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Essays On The Economics Of Intellectual Property Protection

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Preface

This thesis consists of an introductory chapter and four essays. The first essay has been published in *Journal of Economics* and is reprinted here by the permission of Springer-Verlag. The third essay, written together with Vesa Kanniainen (University of Helsinki), has been accepted for publication in *International Journal of Industrial Organization* and appears here with the permission of Elsewier Science. The fourth essay is a joint work with Klaus Kultti (Helsinki School of Economics and Business Administration). Section 7 of this essay draws heavily on our article in *Economics Letters* and is used here with the permission of Elsewier Science.

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The Economics of Intellectual Property Protection: An Overview

1 Introduction

Technological progress depends on the diffusion of new technologies through imitation as much as through invention. The welfare effects of the dissemination of knowledge through imitation have been a topic of interest at least since Plato. In the last pages of Plato's *Philebus* there is a dialogue which gives some sense of the issue at stake. Socrates and Protachos try to see whether imitation should be included in the socially optimal ‘mixture’ of knowledge. Plato assumes that learning and imitation is ‘harmless’ and, as well-known, in the Platonic economy genuine invention is impossible because the basic ideas are eternal. The conclusion in *Philebus* that all skills and knowledge achieved through imitation are socially desirable is therefore hardly surprising:

> ‘..what harm it can do a man to take in all the other kinds of knowledge (through imitation) if he has the first (the eternal ideas).’ (Plato *Philebus*, 62D, parentheses added)

But Plato merely observes the benefits of imitation. The cost side is explained by Jeremy Bentham:

> ‘He who has no hope that he shall reap, will not take the trouble to sow. But that which one man has invented, all the world can imitate.’ (Jeremy Bentham *The Works of Jeremy Bentham*, 1843, vol. 3, p. 71)

Adding this undesirable impact of imitation on the incentive to innovate and the imitation cost into Plato’s model, it seems that the socially acceptable degree of imitation should be restricted.

Overlooking the appropriability problems associated with knowledge spillovers, the analysis in *Philebus* sounds trivial, but evaluating it in historical perspective is difficult for a non-specialist. In a fascinating historical inquiry, Long (1991) finds but little evidence of the undesirable impact of imitation on innovation in antiquity. Knowledge spillovers were not considered a problem until the rise of capitalism early this millennium. In consequence, the development of the institutions to protect intellectual property, particularly the patent system, is *unrelated* to the development of inventive activity directly. Inventive activity is an inherent characteristic of the human being, and most major innovations had been made well before legal protection of intellectual property became known.[1] Only when inventors began regarding their inventions as a property did they begin seeking protection for it.

The development of the legislation to protect intellectual property is therefore related to the evolution of proprietary attitudes toward intellectual output. Long (1991) emphasises the role of medieval craft guilds in promoting these attitudes, the main purposes of the guilds including the maintenance of secrecy concerning the craft techniques. This change in attitudes towards new technology finally led to a novel institutional arrangement to protect intellectual property. The practice of granting a privilege, a patent, for the possession of new devices or knowledge dates back to 13th century Europe. The Venetian Senate passed the first general patent law codifying a common practice on March 19, 1474.

The importance of this development can hardly be underestimated. In accordance with Ronald Coase's (1960) famous hypothesis, if there are transaction costs, the institutional arrangements matter. Inventive work and the protection of its results necessitate transaction costs, and the patent institution did matter:

> 'The development of an incentive structure through patent laws, trade secret laws, and other laws raised the rate of return on innovation and also led to the development of the inventive industry and its integration into the way economies evolved in the Western world in modern times, which in turn underlay the Second Economic Revolution' (Douglas C. North *Institutions, Institutional Change and Economic Performance,* 1990, p.75)

The economic underpinning of intellectual property protection is simple. Despite the short-run welfare losses, to encourage inventive effort government should grant inventors,

> 'in a case of their success, a monopoly of the trade for a certain number of years. It is the easiest and most natural way in which the state can recompense them for hazarding a dangerous and expensive experiment, of which the public is afterwards to reap the benefit.' (Adam Smith *Inquiry into the Nature and Causes of the Wealth of Nations*, 1904 (originally published in 1776), Book V, pp. 277–278)

The fundamental problem in the economics of intellectual property protection is the public good aspect of inventive output. On the one hand, intellectual property does not wear out and it is thus wasteful to restrict its use. On the other hand, without the protection of intellectual property, inventors cannot fully appropriate the return on their work, and, in consequence, there is too little innovation in the economy. This dilemma of Scylla and Charybdis also underlies this dissertation. Accepting that market failure in creating intellectual property rights justifies government intervention raises the question of how intellectual property should be protected and how long.

Beside this normative aspect of intellectual property protection, the essays in this dissertation aim to contribute to the positive analysis by investigating how the existing means of protection influence the supply and diffusion of innovation. In practice, there are myriad devices to appropriate inventive returns. The legal pro-

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[1] According to Niiniluoto (1994) the most welfare-increasing innovation of all time is the ability to write, since it has enabled unprecedented *diffusion* of knowledge. Other such major innovations include agriculture, fire and the wheel.

tection of intellectual property has been traditionally divided into two main branches. *Industrial property protection* deals principally with industrial designs, patents, trademarks and service marks, trade secrets, and appellations of origin. *Copyright protection* usually applies to artistic, audiovisual, literary, musical, and photographic works. In addition to legal protection, other instruments including lead-time, research joint ventures, and secrecy can provide substantial protection for innovators. The emphasis of this dissertation is not only on patent protection, but copyright protection, research joint ventures, and secrecy are also considered.

In the following section of this introductory chapter the assumptions of the four core essays and some central findings of the literature are spelled out in more detail. The discussion does not to pretend to be a thorough review of the literature, as there are several extensive surveys such as Kaufer (1989), Besen and Raskind (1991), De Bondt (1996), Lanjouw and Lerner (1997), Lanjouw, Pakes and Putnam (1998) and Veugelers (1998) on various aspects of intellectual property protection. The contents and main findings of the essays are summarised in section 3. Some concluding remarks can be found in section 4.

2 The Economic Analysis of Intellectual Property Rights

Joseph A. Schumpeter says of Jeremy Bentham's entrepreneur theory that:

> 'It is a curious fact (curious, that is, considering the tremendous influence that Bentham exerted in other respects) that his views on this subject—which were not fully given to the public until the posthumous publication of his collected works—remained almost unnoticed by professional economists' (Schumpeter, 1949, p. 64)

Curiously enough, exactly the same can be said about Bentham's patent theory. The theory is developed in full length in his *Manual of Political Economy*, which was completed by 1795, in a section entitled 'Of patents or exclusive privileges for inventions, and the expediency of granting them'.[2] The analysis encapsulates practically all relevant economic aspects of patent protection:

i) The dynamic inefficiency associated with large knowledge spillovers
ii) The static inefficiency associated with small knowledge spillovers
iii) The innovator's choice between secrecy and patents as a protection instrument
iv) The comparison between patents and prizes as instruments of technology policy

[2] Cheung (1986) led me to observe Jeremy Bentham's contribution to this issue. However, Cheung (1986) exclusively refers to *the Works of Jeremy Bentham* in which patents are mentioned only in passing. Moreover, William Stark, the editor of *Jeremy Bentham's Economic Writings* (1952), argues that *the Works of Jeremy Bentham* is an unreliable source, especially as far as *Manual of Political Economy* is considered.

Bentham's theory is especially advanced in the first point, since he clearly describes the necessity for intellectual property protection to encourage innovation. In addition to Bentham, some other early writers such as J. B. Say (1827), John Stuart Mill (1848) and J. B. Clark (1907) held positive views on the legal protection of intellectual property. F. W. Taussig (1915), however, argues that 'the patent system...is a huge mistake' (Taussig, 1915, p. 18). This conclusion is wholeheartedly supported by A. C. Pigou (1920) and A. Plant (1934a), Plant (1934b) extending the argument to apply to copyright protection. Plant (1934a) even asks whether the patent system is partly responsible for the Great Depression of the 30s.

Despite these exceptions, the study of economic consequences of intellectual property rights did not take off, however. One reason was surely that the process by which innovation influences economic growth was poorly understood before Schumpeter (1911),[3] and even so, some influential empirical studies such as Abramowitz (1956) and Solow (1957) were required to make the economists fully grasp the significance of technological progress in economic growth. Research on innovation subsequently exploded. Considerable effort was directed towards the hypothesis derived from the works of Schumpeter (1942) and Galbraith (1952) that monopolies and big companies are conducive to innovation. This proposition can be broken down into a number of more precise hypotheses including the one predicting that a properly designed system of intellectual property rights increases social welfare by boosting innovation.

Early studies including Arrow (1962) and Usher (1964) describe how the incentive to innovate deteriorates with an increasing level of knowledge spillovers. William Nordhaus (1969) was the first to offer a rigorous model explaining the fundamental trade-off between static and dynamic considerations in designing patent policy: if one wants to spur innovative activity, it is possible only at the expense of the competition. Since Nordhaus's seminal works (1969) and (1972) there has been extensive research on patent protection and its consequences for social welfare. This theoretical literature on patents can loosely be divided into two main strands. These strands are not independent or exhaustive, and do overlap, but they have been chosen for pragmatic reasons. The first, in which the studies by Nordhaus belong, deals with the effects of patents on post-innovation market structure. The focus in this Nordhausian tradition is on the socially optimal term and scope of patent protection, even though other policy issues such as optimal renewal fees and novelty criterion have also recently been taken into closer consideration. These issues are enlarged upon especially in section 2.1 but also to some extent in sections 2.2–2.3.

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[3] As Dasgupta (1988) points out, Schumpeter did not make much advance over Karl Marx on this point. Nonetheless, Schumpeter gave innovation a different weight to Marx, who highlighted capital accumulation. In any case, neither Marx nor Schumpeter developed a theory of intellectual property protection. Given that Schumpeter explicitly glorifies *innovation* at the expense of *invention* (see, e.g. Schumpeter, 1911, p. 178, Schumpeter, 1934, pp. 88-89, Schumpeter, 1947, and Schumpeter, 1954, p. 556) it is quite understandable that he mentions patents and other intellectual property rights only in passing (see e.g. Schumpeter, 1942, p. 88 and pp. 102-103, Schumpeter, 1947, and Schumpeter, 1949). As to Marx, it is clear to me only that he had no illusions about perfect patent protection. He maintains in *Lohnarbeit und Kapital* (1849) that since competition quickly destroys monopolies for new methods and devices, a capitalist must try to beat competitors by employing newer and newer machines.

