OPTIMAL COPYRIGHT OVER TIME: TECHNOLOGICAL CHANGE AND THE STOCK OF WORKS

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Abstract. The optimal level for copyright has been a matter for extensive debate over the last decade. Using a parsimonious theoretical model this paper contributes several new results of relevance to this debate. In particular we demonstrate that (a) optimal copyright is likely to fall as the production costs of 'originals' decline (for example as a result of digitization) (b) technological change which reduces costs of production may imply a decrease or a decrease in optimal levels of protection (this contrasts with a large number of commentators, particularly in the copyright industries, who have argued that such change necessitates increases in protection) (c) the optimal level of copyright will, in general, fall over time as the stock of work increases.

Keywords: Copyright, Intellectual Property, Technological Change, Cultural Decay

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1. Introduction

The optimal level of copyright have been matters of some importance to policymakers over the last decade. For example, motivated, it appears, by the increased ease of unauthorised copying in the digital environment, the WIPO Copyright Treaty of 1996[1] introduced additional measures aimed to 'strengthen' copyright, in particular by offering specific legal support for Technological Protection Measures (TPMs).[2] Similar concerns also seem to have motivated the introduction in 2005 by the European Commission of a second IP Enforcement Directive, which aimed to strengthen the available enforcement measures for IP infringement, in particular by the addition of criminal sanctions.[3]

Policymakers have also been active on other aspects of copyright, most notably the term of protection. For example, in 1998 the United States extended the length of copyright from life plus 50 to life plus 70 years, applying this extension equally to existing and future work. More recently, in the EU generally, and particularly in the UK, there has been an extensive debate over whether to extend the term of copyright in sound recordings.

Using a parsimonious framework based on those already in the literature (see e.g. Landes and Posner (1989); Watt (2000)) we analyze various questions related to the optimal level of copyright protection, deriving, under a simple set of assumptions, several novel results. In particular, we show that (a) optimal protection is likely to decrease as the cost of production for 'originals' falls (and vice-versa); (b) technological change which reduces costs of production may imply a decrease or an increase in optimal levels of protection (this contrasts with a large number of commentators particularly in the copyright industries who have argued that such change necessitates increases in protection); and (c) the optimal level of copyright will, in general, fall over time as the stock of work increases.

Note that costs are usually divided into those related to 'production', 'reproduction' and 'distribution' with the distinction between the first two being that production costs are those relating to the creation of the first instance of a work while reproduction relates to the

[1]Transposed into US law by the DMCA (1998) and into EU law by the EUCD (2001).
[2]TPMs are 'electronic locks' which aim to prevent unauthorised copying of digital material. Specific legal protection was provided in this legislation to prevent tampering with or removing these 'locks'. TPMs, and their legal protections, have aroused a great deal of controversy primarily because of their possibility to cause 'collateral damage' both to existing 'fair use' rights as well as to innovation in non-copyright industries (in particular those supplying the devices with which to use copyrightable material).
[3]The Directive's full title is "Amended proposal for a Directive of the European Parliament and of the Council on criminal measures aimed at ensuring the enforcement of intellectual property rights (COM/2006/0168 final - COD 2005/0127)." The Directive passed its first reading in the European Parliament in April 2007.

costs of producing subsequent copies. However in this particular case we take 'production' costs to include all expenditures, fixed as well as variable, related to the creation *and* distribution of the first version of the work and all authorised reproductions thereof (these are often termed 'originals' in the literature in opposition to 'copies': unauthorised – though not necessarily illegal – reproductions of the work in question).

This first result is of particular interest because recent years have witnessed a dramatic, and permanent fall, in the costs of production of almost all types of copyrightable subject matter as a result of rapid technological advance in ICT and related fields. With the growth of the Internet costs of distribution have plummeted and will continue to do so as both the capacity and the level of uptake continue to increase. Similarly, cheaper computers, cameras, and software have had a significant impact on basic production costs in both the low and high end market.

One caveat needs to be mentioned here. As discussed, there is a distinction to be drawn both between authorised and unauthorised reproduction. The move to a digital environment reduces the costs of both of these types of activities – formally, there is a high degree of correlation between the changes in the costs of producing 'originals' and 'copies'. As a variety of authors have pointed out, a reduction in the cost of making 'copies', that is in the cost of unauthorised reproduction, may or may not necessitate an increase in the optimal level of protection – see e.g. (Johnson, 1985), (Novos and Waldman, 1984), Liebowitz (1985) and Peitz and Waelbroeck (2006). This impact of technological change on 'copies' as well as 'originals' is incorporated in our second result which shows that, when both effects are taken into account, the overall implications for the optimal level of protection are ambiguous. While such a result cannot give immediate guidance to policymakers, it does suggest one should be cautious about drawing 'obvious' conclusions about the implications of a digital environment for the level of copyright protection.

