired alternative. A second broad problem, more serious from the viewpoint of implementing actionable policy changes, is that the policy implications are often too subtle. A good example (though by no means unique), is the following proposal from Chang: “Courts should provide the broadest protection to two distinct classes of basic inventions: not only those that are very valuable relative to possible improvements – but also those that have very little value relative to the improvement that one would expect to follow...” (1995 p. 48). It would be difficult to imagine a practical version of this. In our paper, we aim to avoid the second problem by focussing policy discussion on the much less subtle issue of whether copyright or patent protection is the more desirable for particular industries. But at the same time we will not be able to avoid the first problem – there will definitely be relevant considerations not encountered within the model.

The approach in our paper is to develop a model in which there are a number of potential innovators, each engaged in research programmes, only one (at most) of which will be rewarded with intellectual property protection. However it is envisaged there is the possibility that some of these competitors will develop a subsequent stage product. If the initial protection extends to partial coverage of the subsequent developments, the reward will be dependent upon the expected number of such developments and the degree of coverage afforded by intellectual property protection. This will in turn feed back into the effort expended on research and on gaining the initial key patent or other protection. But the size of inventive step required (relative to the likelihood of success), which if large will dissuade some potential innovators from participating, will also be an important factor. The model focuses inter alia on an element which has arguably received too little attention – the expenditure used in attempts to gain the intellectual property right. The modelling procedure draws extensively on the auctions literature in order to obtain results. Section three develops the auctions framework in the particular desired directions, whilst section four draws some implications. Before that, we locate what we do relative to particular previous contributions.

2 Modelling Multi-Player Research Competition

Research and development activity leading to an innovation can be thought of as a tournament, along the lines of the patent race literature (HARRIS and VICKERS, 1995, and others). Those models are relatively simplistic in their industry structure (commonly being limited to two players) but focus on timing. Instead of the emphasis on timing, we wish to focus on industry structure and so it makes sense to think of a number of players all aiming for a new "basic idea".

The paper closest to that we develop below is due to DENICOLO [1996]. It is one of the few to develop the n-firm patent race concept within a context in which questions about patent policy can be addressed, and it also usefully brings out points from a number of previous contributions. In Denicolo's model, there is explicitly only one stage, in which n firms race for a patent, but losers as well as winners make a return. The incentive to innovate is implicitly a function $I(\theta)$ of the degree θ to which technical knowledge is disseminated ($\theta = 1$ implies complete dissemination) as a result of the narrowness of the patent. Patent breadth, $1 - \theta$, will determine the winner's relative return. Similarly the deadweight loss D created by monopoly pricing of the patented product is also a function of θ. In fact if W is social welfare

$$D(\theta) = W(1) - W(\theta)$$

Therefore the trick is to socially optimise patent breadth by

$$\min \psi(\theta) \equiv D(\theta)/I(\theta)$$

As illustrated by the earlier contributions of GILBERT and SHAPIRO [1990], and KLEMPERER [1990], the outcome is extremely sensitive to the underlying assumptions. Prime amongst these, unfortunately, is the nature of behaviour within the industry. For example if competition is Bertrand, minimum breadth is optimal. However it is difficult to imagine how intellectual protection policy can be made conditional on the form of competition which may be presumed to operate in an industry, since we normally consider the patent is awarded first and only afterwards will pricing policy be determined.

Actually, although Denicolo's model incorporates a clear advance in terms of including n potential patentees, an advance we wish to incorporate, it is potentially problematic in its equilibrium conception (who wants to be a loser?) as a result of the high degree of symmetry. This is something our auction analogy can help relax. It would also appear not to take full account of a new source of private and social loss, (new in the sense of something which did not arise in the earlier cited models). This is the "useless" expenditure of those players who do not win the competition.

In our model, at any one time there are a number of players all approaching a similar question or target, perhaps from different directions or with different skills or different expectations concerning the valuation of the prize for being nearest the target based upon their specific experience. Yet once the prize is achieved by one, the other players are excluded by the prize from benefiting directly, though they may perhaps obtain indirect benefits. Therefore there are a number of players each with independent valuations of the prize, each committing expenditure in an attempt to win. In this scenario, it makes sense to draw upon the results of auction theory in analysing the outcome. (This is not an original suggestion; Leininger, 1991, previously made use of it, though in a very different way). For brevity, we will often describe the prize (intellectual property protection) as a patent, but this is not necessarily the outcome, indeed it is the question of policy choice on which we focus later.