The second strand considers the impact of patents on the supply of innovation. Briefly, during the 70s the economists, notably Morton Kamien and Nancy Schwartz,[4] introduced a stochastic payoff structure with many technically convenient properties, the Poisson distribution, into the analysis of innovation. Kamien and Schwartz (1974a) almost immediately adapted this to the study of patent policy, but only when this was organised in terms of game theoretical principles by Loury's (1979), Lee and Wilde's (1980), Dasgupta and Stigliz's (1980), and Reinganum's (1981a) subsequent contributions, did the second programme began to dominate research. This so-called patent-race literature is surveyed by Beath, Katsoulacos and Ulph (1989), Reinganum (1989) and Martin (1993). With some notable exceptions such as Kamien and Schwartz (1974a), Reinganum (1982) and Delbono and Denicolò (1991), however, the role of patents in the patent-race literature is somewhat degenerate. The 'winner takes all' assumption dominates, that is, patent protection is assumed to be perfect. During the 90s, research has again mainly been conducted in the spirit of Nordhaus, helping to focus more attention on the role of patents.

In an excellent paper Denicolò (1996) reconciles these two strands. He demonstrates within a unified framework that seemingly contradictory results in different approaches, including Tandon (1982), Gilbert and Shapiro (1990), Klemperer (1990), and Gallini (1992), are caused by the dissimilar influences of patent breadth on social welfare and post-innovation profits in these models. Denicolò's (1996) findings clearly deserve careful consideration, and they are assessed in detail in the following section.

While a majority of the economists now adhere to the prevailing systems protecting intellectual property, the claim in Taussig (1915), Pigou (1920) and Plant (1934a, 1934b) that such protection is detrimental to social welfare still persists. Several modern writers such as Barzel (1968), Loury (1979), and Lee and Wilde (1980) argue that competition between potential innovators under perfect patent protection leads to excessive inventive effort. This argument is addressed in the general equilibrium of an economy with imperfect intellectual property protection in the second essay of the thesis.

The prospects for welfare-improving patent policy can also be restricted by the innovator's option of keeping the innovation secret. As J. B. Say explains *un brevet d'invention*:

> 'C'est une récompense que le gouvernment accorde aux dépens des consommateurs de nouveau produit; et...cette récompense est souvent trés-considérable.' (J. B. Say *Traité d'economie politique*, 1827, vol. 1, p. 279).

There is little to add to this explanation. Patents and other forms of legal protection must enable the innovator to extract sufficiently large gains from consumers to make them profitable to apply for, and nothing guarantees that the reward making application profitable is not too great from the social welfare point of view.

While there is a considerable literature on the patent institution, economists should recognise the variety of the legislation to protect intellectual property including other industrial property protection and copyright protection. Some economic aspects of copyright and some other instruments of protection are briefly

[4] See Kamien and Schwartz (1972) for their pioneering contribution and Kamien and Schwartz (1982) for a summary of their work in this area.

summarised in section 2.2. Section 2.3 contains an introduction to secrecy as an alternative means of protection, as one of the main themes in the essays is the innovators' decision to apply for patent protection instead of keeping innovations secret, and its implications for patent policy.

2.1 Socially Optimal Patent Length and Breadth

Nordhaus's (1969) question is simply how long should a patent grant stay in force? The policy-makers' problem is to fine-tune the term of patent protection in order to balance the static and dynamic inefficiencies optimally. To begin the discussion, consider an inventor with a strictly convex cost function

$$C(\alpha) = \frac{1}{2}R\alpha^2, \qquad (1)$$

where parameter R reflects the exogenous efficiency of the existing invention technology. It is assumed that R is large enough that in all circumstances $\alpha \leq 1$ and, accordingly, α can be regarded as the success probability of the invention. For simplicity, I work directly with α instead of treating investment level as a decision variable. With success the inventor accrues monopoly profits π^m during the life of patent, and some competitive return $\overline{\pi}$ after the patent expires and the innovation becomes available to everyone. If imitation or entry to the industry is costly after the patent expires, $\overline{\pi} > 0$. The legal duration of patent protection, often referred to simply as *patent length*, is denoted by T. The inventor's return on successful inventive effort is thus

$$P(T) = \int_0^T e^{-rt}\pi^m dt + \int_T^\infty e^{-rt}\overline{\pi} dt, \qquad (2)$$

and the inventor's problem is thus to choose α so as to maximise

$$\alpha P - \frac{1}{2}R\alpha^2.$$

The solution is

$$\alpha = \frac{P}{R}. \qquad (3)$$

Equation (3) exhibits the classical rationale for intellectual property protection – the investments in innovation increase with the duration of protection, that is, $d\alpha/dT>0$. Similarly the social return on inventive effort is given by

$$S(T) = \int_0^T e^{-rt}W^m dt + \int_T^\infty e^{-rt}\overline{W} dt, \qquad (4)$$

where W^m and $\overline{W}$ depict social welfare as the total of consumer surplus and industry profits when the patent is in force and after it expires. The essential distinction between the private and social return on innovation can be seen by contrasting (4) with (2). The private return P increases while the social return S decreases with the term of protection T. The social planner's task is then to

$$\max_{T} \alpha S - \frac{1}{2} R\alpha^2 ,$$

subject to (3). The first-order condition is

$$\alpha_T S = \alpha(R\alpha_T - S_T), \qquad (5)$$

in which the subscripts denote the derivatives. The trade-off between the static and dynamic considerations facing the policy-makers can now clearly be observed in (5), which simply shows that optimal patent life equalises the marginal dynamic gain of prolonged protection with the marginal static loss. In other words, the left-hand side of equation (5) explains how an increase in patent life encourages inventive endeavours, but after the innovation is made, consumers are worse off because inventor's monopoly lasts longer, as conveyed by the last term on the right-hand side. Notice that the increased R&D expenses due to the accelerated innovative effort must also be counted in the welfare losses; this effect is depicted by the term $\alpha R\alpha_T$ on the right-hand side.

Nordhaus's seminal model outlined above provides a simple description of the patent system in its original purpose, that is, when a patent affords complete but temporary protection over an invention. The pertinence of this view is, however, much in doubt. Since the pioneering study by Mansfield (1961), researchers have reported overwhelming evidence of the inability of patent protection to prevent imitation with a few exceptions such as the pharmaceutical industry.[5] In a controversy with Scherer (1972), Nordhaus (1972) extends his model to allow imperfect patent protection. In other words, Nordhaus (1972) formalises the concept of *patent breadth*.

While the notion of patent length is indisputable, the meaning of patent breadth, or patent width, is relatively vague. The width of the patent grant measures the degree of the patent protection. If patents are narrow, a patent is easy to 'invent around', that is, it is easy to produce a non-infringing substitute for the patented invention. An extremely narrow patent does not protect even against trivial changes such as changes in colour. This kind of description is too loose to provide an unambiguous ground for the modelling attempts, and the definition of patent breadth in the literature varies from one author to another. Nordhaus's (1972) pioneering model deals with process innovations, and he measures patent breadth by the fraction of the cost reduction not freely spilling over to competitors. In Klemperer's (1990) and Waterson's (1990) product innovation models, patent breadth reflects the distance in the product space between the patented product and the nearest non-infringing substitute. In a similar vein, Matutes, Regibeau and Rockett (1996) define patent breadth by the number of different applications protected by the same patent grant.

The simplest definitions of patent width are provided in Gilbert and Shapiro (1990) and Gallini (1992). In Gallini (1992), the width of the patent is equivalent to

[5] Other empirical studies on the rate of imitation include Mansfield, Schwartz, and Wagner (1981), Mansfield (1985, 1986, 1993), Levin, Klevorick, Nelson and Winter (1987), Harabi (1995), and Arundal and Kabla (1998).

an increase in imitation costs caused by patent protection. Such a view is supported by the much-cited queries by Mansfield, Schwartz and Wagner (1981) and Levin, Klevorick, Nelson and Winter (1987). Gilbert and Shapiro (1990) simply identify the patent breadth with the innovator's profit while the patent is in force. In doing so, their analysis also encompasses Tandon's (1982) investigation of the compulsory licensing of patented innovations, because compulsory licensing simply reduces the patentee's profits by facilitating imitation. The compulsory royalty rate, the patent holder's profit with compulsory licensing, can thus be equated with the patent width.

Ambiguous assumptions often lead to ambiguous outcomes, the issue of the socially optimal patent length-breadth mix being no exception. Sometimes the optimal patent has maximum length and minimum breadth, as in Tandon (1982) and Gilbert and Shapiro (1990), sometimes the result is the reverse, as in Gallini (1992), and sometimes the length-breadth mix makes no difference, as in Nordhaus (1972). As if to summarise, Klemperer (1990) provides examples of all these results. Fortunately, Denicolò (1996) establishes a general conclusion about the shape of optimal patent policy, which explains how the seemingly contradictory findings above are explained by the dissimilar effects of the patent breadth on social welfare and post-innovation market structure in these models. In the sequel, I call this general conclusion, i.e. Proposition 1 in Denicolò (1996), *Denicolò's patent theorem*.

Like Denicolò (1996), we can generalise the notion of patent breadth by assuming that the inventor's profit and social welfare are its functions. Let w denote the width of the patent grant. The innovator's profit after successful innovation $\pi(w)$ then depends on patent breadth so that $\pi(1) = \pi^m$ and $\pi(0) = \overline{\pi}$. Similarly, $W(w)$ denotes static social welfare as a function of patent breadth so that $W(1) = W^m$ and $W(0) = \overline{W}$. The strain caused by the static and dynamic inefficiencies manifests itself in the contrary effects of the patent breadth on social welfare and the innovator's profit, i.e. $W'(w)<0$ and $\pi'(w)>0$.

The private and social returns on innovation can now be rewritten as

$$P(T,w) = \int_0^T e^{-rt}\pi(w)dt + \int_T^\infty e^{-rt}\overline{\pi}dt \tag{6}$$

and

$$S(T,w) = \int_0^T e^{-rt}W(w)dt + \int_T^\infty e^{-rt}\overline{W}dt\ . \tag{7}$$

In designing the optimal patent, both length and width have usually been chosen so as to maximise the social utility from existing innovation, constraining the supply of innovation to a predetermined level. In other words, the social planner's problem is to maximise S with respect to T and w, maintaining α as a constant. The first-order condition for the inventor's problem is now re-expressed as

$$\alpha = \frac{P(T,w)}{R}\ . \tag{8}$$

Let $T(w)$ be the patent length which maintains innovation activity at the required level defined by equation (8), and let the term $\underline{T}$ denote the value of T solving equation (8) for perfect patent protection w=1. Similarly, $\underline{w}$ denotes the value of w solving equation (8) when T approaches infinity. To keep the subsequent discussion interesting, the minimum values $\underline{T}$ and $\underline{w}$ are assumed to exist, and to be positive and finite. Differentiating (8) yields

$$\frac{dT}{dw} = -\frac{P_w}{P_T} < 0. \tag{9}$$

According to (8) the policy tools are *substitutes* with regard to innovation, or as Nordhaus (1972), p. 430 says it: 'if breadth is reduced the optimal life must increase to compensate'. The social value of an existing innovation is now $S(w, T(w))$. Take the total differential of $S(w, T(w))$ with respect to w to obtain

$$\frac{dS}{dw} = -\frac{P_w}{P_T} S_T + S_w . \tag{10}$$

Let ε_{ik}, $i \in (P, S)$, $k \in (w, T)$, measure the elasticity of the private and social values of innovation in respect of the policy variables. For example, $\varepsilon_{Pw} = \frac{d \ln P}{d \ln w}$.