The third main result, that optimal protection falls over time, also has importance for policy. In most systems of law, it is extremely difficult to remove or diminish rights once they have been granted. Thus, once a given level of protection has been awarded it will be all but impossible to reduce it. However, according to our result, the optimal level of protection will decline over time (as the amount of work available grows). This being the

case, a prudent policy-maker faced with uncertainty would want to be especially careful about increasing the level of copyright.

2. Framework

In this section we introduce a minimal framework but one which is still rich enough to allow the derivation of our results.

The strength of copyright (also termed the level of protection) is represented by the continuous variable S with higher values implying stronger copyright. For our purposes here it will not matter exactly what S denotes but the reader might keep in mind, as examples, the length of copyright term and the breadth of the exclusions (conversely the narrowness of the exceptions from the monopoly right that copyright affords its owner).

Many possible works can be produced which may be labelled by 1,2,3, ... Let $N = N(S)$ denote the total number of works produced when the strength is S.[4] Note that N may also depend on other variables such as the cost of production, the level of demand etc. however we have omitted these variable from the functional form for the time being for the sake of simplicity.

Assumption 1. The form of the production function for copyrightable work.

(1) At low levels of protection, increasing protection increases the production of works: $\lim_{S \to 0} N'(S) > 0$.[5]
(2) Diminishing returns to protection: $N''(S) < 0$.
(3) (optional) Beyond some level increasing protection further reduces production: $\lim_{S \to \infty} N'(S) < 0$.[6]

[4]Throughout we shall gloss over the fact that N is discrete and allow the differential both of N and with respect to N to exist.

[5]Without this assumption the optimal level of copyright protection is zero. ('Proof': $\lim_{S \to 0} N'(S) \leq 0$, which, combined with the next assumption would imply $N'(S) \leq 0, \forall S \geq 0$. Thus production of works would be non-increasing in the level of protection which, combined with the fact that welfare per work is non-increasing in the level of protection (see assumptions below) implies directly that the optimal level of protection is zero – i.e. there should be no copyright). While there is no a priori reason to support this assumption if it does not hold then, as just shown, the analysis is trivial. Thus, rather than add to each statement of results the rider that it depends on this assumption (and if not then optimal copyright protection is zero) we simply make it here and those who are unconvinced of its validity should simply remember that this implies a zero level of protection.

[6]This assumption is based on a very similar one in Landes and Posner (1989). Unless otherwise stated this assumption will *not* be used when deriving any of the results below.

Each work created generates welfare for society, and we denote by w_i the welfare generated by the i'th work. The welfare deriving from a given work (once produced) depends on the strength of copyright, so $w_i = w_i(S)$ and it is assumed that increasing copyright reduces the welfare generated from a work so $w_i'(S) < 0$.

Total welfare, denoted by $W = W(N, S)$, is then the aggregation of the welfare from each individual work. This need not be a simple sum as we wish to allow for interactions between works – for example we would expect that as there are more and more works the value of new work declines. We shall discuss this further below, but for the time being we may leave the exact form of aggregation opaque.

Assumption 2. Using subscripts to indicate partial differentials:

(1) Welfare is increasing in the number of works produced: $W_N > 0$.
(2) Keeping the number of works produced fixed, welfare is decreasing in the strength of copyright: $W_S < 0$ (this follows immediately from the assumption of diminishing welfare at the level of individual works).
(3) Diminishing marginal welfare from new works: $W_{NN} < 0$.

Since the number of works produced is itself a function of the level of copyright we may eliminate N as an argument in W and write:

$$W = W(S) = W(N(S), S)$$

Where it is necessary to distinguish the different forms of the welfare function we shall denote this version as the 'reduced form'. Finally note that, assuming *only* that $lim_{S \Rightarrow \infty} W(S)$ exists (with the value of infinity permitted), then as $[0, \infty]$ is compact (using the circle projection) and $W(S)$ is a continuous function (in the induced topology), W has a unique maximum somewhere in this range. As this is the welfare maximizing level of protection we term this the *optimal* level.[7]

Finally before commencing on the derivation of results we require the technical assumption that all functions are continuous and at least twice continuously differentiable.