3 An Auction Model of Patent Competition

3.1. General Considerations

Consider the following scenario. There are n potential players in an *all-pay* auction with a reserve. (Clearly the all-pay framework is appropprriate). Each has an *identical* independent distribution from which their valuation v of the patent is drawn. We think of this as a case where each player has their own specialism, but the development is capable of being applied in a variety of alternative areas. The valuation can include a view on royalties to be obtained, so long as it is still independent. Each player has first to decide whether to put in a bid (research programme) in an attempt to capture the prize, and then, if a bid is to be made, how much to spend, given information on its own valuation, while not knowing other firms' v's, only their distribution. The technology of research is assumed to be the following. A bid below a certain value $\underline{b}$ stands no chance of achieving any return – research of less than a certain amount would leave the player out of the race. Thus there are $m \leq n$ active players. This minimum value $\underline{b}$ is in large part technologically determined – research in some areas is inherently more costly than in others – although potentially it may be influenced by the novelty requirement demanded by the patent authorities. Beyond that minimum level, the highest bid wins the prize. We assume, for ease of obtaining results, that each v is distributed uniformly on [0, 1].

Assumptions about competition in our model are more aptly described as "standing on the shoulders of your peers" than on the shoulders of the giants depicted in Scotchmer [1991] and Green and Scotchmer [1995]. As we see it, there is a general view about a particular development being feasible and valuable. A set of players competes for the basic patent rather than it being the result of a blinding flash of inspiration on the part of a particular player. Nevertheless, taking part in the competition is (in general) a pre-requisite for being able to compete at later stages. From their model we take the lesson that it is important to pay some attention to what comes after the initial patent. Such considerations are ignored in most papers although the history of the development of, say, the textile industry is replete with examples of improvement patents enabling the spinning and weaving processes to operate more effectively. Therefore the more participants there are at the first stage the more players can take part in the later opportunities.

We take the view that an observer reading a patent description cannot immediately infer how it can be copied; know-how is necessary in addition. (Perhaps, if nothing else, this is because the skilled patent writer has an incentive to keep the description as opaque as possible subject to satisfying the patent examiners). The patent fills in the gaps in knowledge of a player who has kept up technologically in the particular area. More significantly, in this model it cannot be the case that the original inventor of necessity deserves all the reward from the innovation plus any and every development of it, since the patent holder may have 'won' only by a relatively narrow margin. Nor need such a reward be socially desirable.

We assume the private return to consist of a direct element plus a potential gain from spillovers coming from the developments of other players in the active group. Social returns are treated very simply as the sum of potential players' private returns.

3.2. The Model

The expected utility of a participating firm of type v, making a bid $b \geq \underline{b}$ which implies a probability of winning of $p(b)$ is composed of two elements: a main prize on winning plus a spillover prize gained whether winning or losing the auction. The former component is $(1-\theta)\,v$, where θ is a measure of the imperfection of the intellectual property right, $0 \leq \theta \leq 1$. This main prize is obtained with probability $p(b)$. The "spillover" prize is always obtained. It is composed of a coefficient formed from the property right imperfection (θ) and a spillover parameter α, $0 \leq \alpha < 1$, (the extent to which you benefit from others' work), multiplied into an expression for the v-type's expectation of the winning type: $\theta\alpha\,(vp\,(b) + v^*\,(1-p\,(b))$. Here v^* is some other firm's type (most obviously but not necessarily the highest type among other bidding firms). Note that v^* is independent of v. To check this, recognise that two different v-type firms, *making the same bid* would have the same probabilities of losing and would have no effect on other bidding firms' types.

Putting the two parts together and subtracting the bid b yields

(1) $$U(v) = (1-\theta)\,vp\,(b) + \theta\alpha\,(vp\,(b) + z\,(b)) - b$$
$$\text{where} \quad z\,(b) \equiv (1-p\,(b))\,E\,v^*$$

The conceptual distinction between θ and α will be important in what follows; θ is a policy parameter whilst α is a property of the industry, determined by its technical character. Finally, expected utility of a non-participating firm is scaled to zero.