PROPOSITION 1. The optimal patent policy is determined by the following three conditions:

i) If patent length has a relatively large impact on the incentive to innovate, i.e. $-\frac{\varepsilon_{Pw}}{\varepsilon_{Sw}} < -\frac{\varepsilon_{PT}}{\varepsilon_{ST}}$ holds, the optimal patent has minimum breadth and maximum length, i.e. $w=\underline{w}$ and $T=\infty$.

ii) If patent breadth has relatively large impact on the incentive to innovate, i.e. $-\frac{\varepsilon_{Pw}}{\varepsilon_{Sw}} > -\frac{\varepsilon_{PT}}{\varepsilon_{ST}}$ holds, the optimal patent has maximum breadth and minimum length, i.e. w=1 and $T=\underline{T}$.

iii) If the relative impacts of patent breadth and length are equal, i.e. $-\frac{\varepsilon_{Pw}}{\varepsilon_{Sw}} = -\frac{\varepsilon_{PT}}{\varepsilon_{ST}}$ holds, social welfare is independent of the combination of patent breadth and length.

Proof: When (10) is positive, the optimal patent should have maximum breadth and minimum length. When (10) is negative, the opposite holds. If (10) is equal to nought, social welfare is independent of the breadth-length mix. It is easy to demonstrate that

$$-\frac{P_w}{P_T} S_T + S_w \begin{matrix} > \\ = \\ < \end{matrix} 0$$

equals

$$-\frac{\varepsilon_{Pw}}{\varepsilon_{Sw}} \begin{smallmatrix}>\\=\\<\end{smallmatrix} -\frac{\varepsilon_{PT}}{\varepsilon_{ST}}.$$

QED

This outcome is easy to explain. When an increase in patent width curbs post-innovation social welfare relatively more and accelerates innovative activity relatively less than an increase in patent life, it is desirable to make patents as narrow as possible by prolonging patent life correspondingly. This leaves the incentive to innovate unaltered but expands static social welfare. However, if patent width stimulates investment in innovation relatively more than patent length while reducing the post-innovation welfare relatively less, as short a patent life as possible is socially optimal.

One should now proceed to show that in Gilbert and Shapiro (1990) it holds that $-\varepsilon_{Pw}/\varepsilon_{Sw} < -\varepsilon_{PT}/\varepsilon_{ST}$, and in Gallini (1992) $-\varepsilon_{Pw}/\varepsilon_{Sw} > -\varepsilon_{PT}/\varepsilon_{ST}$, but this is an unchallenging exercise, the work having been done by Denicolò (1996), who demonstrates how the findings in different models such as Tandon (1982), Gilbert and Shapiro (1990), Klemperer (1990), and Gallini (1992) follow from his theorem. It is thus reasonable to try to establish a link between Proposition 1 and Denicolò's patent theorem. Such a link quickly follows upon the introduction of $D(w)=\overline{W}-W(w)$ as the static dead-weight loss assigned to the patent protection, and $I(w)=\pi(w)-\overline{\pi}$ as a measure of the relative incentive to innovate.

COROLLARY 1. *Denicolò's patent theorem* (Denicolò, 1996). The optimal patent policy is determined by the following three conditions:

i) If both static social welfare $S(w)$ and relative incentive to innovate $I(w)$ are convex in patent breadth, with at least one being strictly so, the optimal patent has maximum breadth and minimum length, i.e. $w=1$ and $T=\underline{T}$.
ii) If both $S(w)$ and $I(w)$ are concave in patent breadth, with at least one being strictly so, the optimal patent has minimum breadth and maximum length, i.e. $w=\underline{w}$ and $T=\infty$.
iii) If both S and I are linear in patent breadth, social welfare is independent of the combination of patent breadth and length.

Proof: It is easy to see that $-\frac{\varepsilon_{Pw}}{\varepsilon_{Sw}} \begin{smallmatrix}>\\=\\<\end{smallmatrix} -\frac{\varepsilon_{PT}}{\varepsilon_{ST}}$ is equivalent to $-\frac{P_w}{S_w} \begin{smallmatrix}>\\=\\<\end{smallmatrix} -\frac{P_T}{S_T}$. Differentiating (6) and (7), it almost immediately follows that $-P_w/S_w$ is equivalent to I_w/D_w, and $-P_T/S_T$ is equivalent to I/D. By rearranging (10) and substituting I_w/D_w for $-P_w/S_w$ and I/D for $-P_T/S_T$, one can verify that the sign of dS/dw is determined by the sign of $\psi(w)=I_wD-D_wI$. The rest goes as in Denicolò (1996). Taking the derivative of $\psi(w)$ with respect to w yields $\psi_w=I_{ww}D-D_{ww}I$. Clearly, if I_{ww} and S_{ww} are positive, $\psi_w>0$, and if I_{ww} and S_{ww} are negative, $\psi_w<0$. Because $\psi(0)=0$, the sign of ψ_w determines the sign of dS/dw.

QED

To illustrate the findings in Proposition 1 and in Denicolò's patent theorem, I briefly consider Nordhaus's model of the optimal patent life and breadth (see Nordhaus, 1969, chapter 5, and Nordhaus, 1972), which is an example omitted from Denicolò (1996). Though not explicitly shown, it is apparent that the optimal patent policy in Nordhaus (1972) is independent of the exact combination of the patent breadth and length. Nordhaus (1969) and (1972) consider a homogenous good industry with the demand function $Q = a-\eta p$, where p and Q denote price and output, and η measures the price elasticity of demand. By employing the technology in (1) the innovator can now reduce the marginal cost of production c so that the size of the cost reduction θ is an increasing and concave function of the investment in invention α. The inventor's post-invention marginal cost is thus $c-\theta(\alpha)$. The invention is non-drastic, that is, the innovating firm cannot drive its competitors out of the market. The competitors' marginal cost in the post-innovation market equilibrium given by $c-(1-w)\theta$ depends on patent width. The invention is assumed to be licensed to all firms in the industry with a royalty rate equalling the cost reduction not freely spilling over. The royalty rate is thus θw.

After the patent expires there is free entry, which entirely dilutes the inventor's profit, that is, $\bar{\pi} = 0$. Normalising the level of output before invention to unity,[6] the return on innovation can be written as

$$P(T,w) = I(T,w) = \int_0^T e^{-rt} \varepsilon w dt\,. \tag{11}$$

The static social welfare S is given by

$$S = \int_0^T e^{-rt} \varepsilon w dt + \int_T^\infty e^{-rt} \left(\theta w + \frac{\eta \theta^2 w}{2} \right) dt + \int_0^\infty e^{-rt} (1-w) \left(\theta + \frac{\eta\theta^2}{2} \right) dt\,. \tag{12}$$

The first integral in equation (12) represents the inventor's profit when the patent is in force, the second integral captures the increase in consumer surplus after the patent expires, and the last depicts the effect of the spillover on consumer surplus.

The brilliance of Denicolò's patent theorem is its simplicity. From (11) and (12) the linearity of I and S in w is obvious so that Denicolò's patent theorem implies the independence of social welfare from the width-length mix. In resorting to Proposition 1 we must calculate the elasticities, which is slightly more involved. Clearly, $\varepsilon_{Pw}=1$ and $\varepsilon_{PT}=\frac{rTe^{-rT}}{(1-e^{-rT})}$, and solving for ε_{Sw} and ε_{ST} yields $\varepsilon_{Sw}=-\frac{\theta^2\eta\left(1-e^{-rT}\right)w}{2rS}$ and $\varepsilon_{ST}=-\frac{\theta^2\eta e^{-rT}wT}{2S}$. Therefore, $-\frac{\varepsilon_{Sw}}{\varepsilon_{Pw}} = \frac{\theta^2\eta\left(1-e^{-rT}\right)w}{2rS} = -\frac{\varepsilon_{ST}}{\varepsilon_{PT}}$, and by Proposition 1, the policy variable mix is irrelevant for social welfare.

Whilst Denicolò's patent theorem is convenient, it fails to predict the optimal patent design when the second derivatives of functions $S(w)$ and $I(w)$ take the opposite signs. In such circumstances one must rely on Proposition 1. An example in

[6] Nordhaus (1969, 1972) also normalises the marginal cost before invention to unity. As a result, the size of the cost reduction θ becomes equivalent to the size of the relative cost reduction $B=\theta/c$. He then employs B through both his studies. I think, however, this latter normalisation only confuses the reader.

which the incentive to innovate is concave but static welfare is convex in patent width is discussed in the first essay of the dissertation.

In assessing the reliability of the observations here some caveats should be borne in mind. The incentive to innovate in Denicolò (1996) arises from the equilibrium of a stochastic patent race, whereas here it is determined by a much simpler maximisation problem in which the competitive pressure from other innovators is ignored. As the discussion concerns elasticities, however, adapting more instructive formulation of innovative activity involves no loss of generality. Another caveat lies in the underlying assumption in deriving Proposition 1 and Corollary 1 that an increase in patent length or width invariably stimulates the incentive to innovate and diminishes static social welfare. This assumption covers the most usual cases, and the model above satisfies it. However, in some special circumstances, as in Klemperer (1990) and Waterson (1990), S_w may be positive, and the signs of the inequalities in Proposition 1 should be the reverse, because the proof of the proposition requires dividing by S_w. Changing the signs immediately shows that the optimal patent should have maximum breadth and minimum length when $S_w > 0$ – a heuristic finding indeed.

In sailing between the Scylla and Charybdis of the static and dynamic inefficiencies, the policy-makers may begin to wonder whether there are better means of encouraging innovation. As Spence (1984) and Kanniainen and Stenbacka (1997) argue, the efficient solution to underprovision of innovation is subsidising research, not creating price distortions through the patent system. Raising funds for subsidies, however, creates distortions of its own, and one may also doubt the ability of governments to identify what research is worth paying for. As suggested by Wright (1983), precisely this imbalance of information between researchers and policy-makers makes patents an attractive incentive mechanism. Nevertheless, nothing prevents combining patents with subsidies as in Romano (1989) and Kanniainen and Stenbacka (1997). In general two instruments are better than one. In fact, the legislation protecting intellectual property includes numerous other policy instruments in addition to patent length and width, which may partly alleviate the tension between the static and dynamic dimensions of intellectual property protection.

