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Abstract. We present a model where an incumbent firm has a proprietary product whose technology consists of at least two components, one of which is patented while the other is kept secret. At the patent expiration date, an entrant firm will enter the market on the same technological footing as the incumbent if it is successful in duplicating, at certain costs, the secret component of the incumbent's technology. Otherwise, it will enter the market with a production cost disadvantage. We show that under some conditions a broad scope of trade secret law is socially beneficial.

Keywords Knowledge spillovers, Duplication costs, Covenants not to compete, Inevitable disclosure

JEL classification O31, O34

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1. Introduction

Since patents and trade secrets have generally been perceived as mutually exclusive, with few exception the law and economics literature has separately concentrated on the design of optimal patent policy and on the design of optimal trade secret policy.[1] However, while the interest in optimal patent design is long standing and has given rise to large literature in the field, whose origins can be dated back to Nordhaus (1969),[2] the issue of the optimal strength of trade secret protection has received little attention until a short time ago. Only recently, starting from a provocative paper by Bone (1998), some authors have widely discussed the question of whether trade secret deserves a legal protection which goes beyond the contract law or the tort law.[3] In the words of Lemley (2008), "Trade secret law is a puzzle. Courts and scholars have struggled for over a century to figure out why we protect trade secrets. …It seems odd, though, for the law to encourage secrets …..I argue that, paradoxically, trade secret law actually encourages disclosure, not secrecy. Without legal protection, companies in certain industries would invest too much in keeping secrets." In a similar vein Risch (2007) maintains that "trade secret are justified by the economic benefits that flow from their existence, most notably incentives for businesses to spend less money protecting secret information or attempting to appropriate secret information". According to both authors, the reduction of such costs is a sufficient reason for the existence of a trade secret law as a separate doctrine, whereas Bone (1998) has an opposite opinion.

The papers cited above prevalently refer to cases in which a proprietary innovation is protected by trade secret only.[4] However, in spite of the common misperception of an alternative between patents and trade secrets, an innovator can use both intellectual property rights to protect different aspects of the same invention, as "courts have long held that a published patent does not invalidate those trade secrets that are not disclosed in the patent"

[1] In some papers the choice between patent and trade secret protection is explicitly considered, but the strength of trade secret protection is treated as exogenous (e.g., Gallini, 1992; Denicolò and Franzoni, 2008; Cugno and Ottoz, 2006). For a discussion regarding the interplay between optimal patent and trade secret protection, see Erkal (2004). A general discussion on how innovator can prefer secret to patent protection can be found in Friedman, Landes and Posner (1991).

[2] A selection of the first contributions includes Tandon (1982), Gilbert and Shapiro (1990), Klemperer (1990), Gallini (1992).

[3] Previously, Friedman, Landes and Posner (1991) have yet maintained that, since the law does not protect against the loss of trade secrets by accident or by reverse engineering, there is in a sense no law of trade secret as such, concluding that there are good economic reasons for this. See also Landes and Posner (2003).

[4] In Risch (2010) patent-secret mixtures are considered.

(Garvey and Baluch, 2007).[5] Trade secrets can, in fact, "be used in lieu of patents but, more importantly, they can be relied upon at the same time and side by side with patents to protect any given invention…. With patents and trade secrets it is clearly possible to cover additional subject matter, and thereby exploit the overlap and strengthen exclusivity" (Jorda, 2008).

To illustrate how patent and secret can coexist we can assume, for example, that at the time the patent was filed the incumbent firm disclosed the best mode for carrying out the invention; successively, the incumbent firm discovers a better best mode which it can keep secret without bearing the risk of patent invalidation. A possible alternative hypothesis is that the proprietary product consists of several parts, some of which are patented while others are kept secret. However that may be, with respect to the case where patents and trade secrets are mutually exclusive for an innovation on the whole, mixtures of the two protection tools put a specific policy issue. To explain why, assume for simplicity a patent scope so broad as to make any non-infringing imitation impossible. Then, if the innovator can chose to protect its proprietary product through patent or secret but cannot combine the two form of protection, the policy maker's problem consists in the first place in setting the duration of patent protection and the scope of trade secret law that induce the innovator to choose the socially preferable form of protection, given the incentive to innovate. Thus, as Denicolò e Franzoni (2008) pointed out, it may be the case that social efficiency requires that the duration of patent protection, relative to the strength of secret protection, be such that the innovator's choice falls on the patent itself. If, instead, the innovating technology can be protected jointly by patents and secrets and expected secrets' duration is longer than patents' life, policy makers have to solve a different problem. First of all, note that if the innovator can enjoy full patent protection without disclosing all components of its proprietary knowledge, a lengthening in patent life would not have any effects on disclosure decision: in enlarging the disclosure of its technology, the innovator would have nothing to gain and something to lose. Then, the relevant issue becomes: given the patent duration, what is the socially optimal scope of trade secret law for innovations covered by a patent-secret mix? Or, in other words, since innovations covered by a patent-secret mix enjoy the prospect of some protection even after the patent expiration –that is, they are over protected