We make the natural assumptions (which will be confirmed in the equilibrium that we derive) that bids are a monotonic increasing function of valuations, and that the auction is efficient in that only the player with the highest valuation will win. To derive the bidding function, note that since $U(v)$ is maximised by the bidding strategy $(p\,(b),\,b)$, (1) yields:

$$\frac{dU(v)}{dv} = \frac{\partial U(v)}{\partial v} = (1-\theta)\,p + \alpha\theta\,p$$

Given the assumptions of efficiency and uniform distributions, the probability of winning is the probability of no other player having a higher valuation, *i.e.*

(2) $$p = v^{n-1}$$

Hence:

$$\frac{dU(v)}{dv} = (1 - \theta(1-\alpha))\, v^{n-1}$$

that is, as v increases by dv, so utility increases by $(1 - \theta(1-\alpha)) :\equiv A$ (the marginal coefficient) times the probability of winning.

Therefore, by integration

(3i) $$U(v) = U(0) + A\, v^n/n \quad \text{if } U(0) \geq 0 \,(\text{everyone participates})$$

(3ii) $$= A(v^n - \underline{v}^n)/n \quad \text{if } U(\underline{v}) = 0 \quad \text{for } \underline{v} > 0,\ i.e.\, U(0) < 0.$$

where $\underline{v}$ is the lowest participating type.

LEMMA 1 : All firms will participate if $\underline{b} \leq \alpha\theta\, \frac{n-1}{n}$ (case (i)) because the spillover dominates the entry price. Otherwise there will be some non-participants (case (ii)).

Proof: When another firm is bound to win, a $v = 0$-type firm has utility:

$$U(0) = \max(0,\, \alpha\theta z - \underline{b}) = \max\left(0,\, \alpha\theta \int_0^1 s\,(n-1)\, s^{(n-2)}\, ds - \underline{b}\right)$$

(note again the use of the uniform distribution assumption).

Therefore:

(4i) $$U(0) = \alpha\theta\, \frac{n-1}{n} - \underline{b} \qquad \text{if} \quad \underline{b} \leq \alpha\theta\, \frac{n-1}{n}$$

(4ii) $$= 0 \qquad \text{if} \quad \underline{b} > \alpha\theta\, \frac{n-1}{n}.$$

Clearly, everyone will participate if

$$\underline{b} \leq \alpha\theta\, \frac{n-1}{n},$$

which completes the proof.

We are now in a position to describe participants' actual bidding behaviour relating to the two alternative possibilities. We assume that v^* in (1) is the highest other type, and confirm this later in Lemma 2.

(i) If $\underline{b} \leq \alpha\theta\, \frac{n-1}{n}$, equating (1) (using (2) and the definition of z) with (3i):

$$U(0) + Av^n/n = A\, v^n + \alpha\theta \int_v^1 s\,(n-1)\, s^{n-2} \cdot ds - b$$

Solving for $b(v)$

$$b(v) = Av^n\, \frac{(n-1)}{n} - \alpha\theta\, \frac{n-1}{n} + \underline{b} + \alpha\theta\,(1 - v^n)\, \frac{n-1}{n}$$

(5i) $$= (1-\theta)\,.\, \frac{n-1}{n}\, .\, v^n + \underline{b}$$

recalling the definition of A.

(ii) If $\underline{b} > \alpha\theta\,\frac{n-1}{n}$, so that $U(0) < 0$, from (1) and (3ii) we obtain:

$$A\,(v^n - \underline{v}^n)/n = Av^n + \alpha\theta\,(1 - v^n)\,\frac{n-1}{n} - b$$

Again solving:

$$b\,(v) = (1-\theta)\,\frac{n-1}{n}\,.\,v^n + A\,\underline{v}^n/n + \alpha\theta\,\frac{n-1}{n}$$

For the lowest valuation participant:

$$\underline{b} = \underline{v}^n\left[\frac{(1-\theta)\,n + \alpha\theta}{n}\right] + \alpha\theta\,\frac{n-1}{n}$$

(6) $$\text{hence}:\ \underline{v}^n = \frac{\underline{b} - \alpha\theta\,(n-1)/n}{1 - \theta + \alpha\theta/n}$$

Finally therefore:

(5ii) $$b\,(v) = (1-\theta)\,\frac{n-1}{n}\,v^n + \frac{A}{n}\left[\frac{\underline{b} - \alpha\theta\,(n-1)/n}{1-\theta+\alpha\theta/n}\right] + \alpha\theta\,\frac{n-1}{n}$$

Thus we can state

LEMMA 2 : The bidding function defined by (5i) and (5ii) is continuous above $\underline{b}$, and increasing in v – so that the highest participating v – type will win the patent.