2.2 Copyright and other Instruments of Intellectual Property Protection

As explained in the previous section, a broad interpretation of patent breadth incorporates compulsory licensing. Similarly, a broad interpretation of patent breadth incorporates the *novelty criterion* or patentability requirement. Whereas compulsory licensing is hardly a necessary section of patent law, the novelty criterion has general importance. The patentability of an invention requires ‘novelty’ and ‘non-obviousness’, usually separate requirements in patent law (see e.g. PatL2§), but in practice they are difficult to distinguish. Many authors thus use the novelty criterion as shorthand for both requirements. While patent breadth determines how difficult it is to produce a non-infringing substitute for the patented innovation, the novelty criterion determines how difficult it is to produce a non-infringing improvement. Improvements are substitutes, but not necessarily vice versa. If necessary, the distinction between the novelty criterion and patent breadth can clearly be made and has been made. For instance, Van Dijk (1996) even calls the novelty criterion *patent height*, and O'Donoghue, Scotchmer and Thisse (1998) distinguish it as 'leading breadth' from 'lagging breadth', which protects against imitation.

There has during the past decade been considerable interest in the effects of the novelty criterion on the cumulative innovation process. Suzanne Scotchmer with her co-authors has contributed to this issue particularly, see Scotchmer (1991, 1996), Green and Scotchmer (1995), O'Donoghue, Scotchmer and Thisse (1998). Other recent studies on the interplay between cumulative innovation and optimal patent policy include Cadot and Lippman (1998), Chang (1995), Chou and Shy (1993), Denicolò (1997, 1998), Horowitz and Lai (1996), and O'Donoghue (1997). The chief body of this research concentrates on the division of profits between the first innovation and the subsequent generations. Technological progress is cumulative, and this line of research challenges some views of the basic Nordhausian framework over one innovation period. For instance, Chou and Shy (1993), Horowitz and Lai (1996), and Cadot and Lippman (1998) use repeated-innovation models to demonstrate that long patents retard the introduction of a new product generation, thus casting doubts over the basic hypothesis that long patent life invariably spurs innovation. But my position on this issue exactly corresponds to Schumpeter's:

> 'Jeder konkrete Entwicklungsvorgang beruch auf vorhergehenden Entwicklungen. Um aber das Wesen der Sache ganz scharf zu sehen, wollen wir davon abstrahieren und die Entwicklung sich aus einem entwicklungslosen Zustand erheben lassen.' (Joseph A. Schumpeter *Theorie der wirtschaftlichen Entwicklung*, 1911, p. 107)

A more purposeful question in this setting is to investigate the patentability criterion by comparing a traditionally strict patent system to a more permissive system allowing accidental duplication of innovations, this being the subject of the second essay of the dissertation. Such a permissive system is practically equivalent to copyright protection. The distinction between patent and copyright protection is broadly speaking that a copyright provides much weaker protection, since it merely protects expression, not ideas. In the prevailing patent system only one patent can be awarded among potentially several similar but genuine innovations, whereas copyright law permits independent discoveries.

It has traditionally been thought that the principal policy tool employed to stimulate innovation is patent protection, but there are now several significant industries such as education, entertainment, computer software and many Internet related businesses under copyright protection. There has also been some sign of reviving interest in the subject in economics. Besen and Kirby (1989) summarise the previous literature dealing with copying of books and journals, including the contributions in the influential *Journal of Political Economy* by Novos and Waldman (1984), Johnson (1985), and Liebowitz (1985). Landes and Posner (1989) also provide a fairly comprehensive basic account of the economics of copyright protection. Waterson and Ireland (1998) develop an auction model to compare the welfare effects of the patent and copyright systems. Inspired by the recent debate on the legal protection of computer software,[7] they argue that software should be protected by means of copyrights. The same debate is also a driving force behind Shy and Thisse's (1998) study of copyright protection in the software industry (see the following subsection for more on their paper).

[7] For more on this debate, see, Beresford (1997) for example.

Landes and Posner (1989) advocate the division between copyright and patent protection by referring to the difference in works under copyright and patent protection. Their argument is based on the difficulty of checking all material under copyright to avoid inadvertent duplication of the originally copyrighted work. By contrast, an inventor can avoid infringement of an existing patent, because an invention can be both described accurately and indexed by the Patent Office. This argument may be justified in some circumstances, but is dubious in many others. Taking scientific research as an example, it is arguably feasible to avoid duplication of published research findings.

Nonetheless, even if Landes and Posner's (1989) claim were valid and it was not desirable to tighten the novelty and non-obviousness criterion in copyright law, there are various ways in which the novelty criterion in patent law could be reformed to allow inadvertent duplication of innovation. In fact, La Manna, MacLeod and de Meza (1989) (see also La Manna, 1994, 1995) suggest a permissive patent system allowing accidental infringements of patents and even find this permissive system welfare superior to a traditionally strict patent system under a wide range of circumstances. Their proposal to relax the novelty criterion is based on the real-world lag between receiving an application and granting the patent. This lag would enable the Patent Office to award the patent to all applications received up to the grant of the first patent. Such a modification of the legislation would be relatively easy to achieve, since patent applications are already secret 18 months after filing in many countries.

For modelling purposes, the concept of the patentability criterion raises the same difficulty as the concept of patent breadth – it is hopelessly abstract. In contrast, the concept of a renewal fee is as clear-cut as the concept of patent duration. Currently most patent systems require that patentees pay annual renewal fees in order to maintain their patents in force up to a statutory patent life. Lanjouw, Pakes and Putnam (1998) survey empirical studies of patent renewal data, including Pakes (1986), Schankerman and Pakes (1986) and Lanjouw (1998), demonstrating how patentees optimise to maintain patent protection. While the fees are usually quite moderate, most patents are voluntarily cancelled. For example, after investigating the patent renewal data from France, Germany, and the UK, Schankerman and Pakes (1986) report that only 10% of patents remain in force for their full statutory life.

Several factors may underlie the decision to discard the annual renewal fee, but the primary reasons seem to be technological progress rendering the innovations obsolescent, and unfavourable realisation of demand uncertainty. For example, under demand uncertainty an innovator may initially patent a product and wait until the uncertainty resolves itself. The level of demand may prove to be insufficient to justify commercialisation, and the innovator reasonably refuses to renew the patent. Patents can thus be seen as *options to wait*. The third essay of the dissertation builds upon this view.

Because renewal fees in practice make the patent protection term invention-specific, they can improve welfare, as shown in Cornelli and Pakes (1996) and Scotchmer (1998). Ignoring the implementation costs, it should be no surprise that the introduction of an additional policy instrument is welfare-enhancing in principle, as the policy-makers can use the instrument only in favourable circumstances, and abstain from actual use otherwise. Remarkably, Scotchmer (1998) proves that these favourable circumstances are relatively restricted, advocating a patent system of no renewal fees.

2.3 The Decision to Seek the Legal Protection of Intellectual Property

A patent is by no means the only means to protect research findings in industrial organisations. The patent is not even the most important instrument of protection. Several empirical studies, including Harabi (1995), Mansfield (1986), Levin, Klevorick, Nelson and Winter (1987), Veugelers (1998), and Arundel and Kabla (1998) demonstrate how the percentage of patented innovations varies by industry because of the differences in the ability of patents to prevent imitation, suggesting that secrecy, lead-time, learning advantages and sales and service efforts often provide better protection than patents. Anecdotal evidence is also easy to find: Jorma Ylikauppila, Valmet's deputy manager, recently mentioned that Valmet, the world's leading manufacturer of paper and board machines, resorts to secrecy with regard to process innovations, and Esko Friman, Nokia Telecommunications's intellectual property rights manager, reports that Nokia seeks patent protection only if an innovation cannot be kept secret (*Tekniikka & Talous* 2.4.1998). There is also a significant research tradition, beginning with Nelson (1959) and Ruff (1969), asserting that research joint ventures are established in order to improve the management of knowledge spillovers.

Patents are often still applied for, being necessary to enforce intellectual property. Lanjouw and Schankerman (1997) estimate that a patent may generate more than one suit in the US for every hundred patents.[8] While enforcement costs, as Lanjouw and Schankerman (1998) demonstrate, may seriously undermine the incentive to invest in R&D, the damages for infringements establish a solid ground for the status of a patent as property. This status is further justified because patents facilitate the sales of technologies. Patents are thus usually employed as an additional means of protection against potential infringement cases and technology transfer; quite sensibly, because in practice mere secrecy is at odds with patents as a protection device. There is rarely an opportunity to choose, say, between patents and copyrights. Accordingly, having succeeded in innovative activity, the innovator encounters the problem of whether to publish the research results and apply for patent protection instead of trusting to secrecy.[9]

The innovator's option of keeping the innovation secret may lead us astray in using the number of patents as an index of technological progress. For instance, Griliches's survey (1990) demonstrates that the number of patent applications has been fairly constant for many decades despite tremendous growth in innovative endeavours.[10] Griliches (1990) asks, whether are patents shrinking yardsticks, or whether this phenomenon suggests that our 'stock of knowledge' is going to be exhausted? There are several possible explanations, but Schmookler's (1966) old

[8] Lanjouw and Lerner (1997) provide a survey of recent empirical literature on patent litigation. Such litigation has also recently been incorporated into theoretical models (e.g. Meurer, 1989, Waterson, 1990, and Choi, 1996). Except for the case study, this dissertation retains a strict 'fence-post' system, i.e. the interpretation of patent scope is assumed to be exact.

[9] As careful readers no doubt have already noticed, protection by secrecy is also partially enforced by law. Trusting secrecy also involves trusting trade secret laws. For some economics of trade secret law, see Friedman, Landes and Posner (1991).

[10] The time span covered by Griliches's (1990) survey excludes the sharp increase in the applications in the US in late 80s and early 90s. See Kortum and Lerner (1997) for a detailed investigation of this interesting observation.

hypothesis that there has been an increasing disparity between patenting and the actual pace of innovation in this century is plausible.

This puzzle over patent statistics has long worried the empirical economists, and to some extent the theorists. Not surprisingly, the theoretical discussion on the decision to patent, as in Horstman, MacDonald and Slivinski (1985), Scotchmer and Green (1990), Gallini (1992) and Van Dijk (1996), mainly focuses on the strategic aspects of information disclosure in patent files.