[7]Note that it is possible that there are multiple levels of protection which achieve the welfare maximum – for example consider the case of $W(S) =$ constant. In this case take as the *optimal* level the minimum (infinum) of these welfare maximizing levels of protection.

3. The Relation of the Production and Welfare Maximising Levels of Protection

Lemma 3. *Under assumptions 1.1 and 1.2 there exists a unique level of protection which maximizes the production of creative work. We denote this by S^p. Furthermore, EITHER there exists a finite solution to $N'(S) = 0$ and this is S^p OR no such solution exists and $S^p = \infty$. With assumption 1.3 only the first option is possible.*

Proof. By Assumption 1.1 N is increasing when the level of protection is 0 (the lowest possible) thus 0 cannot be a maximum. By Assumption 1.2 if a finite maximum exists it must be unique and this maximum must be a solution of $N'(S) = 0$ (if there is such a solution then N' is negative from that solution onwards so infinity is not a solution). If no such solution exists then for all $S > 0$ we have $N'(S) > 0$ and the maximizing level of protection is infinite. □

Theorem 4. *If the level of protection which maximizes the production of copyrightable work, S^p, is finite then the optimal level of protection, S^o, is strictly less than S^p.*

Proof. If S^p is finite then $N'(S^p) = 0$ and since $N''(S) < 0$ we have $N'(S) \leq 0, \forall S \geq S^p$. Marginal welfare is:

$$W'(S) = \frac{dW(S)}{dS} = \frac{dW(N(S), S)}{dS} = N_S W_N + W_S$$

Now $W_S < 0, \forall S$, so combining this with the properties of the work production function, $N(S)$, we have that:

$$\forall S \geq S^p, W'(S) < 0$$

Hence, welfare is already declining at S^p and continues to decline thereafter. Thus, the optimal, that is welfare maximizing, level of protection, S^o, must lie in the range $[0, S^p)$. □

Remark 5. If the level of protection which maximizes the production of copyrightable work, S^p, is infinite then no immediate statement can be made as to whether the optimal level of protection, S^o, will be finite (and hence less than S^p) or infinite.[8]

[8]For example, consider a very simple multiplicative structure for total welfare of the form: $W(S) = f(N(S))w(S)$ with $f(N)$ any functional form with $f' > 0, f'' < 0$ (e.g. $N^a, a \in (0, 1)$). Then taking any

From this point on we make the following assumption:

Assumption 6. The optimal level of protection is finite, and is the unique level of protection, S^o, satisfying $W'(S^o) = 0, W''(S^o) < 0$.

4. Production Costs and the Optimal Level of Protection

Let us now introduce production costs by writing $N = (S, C, U)$ where C is a variable denoting production costs of 'originals' (authorised reproductions) and U a variable denoting the production cost of 'copies' (unauthorised reproductions) (we do not need to be specific here as to their form so these may be marginal costs or fixed costs or both).[9] We assume that:

(1) For any given level of protection, as the costs of 'originals' increase (decrease) production decreases (increases): $N_C < 0$. This follows from the fact that increases in cost reduce profits (revenues are constant)

(2) For any given level of protection, as the costs of 'copies' (unauthorised reproductions) increase (decrease) production increases (decreases): $N_U > 0$ (NB: the costs of 'originals' are assumed to remain unchanged). The reasoning behind this is that 'copies' compete with 'originals' and hence increases (decreases) in the cost of 'copies' raise the revenues to 'originals' (more formally, as 'copies' and 'originals' are substitutes so the cross price derivatives of demand are negative). This in turn raises profits to the owners of 'originals' and hence increases production.[10]

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function $g(S)$ with $g' > 0, g'' < 0$ and defining $N(S) = g(S), w(S) = g(S)^{1-a+\epsilon}, \epsilon \in (0, a)$ we have a setup satisfying Assumptions 1 (excluding 1.3) and 2 and with $W(S) = g(S)^{\epsilon}$ – a welfare function whose maximising level of protection is clearly infinite.
Finally note that this does *not* require that the number of works produced be infinite, for example we could have $g(S) = 1 + K - K/(1 + S)$ in which case there is a finite upper bound on the number of works produced.

[9]Note that we would usually assume that the cost of making 'copies' is itself, at least partially, a function of the level of protection. However here we prefer to keep the effect of the level of protection and of the cost of making 'copies' distinct. Thus, it is perhaps better to think of U as encapsulating copying costs as determined purely by exogenous factors such as technology.