Proof: Direct from (5i) and (5ii).

Lemma 2 confirms the assumption that $p = v^{n-1}$ is indeed the probability of a v-type participating firm winning the auction and inter alia justifies interpreting v^* in (1) as the highest type among other bidding firms.

3.3. **Social Welfare**

Let us consider the most straightforward possible social welfare function,

$$W = \underset{v}{E}\,\{nU\,(v)\}$$

which in effect assumes that the intellectual property protection system is run entirely in the (assumed risk neutral) firms' interests, ignoring consumers.

LEMMA 3 : If welfare is defined as $W = \underset{v}{E}\,\{nU\,(v)\}$ then there are again two possible cases as defined in Lemma 1 and, given the regularity of the bidding equilibrium demonstrated in Lemma 2

(7i) $$W = n\,[\alpha\theta\,(n-1)/n - \underline{b}] + \frac{A}{n+1} \qquad \text{if} \quad \underline{b} \le \alpha\theta\,(n-1)/n$$

(7ii) $$W = A\left[\frac{1}{n+1} + \frac{n}{n+1}\,\underline{v}^{n+1} - \underline{v}^n\right] \qquad \text{if} \quad \underline{b} > \alpha\theta\,(n-1)/n.$$

where $\underline{v}^n$ is as given in (6).

Proof: Equation (7i) is obtained from (3i) and (4i) directly. Equations (3ii) and (4ii) yield:

$$W = A \int_{v}^{1} (v^n - \underline{v}^n)\, dv$$

from which (7ii) is obtained by integration.

Of the parameters in the model, we will assume that n, the number of *potential* participants, is fixed (a feature of the industry) and α, the degree of "spillover", is also an industry-specific value. However the size of the minimum investment, ($\underline{b}$), and the degree of protection afforded (θ), are potential policy parameters, although the former is given at least in part by the nature of the technology. In what follows, we shall focus upon θ, asking whether social welfare, as defined above, can be optimised, or at least influenced, by changes in θ, leaving discussion of policy regarding $\underline{b}$ to future work.

We first state

LEMMA 4 : If $\underline{b} > \alpha\,(n-1)/n$ so that case (ii) in Lemma 1 exists, and welfare is given by (7ii) in Lemma 3, then

$$\text{(8)} \qquad \frac{d^2 W}{d\theta^2} = A\, y^{(1-n)/n}\,(dy/d\theta)^2/n + 2\,(y^{1/n} - 1)\,\alpha\,(1 - 1/n)\,(dy/d\theta)/(1 - \theta + \alpha\theta/n)$$

where $y \equiv \underline{v}^n$ defined in (6).

Proof: See Appendix

Now we can state our proposition

PROPOSITION: For the model and assumptions described, the welfare-maximising value of θ is either 0 or 1. Furthermore if θ is technologically-bounded between $\underline{\theta}$ and $\overline{\theta}$ where $0 < \underline{\theta} < \overline{\theta} < 1$ then the welfare-maximising value of θ is either $\underline{\theta}$ or $\overline{\theta}$.

Proof: a) Consider first that $\underline{b} > \alpha\,(n-1)/n$ so that only case (ii) exists.

$$\text{(9)} \qquad \text{Write } W = \frac{1 - \theta\,(1-\alpha)}{n+1}\,(1 + n y^{\frac{n+1}{n}} - (n+1)\,y)$$

(10)

$$\text{Now} \quad \frac{dW}{d\theta} = -\frac{(1-\alpha)}{n+1}\,(1 + n y^{\frac{n+1}{n}} - y) + \frac{1 - \theta\,(1-\alpha)}{n+1}\,(n+1)\,(y^{\frac{1}{n}} - 1)\,\frac{dy}{d\theta}$$

Note that for a stationary value of W, $\frac{dy}{d\theta}$ has to be negative since

$$(1 + n y^{\frac{n+1}{n}} - y) > 0 \qquad \text{and} \qquad y^{\frac{1}{n}} - 1 < 0 \text{ since } y < 1.$$

If $\frac{dy}{d\theta} < 0$ then $\frac{d^2 W}{d\theta^2} > 0$ (see Lemma 4) and so any stationary value of W is a local minimum. Hence the maximum value of W can only be attained at an extreme value of θ (0 or 1).

b) Now consider that $\underline{b} \leq \alpha\,(n-1)/n$ and both cases in Lemma 1 exist.