Only Saarenheimo (1994) seems to stress the empirical considerations in rigorously explaining Schmookler's (1966) old observation of proportionally less patent applications filed by larger companies than by smaller ones. The explanation is also quite natural. Small firms prefer to patent and license intermediate innovations rather than keep them secret and to try and win the whole innovation race, as their probability of doing so is small. The finding in Schmookler (1966) and Saarenheimo (1994) is actually a corollary of another old finding, first established by Mansfield (1963), on the inverse relation between the length of time that a firm waits before introducing an innovation and the size of the firm. The reason is probably that small firms have less resources for completing the entire innovation projects, as emphasised in Williamson (1975). However, the latest research results reported by Arundel and Kabla (1998) thoroughly invalidate this conclusion. Having surveyed the decision to patent of over 600 European companies, they show that the propensity to patent markedly increases with firm size. Merely to see that more research is warranted to settle the matter, it is perhaps superfluous to add that both Saarenheimo (1994) and Arundel and Kabla (1998) provide references to other empirical work supporting *their* conclusions.[11]

The relative ignorance of the empirical considerations in the theoretical literature is regrettable, since should the theorists turn toward empirical issues, they might provide substantial insights. Take the 'demand-pull' hypothesis of technological change for example. Patent statistics are often employed to support this hypothesis. For instance, widely cited studies by Schmookler (1966) and Sokoleff (1988) stress market size as a main stimulant of innovation on the evidence of patent records. The rewards from inventive activity may well increase with market size, but so may the rewards from patenting as shown in Takalo (1996).[12] The evidence in Grupp and Schmoch (1996) indicates that market size assists in elucidating the patenting strategies of multinational telecommunication companies for the 1987-89 period. For instance, the number of patent applications by the Japanese companies in Sweden were approximately one fifth of the corresponding number in the US. Similarly, Arundel and Kabla (1998) invoke market size in explaining the observed difference in the propensity to patent between Europe and the US.

The decision on how to utilise copyright protection in the software industry is evaluated in an intriguing recent paper by Shy and Thisse (1998), who find that it may be beneficial for competing firms *not* to use copyright protection in the presence of significant network externalities to promote their sales. They also provide evidence to support such a decline in firms' willingness to protect their software

[11] Interestingly, Arundel and Kabla (1998, p.139) consider their finding 'not intuitively obvious' for the very same reason entailing Saarenheimo's (1994) contrary prediction or, as Arundel and Kabla (1998, p.139) put it, '...smaller firms may need to sell or license their process innovations in order to recoup the development costs.'

[12] The first essay is a condensed version of this enlarged working paper. The earlier version also includes a formal discussion of how market size affects patenting behaviour.

innovations. Similar reasoning can immediately be extended to patent protection. Hultén (1996) describes how the standard for the Nordic mobile telephone system (NMT) was left unpatented in order to accelerate its adoption.

Finally, let us examine the decision to patent (or to apply for copyright protection) in more detail. The enthusiastic advocates of the legal protection of intellectual property such as Kitch (1986), Dam (1994) and Thurow (1997) sometimes assert that patents provide little if any monopoly power, or that secrecy is much more detrimental to social welfare than any monopoly position authorised by intellectual property laws. It is easy to burst this bubble. Innovations are patented only if patenting is more profitable than secrecy, that is, the condition for patenting, ignoring patenting costs, is

$$\int_0^L e^{-rt}\pi(1)dt + \int_L^T e^{-rt}\pi(w)dt + \int_T^\infty e^{-rt}\pi(0)dt > \int_0^S e^{-rt}\pi(1)dt + \int_S^\infty e^{-rt}\pi(0)dt\,, \quad (13)$$

in which L depicts the lead time when the innovation is patented, S is the length of time the innovation is managed to kept secret, and T is patent length as before. The decision to patent is interesting only if $L<S<T$. The first integral on the left-hand side of (13) thus depicts the monopoly profits when the innovation is patented but no rival introduction has occurred. The second integral reflects the profits during patent protection when at least one rival has appeared in the market, and the third the profits after the patent expires. The first term on the right-hand side captures the monopoly profits as long as the innovation can be kept completely secret. Once a competitor succeeds in reverse engineering the new product or process containing the innovation, there is no additional protection available by law. The profits after losing the competitive advantage created by secrecy are represented by the last term of equation (13). For brevity, these profits are assumed to be equivalent to the profits after the patent expires, even though it is possible that the situation after the patent expires is worse from the innovator's point of view, because the patent files contain technical information about the innovation. Even without recourse to this information-disclosure effect, the argument that patent protection must afford monopoly power is easily shown. After simplifying, patenting condition (13) can be rewritten as

$$\left(e^{-rL} - e^{-rT}\right)\pi(w) > \left(e^{-rL} - e^{-rS}\right)\pi(1) + \left(e^{-rS} - e^{-rT}\right)\pi(0)\,.$$

Now patent width w can clearly be interpreted as a measure of the degree of monopoly power. If patents confer no such power, i.e. $\pi(w) \approx \pi(0)$, we immediately see that there is no reason to patent. Of course, at some level it is a matter of semantics whether one ascribes the advantage over competitors obtained through patenting to monopoly or 'economic rent' as in Kitch (1986) and Dam (1994). But one simply cannot consistently advocate the patent system while at the same time entirely denying its static inefficiency.

3 The Subject Matter of the Thesis

To summarise some essential aspects of the previous section and to provide a setting for the subsequent discussion in this section, let us first outline an innovation project. The initial research investment is usually preceded by the organisational design of the project. For instance, whether to engage in a research joint venture or to invest in one's own research laboratory should be decided. It is even possible to commit oneself to both. The actual research phase follows the project launch. Successful research yields an invention, but an invention as such is seldom immediately suited to profitable use; the development phase succeeds the research. Assuming that the invention satisfies the requirements of patent law rather than, say, copyright law, the innovating firm holds the option of patenting the invention. Neither the decision to patent nor the decision to utilise the innovation is trivial because both patenting and the introduction of the innovation involve considerable sunk costs, and the cash begins to flow only after the market introduction. Besides, the cash flow is uncertain, depending heavily on the demand growth and the speed of imitation. Finally, if the invention is patented, it may be licensed irrespective of the commercialisation decision. The sequence of events is represented in Figure 1.

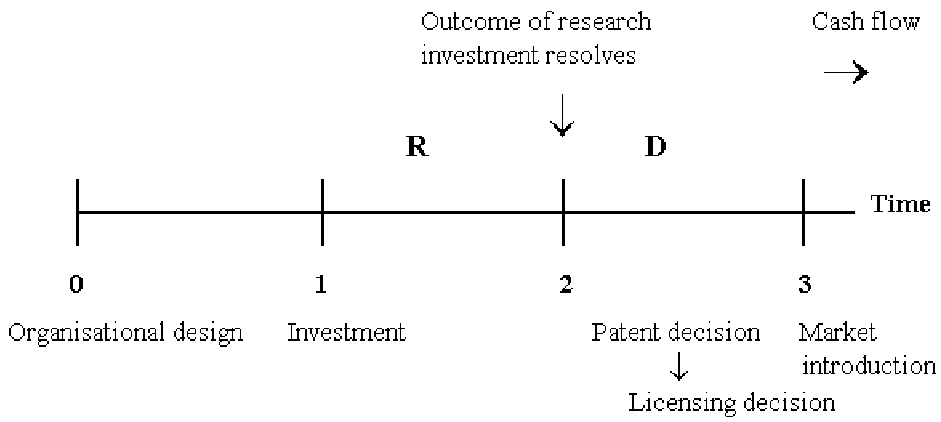

Figure 1. The sequence of events in an innovation project.

This description of an R&D project is admittedly simplified, but the details will be spelt out in the four essays of this dissertation. Even this outline is, however, helpful in comprehending the determination of knowledge spillovers and the nature of intellectual property protection for society as a whole. A spillover has only two origins. First, the level of the spillover is in part a result of the institutional structure protecting intellectual property. Such institutions shape R&D projects, as if they provided the frames for Figure 1. The institutions also crucially affect the timing of events. For instance, the patenting option of product innovations is alive only during the development phase, as one cannot patent an invention that has already been commercialised.

Secondly, the decisions involved at each stage of the project have an impact on the level of knowledge spillover, as noted in the literature. Katz (1986), Severinov (1997), Katsoulacos and Ulph (1998) are examples of papers exploring the impact of organisational design, Cohen and Levinthal (1989), and Kamien and Zang (1998) study the impact of the investments made at stage 1, the impact of the patent decision was briefly evaluated in section 2.3 above, and the role of the licensing decision or the information-exchange is investigated in Katsoulacos and Ulph (1998) as well as briefly in the fourth essay. The market introduction clearly has the major impact, as it ultimately enables the diffusion of new technology through imitation. Of course, investment in imitation can be carried out at other stages of an R&D project; the decision to specialise in imitation is often made either at the outset, or upon failing to succeed in research investment, but perhaps the key advantage of imitation is that imitative products or processes can be introduced only after the market uncertainty has resolved. Only successful innovations are imitated. Determination of the spillover through such a rational investment in imitation elaborated in the first essay and Kanniainen and Stenbacka (1997).

As the previous section demonstrated, there has been considerable progress in our understanding of the economics of intellectual property protection in the past thirty years, especially regarding patent protection. Despite the progress made in previous research, some *patent* defects still persist in the literature. The aim of this dissertation is partly to fill these gaps. In particular, the essays recognise the multi-stage character of R&D projects, as depicted in Figure 1, and concern the policy of protecting intellectual property in this light. Most preceding literature has treated the decisions to patent and commercialise rather casually. The development of the post-innovation market structure has also often been described relatively mechanically. Taken together this has resulted in a research view which considers the knowledge spillovers as an automatic and costless consequence of innovative activity.

A primary concern of this thesis is to advance the theory of intellectual property protection by modelling the spillover process explicitly. Figure 1 illustrates how the decisions in each phase of innovation projects are matters of optimisation for innovators, who also have various means of affecting the post-innovation market structure. The imitator's decisions apparently also have a significant effect on the spillovers. Beside endogenising the R&D spillovers, new insights can be gained by taking account the impact of policy variables at different stages of R&D projects.

Each of the four essays utilises a quite different methodology. The first essay considers optimal patent policy when the innovator has the option of keeping the innovation secret. The analysis is conducted under the usual partial equilibrium assumptions. In the second essay, optimal patent policy is addressed in a general equilibrium environment by adopting a well-specified search model. The notion of a patent as an option to wait for market introduction is formalised in the third essay, which has been jointly written with Vesa Kanniainen. This essay is based on the theory of real options. While the three first essays subsist in the imaginary world of economic models, a detailed inquiry into a real-world innovation project involving all stages of Figure 1 is made in the last essay, jointly written with Klaus Kultti. In tying this case to the theory of incomplete contracts, we evaluate whether some events in the project are relevant beyond our particular focus and specification.