[10]The assumption that decreases in the cost of unauthorised copying are unambiguously bad for the producers of copyrightable works is a standard one. However, there are at least two factors which operate in the opposite direction. First, 'copiers' still need to purchase 'originals' and thus producers of 'originals' may still be able to extract rents from 'copiers' by raising the price of originals much in the way that the price of a first-hand car takes account of its resale value on the second-hand market (see Liebowitz (1985)). Second, greater dissemination of a work due to unauthorized copying may lead to increase in demand for 'originals' or for complementary goods, particularly if 'copies' and 'originals' are not perfect substitutes. For a recent theoretical model see Peitz and Waelbroeck (2006). Empirical work, mainly centred on the impact of unauthorised file-sharing on music sales has, as yet, provided no decisive answer as to whether 'sampling' may outweigh 'substitution' (see, for example, the contradictory results of Oberholzer and

We also need to take account of the impact of costs on welfare. To reflect this we rewrite welfare as a function of both the level of protection *and* the level of costs: $W = W(S, C, U) = W(S, C, U, N(S, C, U))$.[11]

Lemma 7. *Take any exogenous variable X which affects the welfare function (whether directly and/or via its effect on production N). Assuming that the initial optimal level of protection, S^o, is finite, if $d^2W(S^o)/dXdS$ is positive then an increase (decrease) in the variable X implies an increase (decrease) in the optimal level of protection.*

Proof. Denote the initial optimum level of protection, where X is at its initial value, by S^o. Since we are a finite optimum we have that at S^o:

$$W'(S^o) = N_S W_N + W_S = 0 \tag{4.1}$$

$$W''(S^o) < 0 \tag{4.2}$$

Suppose, X now increases. Since $d^2W/dXdS$ is positive we must now have: $W'(S^o) > 0$. For small changes in X, $W''(S^o)$ is still negative and thus protection must increase to some $S^{o2} > S^o$ in order to have $W'(S^{2o}) = 0$; and S^{2o} is the new optimum level of protection. □

4.1. **Production Costs.** Let us consider first, what occurs is there is an increase (or conversely a decrease) in the costs of producing 'originals' with all other exogenous variables, including the cost of producing 'copies', unchanged. Substituting C for X we have:

Corollary 8. *If $d^2W(S^o)/dCdS > 0$ then an increase (decrease) in costs of 'originals' implies an increase (decrease) in the optimal level of protection.*

Given the importance of signing $d^2W/dCdS$ let us explore further by working through the differential:

Strumpf (2007) and Blackburn (2004)). Given these uncertainties, we feel it prudent to stick with the straightforward, and conservative, assumption that decreases in the cost of unauthorised copying decreases the production of creative work.

[11]Note here that total welfare depends both directly and on costs and indirectly via production. We have just discussed the indirect impact via production and we discuss the direct impact further below when signing the partial derivatives of W however it should be obvious that there is a direct impact of costs on welfare because higher (lower) production costs, whether of originals or copies, reduces (increases) producer surplus for a given work and hence reduces (increases) welfare for that work.

$$\frac{d^2W}{dCdS} = \frac{d}{dC}(N_S W_N + W_S) = N_{CS} W_N + N_S W_{NN} N_C + N_S W_{CN} + W_{SN} N_C + W_{CS}$$

Now:

(1) $W_C < 0$ – welfare declines as costs rise because higher costs for a given work mean less producer welfare, and hence less total welfare, from that work.
(2) $W_{NS} < 0$ – increasing S for a given work reduces welfare (which is why $W_S < 0$) and thus increasing the number of works increases the negative effect on total welfare.
(3) $W_{CS} \geq 0$ – the marginal effect of increasing protection declines as costs rise (remember W_S is negative).
(4) $W_{CN} \leq 0$ – increasing production costs reduces the marginal benefit of new work (as each new work provides less welfare).
(5) $N_{CS} > 0$ – the marginal impact of protection declines with lower costs.

The last inequality is the least self-evident of these. One justification for it is as follows: the level of production is a function of the level of (average) profit, π, per work: $N = g(\pi)$. With diminishing returns we would expect $g'' < 0$. Profits can be broken up into income and costs, $\pi = I - C$, with the level of protection *only* affecting income and not costs. In that case we have $N_{CS} = g''\pi_S\pi_C > 0$

Furthermore, by prior assumption or analysis we have: $W_N > 0, N_S > 0, W_{NN} < 0, N_C < 0, W_S < 0$. Thus, four of the five terms in the equation for the mixed second-order derivative for welfare are positive while one, $N_S W_{CN}$ is not.