For $\theta \geq \frac{b}{\alpha}\frac{n}{(n-1)}$ we have

$$W = n\left(\alpha\theta\left(n-1\right)/n - \underline{b}\right) + \frac{1-\theta\left(1-\alpha\right)}{n+1} \tag{11}$$

and

$$\frac{dW}{d\theta} = \alpha\left(n-1\right) - \frac{1-\alpha}{n+1} \tag{12}$$

so that W is linear, with the result that the optimal θ in $(\frac{bn}{\alpha\,(n-1)},\,1]$ yields no higher value of W that one of the extreme values ($\frac{bn}{\alpha\,(n-1)}$ if $\alpha < \frac{1}{n^2}$, else 1).

Now at $\theta^* = \frac{bn}{\alpha\,(n-1)}$, y is zero and the slope of the left-hand derivative of W in (10) at θ^*, $y = 0$ is

$$\begin{aligned}\frac{dW}{d\theta} &= -\frac{1-\alpha}{n+1} - \left(1-\theta^*\left(1-\alpha\right)\right)\frac{dy}{d\theta^*} \\ &= -\frac{1-\alpha}{n+1} + \frac{\alpha\left(n-1\right)\left(1-\theta^*\left(1-\alpha\right)\right)}{n\left(1-\theta^*+\theta^*\,\alpha/n\right)}\end{aligned} \tag{13}$$

because at $y = 0$,

$$\frac{dy}{d\theta} = -\frac{\alpha\left(n-1\right)}{n\left[1-\alpha+\theta\alpha/n\right]}.$$

Now since

$$\frac{\alpha\left(n-1\right)\left(1-\theta\left(1-\alpha\right)\right)}{n\left(1-\theta+\theta\alpha/n\right)} < \alpha\left(n-1\right) \quad \text{for all} \quad \theta\varepsilon\left(0,\,1\right)$$

we have that at θ^* the left-hand derivative (13) of W with respect to θ is smaller (is more negative) than the right-hand derivative (12). The kink is therefore convex, so that if θ^* is better than points to the right, there exist points to the left of θ^* which dominate θ^*.

Finally, directly from the argument used in (a) we know that there is no interior maximum for $\underline{b} > \alpha\,\theta\left(n-1\right)/n$.

For the second part of the Proposition, simply note that the above proof shows the absence of any interior local maximum in (0, 1) and hence there can be no value of θ, $\underline{\theta} < \theta < \overline{\theta}$ which yields higher welfare than both $\underline{\theta}$ and $\overline{\theta}$.

COROLLARY : If $\underline{b} \leq \alpha\left(n-1\right)/n$, the welfare maximising value of θ is 0 if and only if

$$\alpha \geq \left(1 + n\underline{b}^{(n+1)/n} + \left(n^2-1\right)\underline{b}\right)/n^2$$

and unity otherwise.

Proof: We need only consider θ as =0 or 1. Thus directly from (7i) and (7ii), given lemma 3, evaluating (7i) at $\theta = 1$ and (7ii) at $\theta = 0$ and substituting to find when the latter yields more welfare, yields the required condition.

More generally, possible values of θ may be constrained by enforcement technologies or alternative laws. Also comparative statistics are ambiguous in some cases. For this reason we investigate some simulations of welfare as a function of θ for various parameter values in Figures 1 and 2. These plot social welfare values obtained using (7i) and (7ii) for the range of values of the parameter θ for various cases. Figure 1 concentrates on the effect of varying α for $n = 2$ and $\underline{b} = 0.2$. For low α, welfare declines uniformly as θ increases [–indeed this can be shown analytically for $\alpha < 1/n^2$ so

FIGURE 1

Varying α.