3.1 Innovation and Imitation under Imperfect Patent Protection

The diffusion of newly invented technologies, which has been explored by a number of economists, including influential contributions by Reinganum (1981b), Fudenberg and Tirole (1985), and Stenbacka and Tombak (1994), contributes to our well-being. The discussion, however, focuses on the strategic aspects of adapting new technology, omitting the role of patents from the analysis. The research tradition in the literature of optimal patent design in turn considers diffusion trivial. With the exceptions of Gallini (1992) and Kanniainen and Stenbacka (1997), the imitation of patented products is either prohibitively costly or completely costless. Considering the tremendous research effort on R&D spillovers (for a survey, see De Bondt ,1996), this is really surprising, as the results of research and development activities performed by one firm can seldom be used by others as well. While the determination of spillovers is also discussed in other essays, the dangers in adhering to exogenous spillovers are explained most clearly in the first essay.

The first attempts to endogenise spillovers were made by Katz (1986) and Cohen and Levinthal (1989), but Kanniainen and Stenbacka (1997) are the first to introduce the idea of determining the spillover through rational investment in imitation.[13] In the first essay I draw on their framework to construct a simple model where spillovers are a consequence of a follower's investment in imitation. In addition to Kanniainen and Stenbacka (1997), the analysis also incorporates the essential insights from Gallini (1992), where patent breadth raises the imitation costs and the innovator can choose whether to patent the innovation or keep it secret. She imposes the restriction that the imitators can invent around the patent at a fixed cost, whereas the unpatented innovation becomes freely available to everyone. Extending the analysis in Gallini (1992), I introduce rational imitation where the outcome is uncertain regardless of the innovator's decision to patent the innovation or to keep it secret.

It has usually been thought that an increase in patent length merely increases the length of the innovator's monopoly, as in the model in section 2.1. Modelling the spillover process explicitly, however, demonstrates that the increase in patent length also boosts investment in imitation, because the imitator can no longer afford simply to 'wait and see' until the patent expires. It is crucial from the innovator's point of view whether the expected spillover is 'large' or 'small'. An increase in patent length enhances the incentive to innovate only if the degree of spillover is less than one-half.

Denicolò's patent theorem, depicted in Corollary 1 in section 2.1, predicts the optimality of maximum breadth and minimum length when both the incentive to innovate and post-innovation social welfare are convex in patent breadth, and the reverse if both are concave. It is silent about the optimal policy when, say, post-innovation social welfare is convex and the incentive to innovate is concave in patent breadth. This is precisely the case in the model. One must therefore study the relative impact of patent width on static social welfare and the incentive to inno-

[13] Related studies include Jovanovic and Rob (1989), Jovanovic and MacDonald (1994) and Davidson and Segerstrom (1998). Jovanovic and his co-authors construct search models and Davidson and Segerstrom an endogenous-growth model to access the knowledge of others through imitative investments, but these studies remain relatively abstract in treating the rate of spillover.

vate, as in Proposition 1. In consequence, the main finding in Gallini (1992) about the social optimality of short patents is confirmed, but the optimal patent does not need to be broad if the spillovers are high enough.

Finally, the essay highlights the importance of allowing innovators to choose between patenting and secrecy as a protection device. It turns out that the innovator's secrecy option can seriously constrain the scope of efficient patent policy, because a patent policy matters only if it reduces the rate of spillover.

3.2 Intellectual Property Protection in Search Equilibrium

The evaluation of policy to protect intellectual property is often conducted in isolation from the rest of the economy. This is satisfactory in so far as there are no feedback effects from policy variables on the underlying supply and demand functions of innovation specified in advance. Eluding such feedback effects, economists are keen to conclude that the rate of the spillover deteriorates with stronger protection, but one would expect the enhanced protection to accelerate investments in invention, which tend to expand spillovers in the economy. A general equilibrium framework would thus certainly have many advantages in studying the legal protection of intellectual property

A seminal attempt to address optimal patent policy in a dynamic setting incorporating the economy-wide effects of the policy has been made by Judd (1985). Focusing exclusively on patent life and product patents he finds the optimality of infinite patent life where the representative consumer has the CES-utility function. As in the other notable studies of product patents by Klemperer (1990) and Waterson (1990), the patent system may provide society with the right range of products. Judd's (1985) model, however, regards invention as a deterministic activity and patent protection as perfect.

The analysis in the second essay builds loosely on a search model by Lu and McAfee (1996). The intention is to develop a general equilibrium model in which agents search for new ideas, and imitation of patented ideas is possible. Lu and McAfee (1996) are interested in a quite different question, the relative performance of the trading institutions, but their model has many attractive properties and has a wider range of applications. In particular, the matchings are not restricted to be pairwise, and, as shown in Kultti (1998), the matching technology exhibits constant returns to scale. In the context of the model developed in this essay, matching occurs when an agent discovers an idea. The model thus permits multiple independent discoveries simultaneously, and because of the constant returns to scale, only the ratio of agents to ideas matters. As the independent discovery is possible in the model, it is particularly convenient in comparing the welfare effects of the patent and copyright protection.

Besides Lu and McAfee (1996), the model has some similarities with Jovanovic and Rob (1989) and Jovanovic and MacDonald (1994) who construct search-models with endogenous knowledge spillovers to isolate the relationship between inequality and growth. As in their papers, the incentives to innovate and imitate are in this essay determined by the model. In the study of innovation, this essay is the first to derive the discovery probability explicitly. More specifically, the model provides an explanation of the Poisson discovery rate characterising the patent race literature and isolates its determinants.

The welfare effects of copyright and patent protection have previously been compared by Waterson (1990) and Waterson and Ireland (1998). The closest paper to this essay, however, is La Manna, MacLeod and de Meza (1989), even though they explicitly evaluate only a permissive patent system instead of copyright protection, but their permissive system allowing multiple independent discoveries has many characteristics of copyright protection. They find that the permissive regime is less profitable for innovators and requires longer patents by way of compensation than the strict regime, but the dead-weight loss created by longer patents is more than offset by the increased consumer surplus in the permissive regime.

The incentives to innovate and imitate are explicitly determined in the model of this essay. In equilibrium, the permissive regime is actually more attractive for innovators, but the development of multiple simultaneous innovations consumes more resources. There is nothing special in the contrast with La Manna, MacLeod and de Meza (1989) since if the general equilibrium approach did not change any predictions of partial equilibrium analysis it would be of limited importance. The key insight of this essay is that the relative welfare performance of copyright and patent protection is determined by the difference in the spillovers between innovative and imitative activity. The patent system creates greater welfare when specialisation in imitation yields an efficient capacity to absorb the knowledge spillovers, but is unable to match the performance of copyright protection when an investment in innovation renders learning from the others inexpensive.

In addition to comparing the intellectual property rights, the model re-examines the much-debated issue of the optimal patent length-breadth mix (cf. section 2.1). With more than simply one policy instrument, the optimal design of the patent policy has normally been solved by maximising the social utility from existing innovations in respect of the instruments, constraining the incentive to innovate to a predetermined level. In the set-up suggested here, the policy instruments are the patent length and breadth as usual. The incentive to innovate is no longer predetermined but is part of equilibrium in the economy. In the model the agents are free to choose whether they are searching as innovators or waiting as imitators, and they can also choose whether to patent the invention or resort to secrecy as an instrument of protection. These choices establish the level of the spillover.

One conclusion offers support for the optimality of short patent life. As against other studies with the same view, such as Gallini (1992) and the first essay, this finding emerges even with costless imitation. Endogenising the incentive to innovate, however, involves the predictions here being incompatible with Proposition 1 and Denicolò's patent theorem. The conclusion cannot therefore be attributed to the functional forms of post-innovation social welfare and the incentive to innovate, but can be explained by a new feed-back effect alleviating the static inefficiency assigned to strong patent protection, since this increases innovative activity, expanding the spillovers. It is also shown that the optimal patent should be broader but shorter when the invention cost increases. In view of Galbraith's (1952) famous suggestion of the increasing difficulty of inventing, this leads to a specific policy recommendation.[14]

[14] See Kortum (1997) for a rigorous treatment of Galbraith's hypothesis in the context of a search model.

3.3 Do Patents Slow Technological Progress?

The impact of patents on innovative activity is far more wide-ranging than the archetypical Nordhausian framework is able to depict. Patenting rarely involves an immediate monopoly, because innovators usually apply for patents at an early stage in the innovation process, a stage in which a considerable uncertainty about the profitability of adaptation of the patented idea still exists. Early patenting partly arises from the patent laws, which grant a patent by the first-to-file rule, but the uncertainty surrounding the commercialisation of new technologies is undeniably a major source.

A patent seems thus to satisfy the basic definition of a call option as a right but not an obligation to buy an underlying asset whose price is subject to random variation. Now 'to buy an underlying asset whose price is subject to random variation' means 'to introduce an innovation into the market when its benefits are uncertain'. It should be kept in mind that such an interpretation applies not only to new products but to new processes. In the context of process innovation, the question is about bringing an innovation into use instead of market introduction. A patent is thus the option of waiting to see how the expected value of the patented idea will evolve. Only if the prospects are good enough is the option is exercised, and the decision to commercialise the patented idea made. Such non-financial options have become known as *real options*.[15] When investment decisions are made under uncertainty, a real option is valuable because it allows investors to learn about the underlying stochastic process before committing themselves to a irreversible investment. After studying the patent renewal data, Pakes (1986) and Lanjouw (1998) report that the option value of patents is initially high but then declines rapidly, much of the uncertainty resolving itself in the five years after patenting.

If a patent can be regarded as a real option, common wisdom in the theory that strong patent protection accelerates market introduction of new technologies should be reviewed. A good example of this wisdom can be found in Matutes, Regibeau and Rockett (1996). Crucially, their approach abstracts from the uncertainty about the success of commercialisation of innovation. By contrast, our model incorporates the uncertainty and formalises the notion of a patent as the option of waiting. We show that expanding the scope of patent protection may lead to delaying market introduction of new technologies. We maintain that such delay is a relatively common phenomenon.[16]

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[15] There are two comprehensive treatments of the real-option theory: Dixit and Pindyck (1994) and Trigeorgis (1996). Furthermore, as is usually the case, when a new economic theory with strong implications for corporate management is developed, some excellent, short, and non-technical overviews appear in *Harvard Business Review*. See, for example, Dixit and Pindyck (1995), and Luehrman (1998a, 1998b).