[5] Interesting examples of patent-secret mix reported by Arora (1997) include German organic dyestuff in the nineteenth century, the Haber Bosch process for producing ammonia, the industrial diamond process technology by General Electric in the fifties. Court decisions such as *C&F Packing v. IBP and Pizza Hut* (Fed. Cir. 2000) illustrated by Jorda (2007) and *Celeritas Technologies v. Rockwell International* (Fed. Cir. 1998) provide more recent examples of a complementary use of patents and trade secrets. Moreover, it is well known that in the software industry source code secrecy frequently complements patents.

with respect to comparable innovations covered only by patents– does society benefit from a low scope of trade secret law?

In this paper we attempt to face this issue by using a model in which the social cost associated with the mixtures of patents and trade secrets includes, besides dead-weight losses and innovative R&D costs, the costs borne by an entrant trying to duplicate that part of the technology protected by trade secret. Leaving aside, for sake of simplicity, costs sustained by the two firms to protect or illicitly obtain information,[6] we focus on the relations between duplication costs (by legal means) and social welfare, along the lines of previous models present in the literature (Gallini, 1992; Maurer and Scotchmer, 2002; Denicolò and Franzoni, 2008). A special feature of our model is nevertheless the relation between duplication expenses, the probability of duplication success, and the scope of trade secret law.

Considering a situation in which transaction costs of trade secret licensing are prohibitive, we determine conditions under which a strong legal protection of trade secret is socially beneficial even if it implies innovator's over-rewarding. This is due to the fact that in our model a broad scope of trade secret law has beneficial effects on the incentive to invest in R&D for the original innovator and permits society to save on wasteful duplication costs borne by a potential entrant. These benefits may more than compensate the reduction in the probability of competitive entry.

The paper is organized as follows. In Section 2 the model is presented and some legal issues are briefly discussed. Section 3 is dedicated to the design of optimal secret protection when secrets complement patents and Section 4 concludes.

2. Employee mobility, knowledge spillover, and duplication costs

The model we will put forward in Subsection 2.2 below refers to a duopoly environment where employee mobility is subject to some contractual and legal restrictions intended to limit spillovers of proprietary non patented information. The scope of trade secret protection is identified with the strength of these restrictions, which we shortly expound in the following subsection.

[6] Accurate analyses of the relation between costs incurred by rival firms in order to protect or misappropriate secret information and the scope of trade secret law can be found in the cited papers by Bone, (1998), Risch, (2007), and Lemley (2008).

2.1. Labor mobility restrictions

Apart form clearly illegal means for appropriating secret information, such as industrial espionage, employee mobility seems to be the main cause of technology spillovers between firms.[7] To the purpose of limiting harmful losses of proprietary information, in employment contracts firms may insert post-employment clauses, known as "post-employment covenants not to compete". In the absence of these covenants, in some cases firms may still resort to a lawsuit by appealing to the "inevitable disclosure doctrine" or similar arguments. The scope of trade secret law largely depends on the degree of jurisdictions' acceptance (and enforcement) of these protection tools.