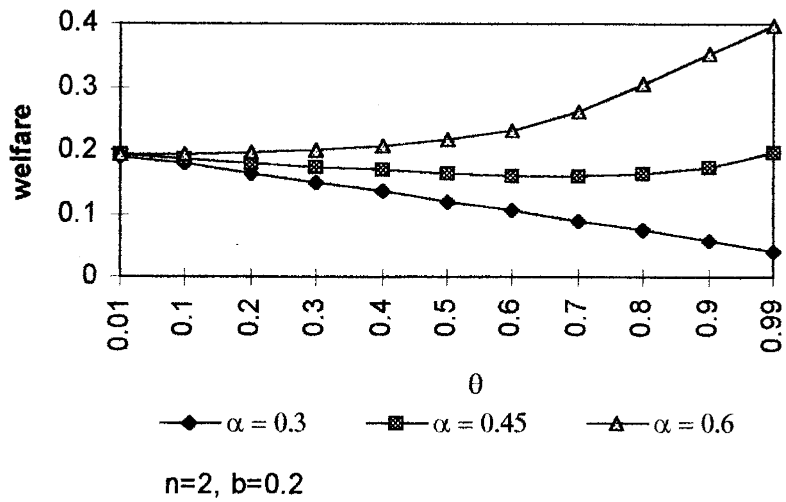
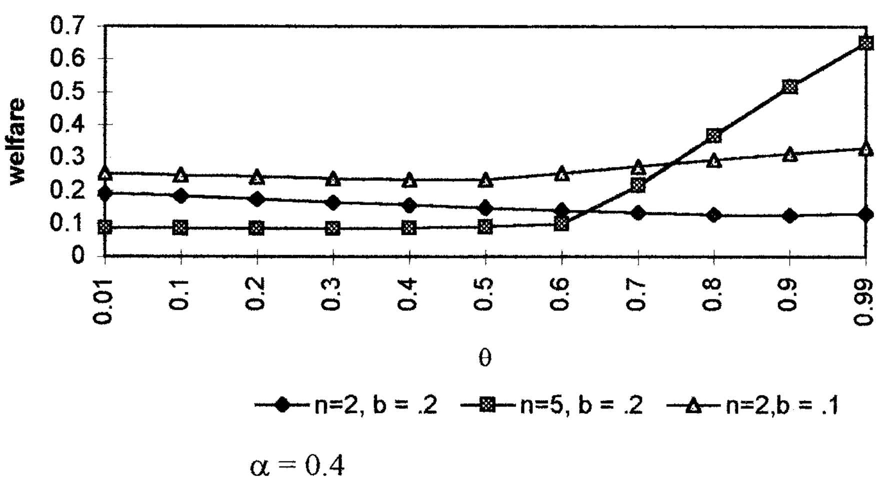


FIGURE 2

Varying n ***and*** b.



long as all firms participate – see (12)]. However for higher α values, eg $\alpha = 0.6$, welfare rises as θ increases. Figure 2 keeps α fixed at 0.4 but varies n and $\underline{b}$. As n increases it becomes more likely that welfare rises as θ reaches high values. Decreases in $\underline{b}$ also have this effect.

3.4. **Discussion**

Our Proposition relates to the results on the absence of internal maxima with respect to θ. It might be thought that our welfare function would be likely to yield a policy prescription of extensive protection. However, dependent upon the relevant values, it is optimal either for θ to be very low (zero if possible), that is for protection provided to be very extensive, or for θ to be very high (one if possible). In this sense, our results have something in common with the existing "parent breadth" literature, which tends either to suggest very broad (but short life) or very narrow (but long life) patents.

What, specifically, are the major factors influencing the choice between full and very little protection? Clearly, the higher is α, the extent of spillovers, the more likely is it that very little protection should be provided. Also, examining Figure 2, the greater the number of potential players, n, the more likely it is that little protection should be provided. Finally, the lower the minimum feasible bid, $\underline{b}$, the more likely that little protection should be provided. There is also some indication (though caution is needed here) that the result of getting things wrong in the sense of welfare differences is greater in magnitude if extensive protection is chosen.

Let us consider the intuition underlying these outcomes. A naive (or first glance) view might be that welfare as defined here will fall as θ increases. From (1), partial differentiation gives this result. Reducing the degree of protection reduces the direct benefits from winning but enhances the indirect benefits from participating. However the latter are on average smaller than the former, so reducing protection reduces the expected pay-off. We call this the direct effect, and it would argue for extensive protection.