[16] Our view is grounded on some anecdotal evidence from earlier literature and our own interviews with industry practitioners. Some of this evidence is reported here. It is unfortunate that no large-sample study evaluating the pertinence of our prediction exists. The queries by Mansfield, Schwartz and Wagner (1981), and Mansfield (1986) provide some indirect evidence in establishing that, excluding the pharmaceutical industry, less than 30 percent of patented innovations would not have been commercialised if no patent protection had been available. Furthermore, Mansfield (1986, p.273) reports that he failed to prove the common wisdom: 'Of course, there is also question about timing. Under some circumstances, an invention might developed or commercially introduced more

Another finding of this essay has implications for the real-option theory generally. The theory predicts that when an investor holds multiple options over the same underlying asset, they all should be exercised simultaneously (for details, see chapter 10 in Dixit and Pindyck, 1994). In other words, sequential investment never occurs in theory. This prediction accords badly with experience of every-day life. The major projects of firms and in human life are typically undertaken in steps. Between the steps we operate under uncertainty in committing ourselves to a irreversible investment to move into the next stage. According to the theory, however, the threshold values of consecutive investments decline over time, and if a project is ever launched, it should be completed as quickly as possible.

The defect of the theory is simply its failure to consider the possibility that an investment may alter the underlying stochastic process. We demonstrate simply that if there is a risk of substantial change in the stochastic process, the investments should be made sequentially. Our analysis is carried out in the context of an R&D project, but the finding is applicable more generally. It is characteristic of the critical decisions in life that they may fundamentally change the directions and guidelines of future actions. For instance, dating, moving in together, and marriage deeply influence our lives and the underlying relation, and it may thus be optimal to wait before moving from one stage to another. Indeed,

> 'Of all the reasons for the failure of able men the most important is the inability to wait.'
> Joseph A. Schumpeter. (Richard Swedberg *Aphorisms from Schumpeter's Private Diary*, 1991, p. 206)

3.4 Incomplete Contracting in a Research Joint Venture: the Micronas Case

In industrial economics, case studies can provide useful insights in constructing new theories and evaluating old ones when it is impossible to obtain sufficient data for econometric testing. Incomplete contracting is regarded as a normal feature of real-life business relationships. There is plenty of theoretical work on the implications of less than perfect contracts, one of the main interests being the hold-up problem (see, e.g. Williamson, 1975, and Hart, 1995). Systematic empirical evidence, however, is scant, because contracts between firms are often classified as business secrets, and are hence difficult to obtain for research purposes. In this study we employ the extensive information from the life of a Finnish research joint venture, Micronas, to provide examples of the consequences of incomplete contracts. Of particular interest is the contract governing the licensing of a patent from a foreign source.

In 1980 three Finnish companies Nokia, Aspo, and Salora established a research joint venture called Micronas in order to develop and manufacture semiconductors.[17] Underlying the project was the transition in the semiconductor industry. Un-

slowly or later if the firm could not obtain patent protection. However, according to the firms in the interviews, this is not an important caveat.'

[17] The name 'Micronas' comes from the word 'Micro' and the initials from the names of the founder companies.

til the late 70s semiconductors were relatively homogenous products that were available from numerous manufacturers. In the late 70s it became evident that in future semiconductors must be application-specific. In other words, the degree of product differentiation was increasing. As against other countries with a significant electronics industry, Finland had no semiconductor business of its own, which worried both the venture partners and technology policy-makers. The firms did not consider it desirable to rely wholly on foreign and outside suppliers; the view was held across the world that semiconductor manufacturing would be integrated so that companies in the electronics industry would make their own semiconductors.

The initial technology was bought and transferred from a Californian company, Micro Power Systems (MPSI), which was selected amongst nearly twenty tenders. The contract with Micro Power Systems was detailed and complicated, including ownership arrangements. Even so, co-operation with Micro Power Systems ran into difficulties because of disagreements about the interpretation of the contract. The research joint venture also encountered various other troubles, and as a consequence its ownership structure changed several times. Both as a joint venture and Nokia's subsidiary Micronas was never profitable. Finally, after years of dismal economic performance, it was sold to an outside party in 1992, who rapidly rendered it economically viable, and by 1994 net profits were considerable.

The difficulties associated with the initial patent licensing and the research joint venture would not have occurred in a world of complete contracts. This fairly trivial observation has inspired our study of the contracts and the related problems from an incomplete contracting point of view. We show that some of the major events leading to the sale of Micronas to the outside party in 1992 can be seen to have originated from the hold-up problems. As to the licensing of the patent, theory suggests two relevant problems. Standard licensing literature highlights asymmetric information about the quality of the technology, and incomplete contract theory focuses on the hold-up problem where investment costs have been sunk when the parties bargain over the proceeds of the project. A careful study of the agreement and the actual licensing process indicates that both hold-up problems and asymmetric information were present, but that hold-up problems were a more serious threat in this case.

As a corollary we elaborate the theory of patent licensing. The prevailing view in the licensing literature, e.g. Gallini and Wright (1990), Macho-Stadler and Pérez-Castrillo (1991), Begg (1992) and Wright (1993), is that the extensive use of royalties in licensing contracts is a response to pervasive asymmetric information about the quality of technology. More recently, an alternative argument has been advanced. Macho-Stadler, Martinez-Giralt, and Pérez-Castrillo (1996) and Jensen and Thursby (1998) suggest that an output-based payment is necessary to solve a moral hazard problem if the technology transfer involves active participation by the licensor. Such a moral hazard problem is practically equivalent to our hold-up problem. We feel that these explanations of output royalty are to some extent unsatisfactory, because there is a simpler contract form solving the problem of private information as well as the hold-up problem than the output royalty. This is shown formally in the essay. Our solution is a version of the option-to-own contracts in Nöldeke and Schmidt (1995) and (1997). The basic idea behind such a contact is simple: the seller holds the right but not the obligation to complete the delivery, and the payment of the buyer is contingent on the delivery decision of the seller.

We also consider some other issues including the formation of the research joint venture. Theory suggests several reasons to establish a research joint venture, such as internalisation of the externality created by R&D spillovers, cost or risk-sharing, avoidance of research duplication, the final output cartel, and technological and product market complementarities. From the seminal papers by Nelson (1959) and Ruff (1969) to a recent contribution by Leahy and Neary (1997), the bulk of theoretical literature highlights the internalisation of spillovers as the principal reason, but there seems now to be significant evidence that this hypothesis should be rejected (see e.g. Röller, Tombak and Siebert, 1997, Hamel, Doz and Prahalad, 1989). We provide one addition to this evidence of rejection. In our case, cost sharing, avoiding duplication and complementarities in technology and product market seemed to be the chief reasons to set up the research joint venture.

Finally, we show how R&D spillovers can be endogenised in the sense that even without spillovers firms always have an incentive to exchange the R&D information when the investment costs have been sunk. This may to some extent explain patent pooling and ex-post cross-licensing. We first demonstrate how the spillover parameter in d'Aspremont and Jacquemin's celebrated model (1988) can be explained as the outcome of a simple information-exchange game, and we then offer a real information-exchange agreement between Micronas and Micro Power Systems as an example. Katsoulacos and Ulph (1998) have also recently resorted to the information-exchange in modelling endogenous R&D spillovers, but their framework is much richer, incorporating the impact of organisational design on the degree of the spillover as well.

4 Concluding Remarks

Intellectual property lies at the heart of a modern economy. The performance of the institutional structure protecting this property is a matter of deep concern in determining future economic well-being. These observations have inspired this work on the economics of intellectual property protection. The core of the work consists of the four following essays, each of which adopts a quite different framework. To derive policy recommendations is thus a delicate task. Nevertheless, to be provocative, I draw attention to three findings which seem to survive different approaches. These findings are taken in turn in the following subsection. To finish this introductory essay, the pertinent challenges to future research are briefly reviewed in section 4.2.

4.1 Three Implications for Technology Policy

Perhaps the key lesson from this dissertation is that in researching intellectual property protection, one should pay careful attention to the determination of knowledge spillovers. Most new insights in the essays of this dissertation stem from explicit modelling of these spillovers. Given the versatility of the methodological framework of the essays, it is extraordinary to discover that some conclusions are unrestricted to the particular framework but emerge from different sources. The first conclusion is almost self-evident but fundamental:

i) Patenting reduces the spillover rate.

Despite the substantial insights gained from previous research, there seems to be considerable confusion surrounding the issue of information disclosure in patenting. One of the chief arguments put in favour of the patent system is that it provides public access to research information, as one can see, for instance, in Scotchmer and Green (1990), Ordover (1991), Mansfield (1993), Dam (1994), Dnes (1996), and Thurow (1997). As already noted in Penrose (1951), and rigorously proved in the first three essays of this dissertation, however, this argument for the patent system is very weak, since patenting is useful for the innovator only in efficiently retarding the dissemination of research findings. A concession to the supporters of the public-access rationale can, however, be made. Because the innovator might ignore information flow to other industries in making the decision to patent, a logical possibility still exists that such disregarded information disclosure is sufficient to invalidate this conclusion.

The second implication is in part a corollary to the first:

ii) The prospects for a welfare-improving patent policy are restricted.

Because a patent policy matters only if it reduces the rate of spillover, the innovator's option of keeping the innovation secret can constrain the scope of efficient patent policy. It is shown in the first essay that if the competition at the product market stage between the innovating and imitating firms is fierce, the patent system can hardly increase welfare. Furthermore, the innovator's option of keeping the innovation secret turns out to be relatively insignificant in the second essay, because there is another, even more stringent constraint on the policy. Patent protection, and to some extent copyright protection, should be employed to stimulate innovation only when the appropriability problems are pervasive and the elasticity of the innovator's productivity with respect to the share of resources devoted to innovation is low. The root of the problem with extensive protection, that even with no policy intervention market equilibrium may generate too much duplication of research investments, has been known at least since Barzel (1968).

The last policy implication is somewhat more tentative:

iii) Optimal patent life is short.

This conclusion is based on several distinct reasons. The first essay verifies that the finding in Gallini (1992) on the optimality of short patents when imitation is costly is robust to extensions. In the second essay, technological progress may make patented ideas obsolescent before their patents expire and, accordingly, expanded protection involves an increase in the probability of ideas being no longer useful in reaching the public domain. The principal finding reached in the third essay maintains that a decrease in patent life might lead to a surge of new technologies into the market. There may also be other reasons for the optimality of relatively short patent life, investigation of which is left to future research. For instance, a shorter patent term might reduce patent disputes, especially such as those in the Micronas case over the rights to the improvements of licensed technologies, whereas Lanjouw and Lerner (1997) report some evidence of the likelihood of patent disputes being unaffected by patent breadth. In consequence, provided that the policy tools are substitutes as regard their impact on innovation, shorter but broader patent protection would result in a decline in the number of costly litigation processes.