This means, that we cannot unambiguously say whether an increase or decrease in the costs of 'originals' implies an increase or decrease in the level of protection. In some ways this is somewhat surprising. Increased costs reduces the number of works and reduces the deadweight loss per work from protection so we might expect that increasing protection would unambiguously improve welfare.

The reason this is not necessarily so is that increased costs also reduce the welfare per work and hence while the number of works falls, which increases the marginal value of a new work, the increase in costs provides a countervailing effect (W_{CN}). As a result it is possible that the reduction in welfare per work due to higher costs is so dramatic as to

outweigh all the other effects which favour an increase in term. Thus, a general statement based on theory alone is not possible.

That said, all of the reduction in welfare comes via a reduction in producer surplus due to higher costs. Hence the proportional reduction in income, and hence output, is likely to be substantially higher than the proportional reduction in welfare. As a result one would expect the effect of a reduction in output (N) to outweigh the effect of a reduction in welfare and therefore for $d^2W/dCdS$ to be negative. Formalizing this condition we have:

Proposition 9. *Assuming an initial finite optimal level of copyright, a sufficient condition for a reduction in the cost of 'originals' (leaving other variables unchanged) to imply a reduction in the strength of copyright is that an increase in costs C, results in an increase in the marginal value of new work: $\frac{d}{dC}W_N > 0$.*

4.2. **Technological Change.** Let us now introduce 'technological' change explicitly as a variable T. We shall assume that T has no direct effect on welfare but only operates through its impact on the costs of 'originals' and 'copies' (C and U), and does so by reducing both types of costs (so $C_T < 0, U_T < 0$). Thus total welfare now has the form $W(S,T) = W(S,C(T),U(T)) = W(S,C(T),U(T),N(S,C(T),U(T)))$. Substituting T for X in Lemma 7 we have:

Corollary 10. *If, at the current optimal level of protection, $d^2W/dTdS < 0$ then technological change implies a reduction in the level of copyright. Conversely if $d^2W/dTdS > 0$ then an increase in the level of copyright is required.*

Turning again to an explicit consideration of the second derivative we have:[12]

$$\frac{dW^2}{dTdS} = \frac{d}{dT}(N_S W_N + W_S) = N_{TS}W_N + N_S W_{NN} N_T + N_S W_{TN} + W_{NS}N_T + W_{TS}$$

Focusing on the effect on the output of works: $N_T = N_C C_T + N_U U_T$, the effect of technological change will be ambiguous: the first term is positive since improvements in technology reduce the costs of originals ($C_T < 0$), while the second is negative since production goes up (down) as the cost of unauthorised copying decreases (increases):

[12]Note that $N_{TS} = \frac{\partial}{\partial T}N_S = \frac{d}{dT}N_S = N_{CS}C_T + N_{US}U_T$, $W_{TN} = \frac{\partial}{\partial T}W_N = W_{CN}C_T + W_{UN}U_T$, $W_{TS} = \frac{\partial}{\partial T}W_S = W_{CS}C_T + W_{US}U_T$ etc.

$N_U > 0$. However unlike welfare, N is (easily) observable, and it seems that recent years have seen an increase in the amount of work available. Thus, let us assume $N_T > 0$. We then have:

(1) $N_{TS} < 0$ – as costs drop value of increasing protection diminishes (as the number of works is increasing).
(2) $W_{TN} > 0$ – marginal value of new work increases as T increases (a reduction in both types of costs increases welfare: $W_U, W_C < 0$).
(3) $W_{NS} < 0$ – see above.
(4) W_{TS} is ambiguous – increasing T reduces both C and U and while a reduction in the costs of 'originals' increases deadweight losses a reduction in U reduces them with the overall effect ambiguous.

Thus, we have:

$$\frac{dW^2}{dTdS} = \text{-ve} + \text{-ve} + +\text{ve} + \text{-ve} + ?$$

In many ways this is similar to the previous situation. However the ambiguities here are more pronounced. In particular, one term can not be signed unambiguously from theory alone (W_{TS}) and it is less likely that the 'contrary' term here, $N_S W_{TN}$, will be small relative to the others. The key trade-off then is similar to the one discussed above.

On the one hand technological change reduces costs and thereby increases output which diminishes the value of new work (implying a reduction in copyright). However, at the same time, by reducing costs technological change increases the value of new work. These two effects operate in opposite directions and it is not a priori clear which will be the stronger. Again one might argue that the proportional increase in incomes for producers is likely to be at least as large as the increase in welfare and hence the increase in output will more than offset the impact on welfare per work. However, one must be cautious here because technological change may also reduce deadweight losses via a reduction in the cost of unauthorised copying and overall it would seem impossible to draw unambiguous conclusions from theory alone.