While post-employment covenants consist of promises by employees not to work for a competitor for a specified period after employment ends, the inevitable disclosure doctrine refers to cases in which such covenants are not signed in the hiring contracts or during the employment relationships. This legal doctrine assumes that "if an employee has knowledge of trade secrets, and accepts a similar job with a direct competitor in a highly competitive firm, he or she will "inevitably" disclose the trade secrets in the course of performing his or her new employment duties" (Paetkau, 2003), so that when the former employer would suffer "irreparable harm" from disclosure this sort of employee mobility should be restricted irrespective of the existence of post-employment covenants. Classical cases where the inevitable disclosure doctrine has been adopted are *PepsiCo., Inc. v. Redmond* (7th Cir. 1995) 54 F.3d 1262 and *IBM v. Papermaster*, 2008 WL 4974508 (S.D.N.Y.), where the notion of "irreparable harm" is introduced. An example of rejection is *Schlage Lock Company v. Whyte* (2002) 101 Cal. App. 4th 1443.

It is worth noting that while enforceability of post-employment covenants not to compete are provided for by the law in almost all U.S. and E.U. jurisdictions, with more or less differences and with the notable exception of California where they are banned, the adoption of inevitable disclosure doctrine is typical of several, but not all, U.S. courts. Besides California, where the doctrine is explicitly refused, some jurisdictions such as Michigan, Missouri, Maryland and Minnesota expressed a few reservations about its application. Despite European courts never refer to some form of inevitable disclosure doctrine, something similar has nevertheless been formulated by the Court of Appeals of Paris in a case reported by Thiébart (2003), where the employee did not signed any post-employment restrictive clause. In its decision rendered on November 10, 1994, the court ruled that "if it is legitimate, in all cases,

[7] With reference to high technology districts see, for example, Saxenian (1994) and Gilson (1999).

that an employee harvest the fruit of the experience he gained with prior employers, which constitutes for the employee a normal factor of enhanced value, this does not justify unfair behavior which can consist in disorganizing a former employer by massive employee departure or in disclosing manufacturing secrets and technical or commercial knowledge in order to enable the latter to capture the clients of the former employer".

In any case, where the inevitable disclosure doctrine –or some equivalent argument– is adopted, the scope of trade secret law tends to be broader than elsewhere. For example, applying the inevitable disclosure doctrine, in *PepsiCo., Inc. v. Redmond* the court analogized PepsiCo's position with respect to a former employee who was about to be hired by a competitor (Quaker) as similar to that of "a coach who had lost a valuable player to the opposing team, playbook in hand, on the night before a decisive game. Accordingly, it affirmed the district court order enjoining Redmond from assuming his position at Quaker and preventing him forever from disclosing PepsiCo trade secrets and confidential information" (Kaplan and Hanlon, 2004)

The differences in conditions for enforceability of post-employment covenants mainly concern geographical and temporal restrictions, employees' job positions with respect to access to trade secrets, and employee financial compensations. For example, financial compensation to the employee must be explicitly provided for in employment contracts (personal or collective) in almost all E.U. states, while other jurisdictions –notably, the overwhelming majority of states in the U.S., Norway, Switzerland, Iceland and, inside E.U., Great Britain– do not require special consideration in labor contracts for worker's agreement to a non competition covenant.[8] As far as California is concerned, Business and Professions Code section 16600 provides that "every contract by which anyone is restrained from engaging in a lawful profession, trade, or business of any kind is to that extent void." Californian courts have interpreted section 16600 "as broadly as its language reads",[9] so that they not only reject the doctrine of inevitable disclosure, but they also refuse to enforce post-employment covenants. See Gilson (1999), where the high labor turnover in Silicon Valley is ascribed to the weakness of trade secret protection in California, in contrast with the low employee mobility in Route 128 district governed by Massachusetts trade secret law.

[8] Source http://www.ilo.org/public/english/dialogue/ifpdial/downloads/judges06/nc.pdf.

[9] *Scott v. Snelling & Snelling, Inc*. 732 F. Supp. 1034, 1042 (N.D. Cal 1990).

2.2. The model

First, let's distinguish between pre- and post-innovation stages. In the post-innovation stage, a firm, labeled I (innovator/incumbent), owns a proprietary product jointly protected by patents, whose normalized length is T,[10] and trade secrets, which have no fixed expiration date.[11] Patents are assumed to be broad enough to make any non-infringing imitation impossible, so that competitors cannot enter the market before patent's expiration –that is, we assume that the disclosed part of the technology is protected by ironclad patens, and no imitating product can be obtained without it. As a consequence of this assumption the overall strength of patent protection is fully captured by the patent's life. At the patent expiration date a new firm, called firm E (entrant), is founded. This new-generation firm will attempt to duplicate the secret information by spending resources at this aim: it will enter the market bearing the same production costs of firm I, if duplication is successful, or higher costs –those associated with the information disclosed in the patent– if the duplication attempt fails.