4.2 Beyond the Scope of this Dissertation

There are many significant issues in the economics of intellectual property protection that neither previous research nor this thesis addresses adequately, if at all. Foremost among these is the question about the optimal system of intellectual property rights globally. Let us first emphasise the word ‘optimal’. The current system of intellectual property protection was designed long ago to satisfy the requirements of economies essentially different from ours. Perhaps the time has come for a thorough rethinking of the whole system, as strongly urged by Thurow (1997). In this task it is better to forget the existing institutions and instead simply ask, what the optimal incentive mechanism for innovation is and how to implement it. This point is pursued to some extent in interesting recent papers by Cremer and Scotchmer (1997) and Kremer (1998).

As to the word ‘global’, economic analysis of the global system of intellectual property rights is still in its infancy despite the Paris Convention being signed in 1883 to create a mechanism for world-wide patent grant coordination. Moreover, the legislation to protect intellectual property has recently been harmonised within the European Union and there is a strong pressure to harmonise it globally. The economic implications of the global system of intellectual property rights involve a number of delicate aspects, not least because of the special difficulties of less-developed countries. The historical experience in Germany, Holland, Japan and Switzerland suggests that it may initially be advantageous to have weak intellectual property protection. Only when the technological skills in a country have progressed to a sufficiently high level is it profitable to strengthen intellectual property rights to accelerate the development of the domestic innovation industry.

This points directly to a thin line between intellectual property protection and strategic trade policy. Given that Spencer and Brander’s (1983) trail-blazing work in strategic trade theory deals with R&D subsides, it is surprising to find that the subsequent developers of the theory have omitted this line, notwithstanding the role of product standards. Such an omission is difficult to justify. The history of the patent institution illustrates its use as a strategic weapon in trade policy right from the beginning.[18] It is perhaps here worth mentioning a finding in the second essay providing some indirect support for the claim in Spero (1990) and Ordover (1991) that the advantages of the Japanese patent system, which is characterised by a weak novelty criterion, stem from the strategic dimensions of trade policy.

Putting aside these problematic issues rooted in international trade and the dispersion of economic development across countries, there is a relatively straightforward way to approach the economics of the globally optimal system of intellectual property protection. It seems that the current international intellectual property laws enable innovators to optimise the geographical scope of protection, and this feature of the laws could be beneficial for global welfare, much as the renewal fees may be welfare-enhancing in Cornelli and Pakes (1996) and Scotchmer (1998) (cf. also section 2.2). One should, however, take the development dimension seriously. The endogenous-growth literature, including notable contributions by Ro-

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[18] For some intriguing historical details, see e.g. Penrose (1951), Kaufer (1986) and Long (1991) In particular, one objective of the Paris Convention was to settle the problems associated with the strategic use of patent law in international trade in the 19th century. For a comprehensive discussion of the international aspects of intellectual property protection, see Wallerstein, Mogee, and Schoen (1993).

mer (1990) and Kortum (1997), clearly recognise the demand for intellectual property rights to boost economic growth, but until recently there has been surprisingly little interest in exploring how various aspects of intellectual property protection do actually influence growth. O'Donoghue and Zweimüller (1998) finally make up some of the deficiency and examine the effects of patent policy by employing an endogenous-growth model. They simultaneously elaborate the theory of intellectual property protection by evaluating patent policy in a general equilibrium framework, as these growth models typically have a general equilibrium character. Herein lies another largely neglected area.

As explained in section 3.2, the evaluation of optimal patent protection, not to mention other instruments of technology policy, is usually carried out in isolation from the rest of the economy. This is particularly unsatisfactory when one would like to investigate technology policy as a whole, even though partial equilibrium analyses such as Romano (1989), Leahy and Neary (1997), Petrakis and Poyago-Theotoky (1997), Hinloopen (1997, 1998), and Stenbacka and Tombak (1998) have provided important insights into the interplay between various policy tools. The principal tools of technology policy, cooperative research, intellectual property rights, and subsidies, undeniably create distortions and have various advantages. Finding the best balance between these tools requires a general equilibrium framework. In the context of endogenous-growth theory, the task should in principle be accomplished, first by combining O'Donoghue and Zweimüller's (1998) model with Davidson and Segerstrom's (1998) study of R&D subsidies and growth and then adding appropriate organisational ingredients. Alternatively, one could adapt a standard public economics approach, a natural point of departure being the general equilibrium model of taxation and imperfect competition, described e.g. in Myles (1995) and Pirttilä (1998).

An economy-wide emphasis does not mean that the microfoundations of the economics of intellectual property protection have thoroughly been explored. Several challenges remain. A topical question is who should own intellectual property. This question clearly has philosophical aspects, and it is no surprise that philosophical arguments in addition to the economic ones have often been put for and against protection of intellectual property. Consider, for instance, the word 'natural' in the quotation from Adam Smith's *The Wealth of Nations* in the Introduction. For economists the question is about efficiency – what innovation ownership structure would maximise social welfare? This question is pursued in Aghion and Tirole (1994a, 1994b) but otherwise there has been little research interest on this topic.

Currently the inventors and the authors in principle hold the property rights to their works, but in practice this right is held by their employers. This satisfies the basic assumption of optimal risk-sharing that all risk should be borne by those less risk-averse, but the task then translates into designing an appropriate incentive scheme to produce inventions. Unlike in the private sector, the right to the inventions in universities in all Nordic countries, Germany and Switzerland is held by the inventor rather than the university. The recent change in the law in the US giving universities the right to retain title to and to licence inventions has stimulated economic research on the optimal ownership of intellectual property in this particular institutional setting. See Jensen and Thursby (1998) for an elegant piece of such research. There is also a considerable policy debate about this issue going on in Finland (see e.g. *Taloussanomat* 6.11.1998 and *Helsingin Sanomat* 9.11.1998).

In general, the role of intellectual property in organisational design relates to an unsolved puzzle of human-capital loss. Why is the departure of key R&D personnel a considerable threat in high-technology companies as well as public-sector research teams, as also pointed out in the fourth essay? Why can the human capital critical for the future economic success of private corporations and other institutions not be prevented from leaking out? Severinov (1997) makes a preliminary attempt to tackle this problem but it still remains far from solved. Beside taking into account intellectual property ownership arrangements, unravelling this puzzle seems to require considering the performance of the labour market and redistributional institutions. Such considerations, properly conducted, may even unravel a much greater mystery in economics. Could the ownership structure of intellectual property be the long-sought origin of permanent inequality?

Turning now to other unanswered questions directly relating to the essays in this dissertation, why has search theory been forgotten in the economics of intellectual property protection, although it was introduced into the economics of innovation by Evenson and Kislev (1976) and Weitzman (1979)? One can also justifiably ask whether there are alternative and more fruitful ways to model innovation than the extensively used Poisson process, even while recalling that the line of research leading to Poisson distribution began with a general payoff distribution (see e.g. Kamien and Schwartz, 1974b). The second essay in this dissertation demonstrates how the Poisson discovery rate arises from a search model as a special case. The next step in research is perhaps to direct effort towards the interaction theory of intellectual property protection and the theory of dynamic R&D competition in a setting in which the pay-off distribution of R&D investments is explicitly modelled. With a recent wave of Bayesian learning models, such as Bolton and Harris (1993), Moscarini and Smith (1997), Bergemann and Välimäki (1998), this should no longer be impractical.

Yet another important but largely overlooked issue is copyright protection, whose importance is only growing with the rise of the Internet. While there are a few papers dealing with the economics of copyright, it is fair to say that the labelling of copyright protection as against patents is usually more a matter of convenience than the result of a conscious effort to make a distinction between an idea and an expression, a distinction which is a salient feature of copyright law. A step in this direction is taken in Essay 2 of this thesis, but the treatment remains inadequate in several respects. Ideally, one would like to have a model incorporating various technologies to innovate and imitate, and heterogeneous consumer preferences in order to be able to distinguish expressions from ideas. This would provide a fruitful ground for the attempt to assess the suitability of various intellectual property laws for discoveries in a wide range of industries. The most obvious and urgent reform in the current system of intellectual property rights is to make it industry-specific.

In doing the case-study included in the fourth essay, we eschewed exploring a number of interesting questions. As a reader of this essay will no doubt notice these questions, only one of them is now explained. Determining the optimal trading mechanism in general is important, but seemingly a complex challenge. In particular, it is unclear why trades are often consummated by bargaining rather than auctions, even if the theory unambiguously predicts the superiority of auctions from the seller's point of view. A special case of this general problem category is the licensing of patented innovations. As Kamien's (1992) careful account of the early licensing literature clarifies, according to the theory the licensor's profit can be maximised by employing auctions. This contrasts strikingly with real-world experience.

Jensen and Thursby (1998) hint that the reason for this contrast between theory and practice in licensing lies in the search frictions, and this may indeed be an explanation of the extensive use of bargaining as shown in Kultti (1997), at least in limited circumstances. But as our case also suggests, the buyer of technology can also let the sellers compete in an auction. Indeed, one result of our own research in this area (Kultti and Takalo, 1998) predicts the superiority of auctions over bargaining even when the agents can choose freely whether to wait or to search, provided that the agents can also commit themselves to a particular trading institution.

A final remark on this problem emerging from our case study is that such a commitment is often not feasible in practice, indicating that bargaining may be an equilibrium trading mechanism because of contract incompleteness. For instance, Seiko, Micro Power Systems's main share-holder, was able to transform the licensing process from an auction to bargaining and managed to alter the licensing contract to its advantage, and in the building project for the manufacturing plant the building company tried to achieve the same change. Transaction cost economists have long insisted that such transformations from auctions to bargaining should be a central concern in the study of contracting, Williamson (1985, 1989) even refers it to as the 'fundamental transformation'. Although this view is no doubt justifed, my conjecture is that the possibility of the 'fundamental transformation' only affects initial bids, leaving the sellers' and buyers' final payoffs unchanged.

One case cannot by definition hope to establish a proof of general propositions, but it can shed light on the opportunities in pursuing large-sample examinations. For instance, it would be intriguing to know whether asymmetric information at the moment of writing a contract is an inherent problem of patent licensing, or an imaginary problem of economists. This directs us to the ultimate question of theory and evidence.

Despite the spectacular growth of theoretical literature over the past 30 years, few general predictions in the economics of intellectual property protection have emerged. It should be evident to every open-minded economist that the theory includes a large number of 'empty economic boxes', a notion attributed to Clapham (1922) which describes logically consistent economic models providing little empirical cutting edge. Against this background, empirical research with sound theoretical foundations has become crucial to progress in these areas. It is perhaps merely wishful thinking that a theory can be built and always verified against evidence within a single piece of research. But a box is not worth making unless one has something to put in it.

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