4.3. **Discussion.** Examples of cost-reducing technological change are ubiquitous in recent years arising, in the main, from the move to a digital environment. As discussed, focusing

on the case of 'originals' alone, it seems likely that such changes would imply a reduction in the optimal level of copyright. However, this gives only half the story – technological change is likely to reduce the costs of both 'originals' and 'copies' at the same time. While it is unclear whether technological advance has reduced the costs of one faster than the other – the reductions in both cases seem dramatic – it appears that the overall level of output has risen. Using this fact, we examined whether optimal term should rise or fall as technological progress reduces costs. While based on theory alone, it was not possible for an unambiguous answer to be given, we were able to characterise (and sign) most of the main factors impacting on welfare.

This ambiguous result is not surprising given the contrary effects at play. Furthermore our work highlights the key terms in need of empirical estimation in order to obtain an unambiguous conclusion regarding the implications of technological change for copyright.[13] We also think it important in demonstrating that care must be taken when drawing 'obvious' conclusions for copyright policy from changes in the external environment. Much of the motivation for strengthening copyright in recent years, whether by extending term or by the addition of legal support for technological protection measures (TPMs) – as in the WIPO Copyright Treaty of 1996 and its subsequent translation into national laws such as the DMCA (1998) and the EUCD (2001) – has been based on the implicit assumption that the move to a digital environment necessitated an increase in the strength of copyright because technological change made unauthorised copying ('piracy') easier. But focusing only on the reduction in the costs of unauthorised copies ignores the impact of technology on authorised production and distribution. As we have shown, such an approach omits a major part of the overall picture and may lead to erroneous conclusions regarding both the necessity and direction of policy changes.

5. Optimal Copyright in a Dynamic Setting

Our previous analysis has dealt only with a static setting in which all production could be aggregated into a single figure, N. In this section we will need to enrich this basic approach by introducing 'time'. To do this let us define n_t as the number of works produced

[13] This is very similar to situation regarding copyright term. There too theory cannot tell us what level of term is optimal but can help us pinpoint the key variables in need of empirical estimation.

in time period t and N_t as the number of works available to society in period t.[14] N_t will be the 'real' or 'effective' amount of work available, that is it takes account of cultural depreciation and obsolescence – which represent the fact that many works are 'of their time' and are, or at least appear to be, of little value to future generations. Specifically we expect N_t not to be the absolute amount of past and present work available but rather an 'equivalent' amount denominated in the same terms as n_t. Formally, if we let $b(i)$ be the 'rate of cultural decay' after i time periods ($b(0) = 1$), then the 'effective' amount of work in period T is the sum of the production of all previous periods appropriately weighted by the level of cultural decay:

$$N_t = \sum_{i=0}^{\infty} b(i) n_{t-i}$$

Then total welfare calculated at time t is:

$$W_t^{Tot}(S) = \sum_{i=0}^{\infty} d(i) W(N_{t+i}(S), S)$$

We shall assume this is single-peaked and differentiable (so the first-order condition is necessary and sufficient).[15]

[14]Both numbers will have the same set of arguments as the static N we had before so we will have $n_t = n_t(S, C)$, $N_t = N_t(S, C)$ though note that if the arguments can vary over time then the arguments would have be modified appropriately (those to n would need to include future values and those for N both past and future values).

[15]This dynamic problem has substantial similarities with the standard optimal control problems of dynamic growth models. Specifically, let $b(i)$ takes a standard exponential form $b(i) = \beta^i$ and allow S to be set anew each time period (it can then take the role of a standard control variable). Then:

$$\begin{aligned} N_t &= \beta N_{t-1} + n_t \\ n_t &= f(S_t, S_{t+1}, ..., N_t, N_{t+1}, ...) \\ W_t &= W(N_t, S_t) \\ W_t^{Tot} &= W_t + \beta \sum_{i=0}^{\infty} \beta^i W_{t+1+i} = W_t + \beta W_{t+1}^{Tot} \end{aligned}$$

Then, comparing to growth models, N_t is K_t (capital), n_t is Y_t (production), S_t is c_t (the control variable – usually consumption), W_t is $U(c_t)$ (utility from consumption) and W_t^{Tot} is the value function (overall welfare). Of course our setup is more complex than the standard growth framework since output (the number for works produced) depends not just on current values for the control variable but on future values of the control variable and future levels of output (this is because creative works are durable).
We note that these sorts of problems have been extensively analyzed – see Stokey, Robert E., and Prescott (1989) for a mathematical survey – and while it is relatively straightforward to ensure the existence of an equilibrium it is hard to state any general results about the time paths of the state and control variables (see e.g. the 'anything goes' result of Boldrin and Montrucchio (Stokey, Robert E., and Prescott, 1989, Thm 6.1) which demonstrates that any twice-differentiable function g can be obtained as the policy function of a particular optimal dynamic growth problem).