This reasoning is incomplete in two, possibly opposing, respects, both relating to aggregation. The analysis above ignores the effect of differing numbers of active participants. We know that everyone participates so long as $\underline{b} \leq \alpha\theta(n-1)/n$, a locus which may be sketched on Figure 1 as an inverse relationship between α and θ. The greater is n, the more individual expected utilities there are to be aggregated, and the more likely therefore that the welfare locus rises due to spillovers. The other major factor is the expected number of active participants when not everyone participates. This is directly influenced by $\underline{v}$, namely the higher is $\underline{v}$, the smaller the expected fraction of firms which will participate. In turn $\underline{v}$ is influenced by the underlying parameters through equation (6). Straightforward differentiation reveals that for $\underline{v} > 0$

$$\partial \underline{v}/\partial\theta \gtrless 0 \quad \text{as } \alpha \lesseqgtr n\underline{b}/(b+n-1) \tag{14}$$

If the upper inequality is true, the "aggregation effect" goes in the same direction as the naive effect, and welfare will fall as θ rises. In the other case there are offsetting factors. As a result of the "aggregation effect" there is a greater expected number of participants as θ rises, leading to welfare increases, whilst the direct effect leads to welfare falling.

Seen in the light of these two offsetting factors, the detail of the results is readily understood. An increase in α both lessens the impact of reduced protection and makes it more likely that α exceeds $n\underline{b}/(\underline{b}+n-1)$, increasing expected participation. Thus the higher is α, the more likely that no protection becomes the optimum. Increasing the number of potential participants magnifies the impact of falls in $\underline{v}$ as θ increases, again making it more likely that no protection is best. Reducing $\underline{b}$ again increases the expected number of active participants, so magnifying the aggregation effect. An interior optimum is unlikely, because the aggregation effect increases in intensity as high θ values are increased, so if it is opposing in direction to the direct effect it becomes more likely to outweigh the direct effect as θ increases. (The *sign* of $\partial\underline{v}/\partial\theta$ does not depend on θ, although its magnitude does.)

Clearly, the detail of our results is specific to the particular assumptions, which include the uniform distribution assumption which has allowed us to generate explicit results. However the effects which this particular assumption has allowed us to demonstrate would seem to emanate from much more general forces. The direct effect is clearly general. But so too should be the aggregation effect. Whatever the underlying distribution, the minimum participation valuation, $\underline{v}$, will be influenced by the degree of spillover, α. Therefore we can expect that opposing forces will exist much more broadly, leading to the likelihood of optima at one or other extremes for any particular case.

4 Implications and Conclusions

In practical terms, fine tuning of the intellectual property system largely occurs through moving particular categories of things from being not protected to being covered by patents or covered by designs or copyright legislation, or vice versa. An example is provided by plant varieties and seeds, which first received some protection in the UK as a result of an eponymous act of 1964. It is in making such decisions about categorisation, rather than in modifying patent protection itself, that we feel our approach has most to add.

If this interpretation be accepted, a rationale is provided for the continuing existence of alternative schemes for protecting intellectual property. More significantly, the model suggests that there should be very specific reasons for moving particular new ideas from copyright to patent, rather than it being seen as a tidying up exercise, or, indeed, a matter for gradual case-law development.

In the context of our framework, an industry like pharmaceuticals seems an obvious candidate for tight intellectual property protection. The investment required to develop a new drug (boosted of course by government requirements regarding testing) is measured in tens of millions of dollars (GRABOWSKI and VERNON [1994]). Thus $\underline{b}$ is clearly large. In part as a result, the number of potential players in the pharmaceutical industry is small, even on a worldwide basis. In addition it is likely that spillovers (α) are low. Thus the industry would appear to be a classic example of one suited to patent protection, based upon our model, since the optimal θ is likely to be zero.

At the other end of the spectrum, computer software is an industry where $\underline{b}$ is low. Industry estimates of the investment required to produce a significant development range as low as two person-years and also reflect a rather modest equipment requirement, measured at most in tens of thousands of dollars (see eg MMC 1995). There are large numbers of potential players in many application areas. Additionally, spillovers from developing a particular procedure are likely to find a wide range of applications, and the chances of independently rediscovering something another investigator has already discovered are relatively high. This appears a classic case for copyright protection, based upon the results of our model. If the argument is accepted, moves to change the status of protection of software towards patents (as has happened in the US in some instances) should be resisted.