Theorem 11. *Assume that at time $t = 0$ production is approximately zero (this could be for several reasons the most obvious being that this type of work only comes into existence at this point, e.g. film around 1900, sound recordings in late 19th century). Then, assuming that sequence of works produced per year, n_i is such that $N(t) = \sum_{i=0}^{t} b(t-i)n_i$ is non-decreasing, optimal protection declines over time asymtoting towards what we term the 'steady-state' level.*

Proof. We first provide an informal justification for this result before turning to a formal, mathematical, 'proof'.

No works are produced before time zero so, as time increases, the backlog of work will grow. As the backlog grows a) the value of producing new work falls and b) the welfare losses from increased protection are levied not just on new works but on the backlog as well.

To illustrate consider the situation with respect to books, music, or film. Today, a man could spend a lifetime simply reading the greats of the nineteenth century, watching the classic movies of Hollywood's (and Europe's) golden age or listening to music recorded before 1965. This does not mean new work isn't valuable but it surely means it is less valuable from a welfare point of view than it was when these media had first sprung into existence. Furthermore, if we increase protection we not only restrict access to works of the future but also to those of the past.

As a result the optimal level of protection must be lower than it was initially in fact it must fall gradually over time as our store of the creative work of past generations gradually accumulates to its long-term level. We now turn to the formal argument.

Optimal protection, S^t, at time t solves:

$$\max_S W_t^{Tot}(S)$$

The first-order condition is:

$$\frac{dW_t^{Tot}(S^t)}{dS} = 0$$

Thus, here we restrict to the case where the control variable may only be set once (S is given forever) and we also assume, when stating our result, that the time path of the number of works ('capital') is non-decreasing – a result obtained in many, though not all, growth models and which, in the case of copyright, appears to fit well with the available data.

Consider this at time t then:

$$\sum_{i=0}^{\infty} d(i) \frac{dW(N_{i+t}(S^t), S^t)}{dS} = 0$$

Recall that $\frac{\partial}{\partial N}\frac{dW}{dS} < 0$ (the marginal value of protection goes down as the number of works increases and the total deadweight loss increases) so that, if $N^1 > N^2$:

$$\frac{dW(N^1, S)}{dS} < \frac{dW(N^2, S)}{dS}$$

Now, by assumption on the structure of n_i, $\forall i, N_{i+t+1} > N_{i+t}$. Thus, we must have:

$$\frac{dW_{t+1}^{Tot}(S^t)}{dS} = \sum_{i=0}^{\infty} d(i) \frac{dW(N_{i+t+1}(S^t), S^t)}{dS} < \sum_{i=0}^{\infty} d(i) \frac{dW(N_{i+t}(S^t), S^t)}{dS} = \frac{dW_t^{Tot}(S^t)}{dS} = 0$$

So we have that:

$$\frac{dW_{t+1}^{Tot}(S^t)}{dS} < 0$$

Since W^{Tot} is single-peaked this implies that the level of protection which maximizes W_{t+1}^{Tot} must be smaller than S^t. That is the optimal level of protection at $t+1, S^{t+1}$, is lower than the optimal level of protection at t, S^t.

Finally, we show that the optimal level of protection will tend to what we term the steady-state level. We have just proved that S^t is a declining sequence. Since values for S are bounded below by 0 by Bolzano-Weierstrass we immediately have that the sequence must converge to a unique $S = S^{\infty}$. By analogous arguments associated with this 'steady-state' level of protection will be a steady-state level of output per period n^{∞} and effective number of works N^{∞}.

□

5.1. **Remarks.** The preceding result has important implications for policy. In most systems of law, it is extremely difficult to remove or diminish rights once they have been granted. Thus, in most circumstances, once a given level of protection has been granted it will be all but impossible to reduce it. However, according to the preceding result, in general the optimal level of protection will decline over time.