We should recall that our social welfare function is simply the aggregate of the potential players' expected utilities. This raises two additional issues. The first is that we should consider (static) consumer welfare. From previous work (eg DENICOLO [1996]) it is likely that this would be a factor arguing against strong intellectual property protection, because of the monopoly welfare losses incurred. The fact that we have found arguments in some cases against strong protection without recourse to consumer welfare considerations is noteworthy.

The second issue is that, since we have employed expected n-firm utility as our welfare function in the body of the analysis, might it be the case that the players can reach such an optimum themselves, unaided? This would seem to be more likely when firms find themselves in a symmetric position. A firm with a major development is hardly likely to give up the chance of strong patent protection if it is available even if all other firms in the group want to share it! But in an environment of weak protection, where each player fully recognises mutual benefits from spillovers, there is unlikely to be much pressure to strengthen intellectual property protection. On the other hand, where there is a group view that property rights need to be strengthened, ex ante they can speak with one voice. (This happened in the case of plant breeders' rights in the UK, see PHILLIPS and FIRTH, 1995, ch 25). It is interesting to note that in this case, the breeders wanted protection but argued as a group against such extensive protection as would be allowed by a patent system, (ibid. p. 14). This indicates a bias in the pressures for change. Those cases where strong protection exists may be reluctant to accept change even if it is in the interests of the group as a whole, whereas there will be no individual/group conflict regarding a possible strengthening of property rights.

Moving further outside the model, there is at least one other issue worthy of consideration, namely the question of compatibility or diversity. An important source of welfare in using particular innovating developments is their compatibility (or, to put it another way, a source of annoyance is their lack of compatibility). A strong patents system will tend to encourage diversity (WATERSON [1990]). In some respects this is welfare enhancing, but where compatibility is important, it is welfare reducing. The point is that the context is of considerable relevance in determining an appropriate system. If compatibility is important then a system which encourages developments to have a similar look and feel is desirable – this would not easily be provided by a framework of broad-based protection but might be better promoted by narrow protection. Arguably copyright fits this bill more closely.

APPENDIX

Proof of Lemma 4: Consider (7ii) in Lemma 3, and write this as

$$W = \frac{A}{n+1}\, z$$

where $z = 1 + ny^{(n+1)/n} - (n+1)\, y$ and $y \equiv \underline{v}^n$.

Calculate

$$\text{(A1)} \qquad \frac{dz}{dy} = (n+1)\,(y^{1/n} - 1) < 0$$

$$\text{(A2)} \qquad \frac{d^2\, z}{dy^2} = \frac{n+1}{n}\, y^{(1-n)/n} > 0$$

Now

$$\text{(A3)} \qquad \frac{dW}{d\theta} = -\frac{(1-\alpha)}{n+1}\, z + \frac{A}{n+1}\, \frac{dz}{dy}\, \frac{dy}{d\theta}$$

$$\frac{d^2\, W}{d\theta^2} = -\frac{2\,(1-\alpha)}{n+1}\, \frac{dz}{dy}\, \frac{dy}{d\theta} + \frac{A}{n+1} \left(\frac{d^2\, z}{dy^2} \left(\frac{dy}{d\theta} \right)^2 + \frac{dz}{dy}\, \frac{d^2\, y}{d\theta^2} \right)$$

From (6)

$$\text{(A4)} \qquad \frac{d^2\, y}{d\theta^2} = \frac{2\,(1-\alpha/n)}{(1-\theta+\alpha\theta/n)}\, \frac{dy}{d\theta}$$

Substitution of A1, A2 and A4 into A3 yields:

$$\frac{d^2\, W}{d\theta^2} = Ay^{(1-n)/n}\, (dy/d\theta)^2/n + 2\,(y^{1/n} - 1)\, B\, (dy/d\theta)$$

where

$$B = -(1-\alpha) + (1-\alpha/n)\,(1-\theta\,(1-\alpha))/(1-\theta+\alpha\theta/n)$$

which then simplifies to (8).

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