In many ways this is a classic 'dynamic inconsistency' result: the preferences of a welfare-maximizing policy-maker at time zero are different from those at some future point T.[16] Furthermore, it is clear that no particular point in time has any more validity over any other point as regards being chosen as a reference point. Moreover, from the perspective of any given point in time the ability to 'commit' to a given level of protection may be very valuable.[17] That said the result is still important for two reasons.

First, whether because of a paucity of data or disagreement about the form of the model, there is frequently significant uncertainty about the optimal level of protection. But one thing we do know from the preceding result is that, whatever optimal level of protection currently, it will be lower in the future. Combined with the asymmetry in decision-making already mentioned – namely, that it is much harder to reduce protection than to extend it – this implies it is prudent for policy-makers to err on the low side rather than the high side when setting the strength of copyright.

Second, and more significantly this result provokes the question: if optimal protection should decline over time why does the history of copyright consists almost entirely of the opposite, that is to say, repeated increases in the level of protection over time (duration, for example, has been increased substantially in most jurisdictions since copyright was first introduced[18]). After all, while one can argue that for 'commitment' reasons a policy-maker would not reduce the level of protection over time, our result certainly runs counter to the repeated increases in protection, many of which have taken place in recent years (when the stock of copyrightable works was already large).

The obvious answer to this conundrum is that the level of protection is not usually determined by a benevolent and rational policy-maker but rather by lobbying. This results in policy being set to favour those able to lobby effectively – usually groups who are actual, or prospective, owners of a substantial set of valuable copyrights – rather than to produce any level of protection that would be optimal for society as a whole. Furthermore, on

[16]However we should note some important differences. In the classic case of dynamic inconsistency, even at stage two (in a two-stage game) the policy-maker would have preferred to have been able to commit at stage one (to a different policy). By contrast here the policy-maker at stage two simply has a different optimum policy than at stage one – i.e. the stage two policy (which includes specifying action at at all stages including previous ones) is optimal from the point of view of stage two but is not optimal from the point of view of stage one (and vice-versa).

[17]It is precisely concerns over the ability of a policy-maker to credibly commit to a particular macroeconomic target that animates many of the traditional models of dynamic inconsistency.

[18]Most prominently in recent times in the United States in 1998 and in the EU in 1995.

this logic, extensions will be obtained precisely when copyright in existing, and valuable, material is about to expire. In this regard it is interesting to recall that many forms of copyrightable subject matter are of relatively recent origin. For example, the film and recording industry are only just over a hundred years old with the majority of material, in both cases, produced within the last fifty years. In such circumstances, and with copyright terms around 50 years, it perhaps not surprising that the last decade has seen such a flurry of extensions and associated rent-seeking activities.

6. Conclusion

In this paper we have developed a simple framework for analysing copyright grounded in the existing literature. Using it, we obtained two sets of separate, but complementary, results. In the first section, we investigated the effect of changing production costs on the optimal level of copyright. We demonstrated in substantial generality that (a) optimal protection is likely to fall with a decline in the costs of production and distribution of 'originals' (b) in contrast to the presumption of some existing policy making, technological change which decreases costs, because it effects both 'originals' and 'copies' may imply a decrease as well an increase in optimal copyright.

In the second section we examined how the level of optimal protection varies over time. Making the reasonable assumption that the stock of 'effective' work is non-decreasing we showed that the level of optimal copyright falls over time. This section was also noteworthy for its introduction of a formal approach to 'cultural decay'. This is the first time to our knowledge that this aspect of copyright has been incorporated into a formal model and, as demonstrated, it is central to understanding copyright dynamics.

All our results have significant implications for policy. In recent times technological change has substantially reduced the costs of production and distribution of most copyrightable goods. Much of the existing policy discussion has focused, almost exclusively, on reductions in the costs of 'unauthorised' ('pirate') copies and has tended to assume that this necessitates an increase in the level of protection. However, as we pointed out, the costs of 'originals' have also fallen dramatically, and this change is likely to require a *reduction* in the strength of protection. Looking more generally at the case of technological change which reduces the production costs of both 'originals' and 'copies', the

implications for copyright policy were ambiguous – not surprising given the two contrary effects at play – and we highlighted the key terms in need of empirical estimation if an unambiguous answer were to be obtained.

Finally, there remains plentiful scope to extend and build upon the work here. In particular, there is room for further empirical work on all aspects of these results. For example, it would be valuable to calibrate the production costs model to investigate what changes in the level of copyright would be implied by the recent reductions in the cost of production and distribution. Similar work could be done in relation to changes of copyright over time where one would need to collect data on the level of production and the form of the welfare function.

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