We assume that each employee of the incumbent firm has only a piece, more or less important, of information on the whole set of secrets owned by his or her employer.[12] To the purpose of duplicating the secret parts of firm I's technology, firm E may take advantage of some knowledge spillover, whose intensity essentially depends on how easily firm I's employees can join the new generation firm. Employee mobility in turn depends on the scope of trade secret law, more specifically on the enforceability of post-employment covenants not to compete, and on the adoption or rejection by courts of the inevitable disclosure doctrine (in the U.S.) or similar legal arguments. For example, under California law, which bans covenants not to compete and refuses the inevitably disclosure doctrine, employee mobility practically has no limits: in our meaning, the scope of trade secret law is at a minimum. Elsewhere, covenants non to compete are enforceable if they respect some more or less restrictive standards, according to which labor mobility is more or less facilitated. Note that a typical standard regards covenants' duration (often 3 or 5 years after the employment relationship has been terminated): but even if

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[10] Given a patent life of t years, the normalized length is defined as $T = 1 - e^{-rt}$, where r is the discount rate.

[11] Although an innovator can often choose the extent patents and trade secrets combine with one another, in this paper we assume a given patent-secret mix. For a model where the patent-secret mix results from a maximizing choice, see Ottoz and Cugno (2008).

[12] Fragmentation of secret information is a common defensive practice. It is the most prominent example of what Risch (2007) refers to as a "non-standard" precautionary measure.

their validity is limited in time, enforcement of such agreements make up a hindrance to labor mobility, so reducing knowledge spillover (Gilson, 1994; Hyde, 2003; see also Fudenberg and Tirole, 1983, p. 529).

By utilizing the set of information obtained through employee mobility, whatever its dimension, at time T firm E will spend resources to duplicate all components of firm I's technology protected by trade secret. Given the sum spent for duplication, called K^E, the probability of success, γ, will increase with the dimension of the set of disposable information, which in turn diminishes as the scope of trade secret law increases. In what follows, for sake of simplicity we treat the scope of trade secret law as a continuous variable depending on the conditions required by the relevant courts for enforcing post-employment covenants or applying the inevitable disclosure doctrine.

On these bases, and adopting the usual convexity hypothesis for a cost function, we assume that the probability of duplication success, the duplication effort, and the scope of trade secret law, are linked by the relation

$$K^E = \theta g(\gamma), \tag{1}$$

where $g(0) = 0$, $g'(\gamma) > 0$, $g''(\gamma) > 0$ and the shift parameter θ is a measure of the duplication difficulty which increases as the scope of trade secret law is broadened. Note that this approach is very similar to the one adopted by Takalo (1998) in a model with costly patent imitation: the only difference is that in our case the duplication difficulty depends on the strength of trade secret protection, not on patent breadth.

If the attempt is successful, from time T firm E will compete on the same technological footing with firm I, so that it will obtain for ever a stream of symmetric-cost duopoly profits equal to π_{SD}^E. If the attempt fails, firm E may enter the market with a production cost associated with the information disclosed in the patent application, that is with higher costs than firm I. In this case firm E will gain a stream of asymmetric-cost profits $0 \le \pi_{AD}^E < \pi_{SD}^E$. Given that r represents the discount rate, firm E will then choose γ by maximizing the expected rent

$$R^E = \frac{(1-\gamma)\pi_{AD}^E + \gamma\pi_{SD}^E}{r} - \theta g(\gamma). \tag{2}$$

If an interior solution exists, the privately optimal value of γ will be determined by

$$g'(\gamma) = \frac{\pi_{SD}^E - \pi_{AD}^E}{r\theta}, \tag{3}$$

from which

$$\frac{d\gamma}{d\theta} = -\frac{\pi^E_{SD} - \pi^E_{AD}}{g''(\gamma) r\theta^2} = -\frac{g'(\gamma)}{g''(\gamma)\theta}. \tag{4}$$

So, as it was logical to expect, an increase in the scope of trade secret law reduces the privately optimal level of γ.

Let's now go backward to the pre-innovation stage. In analogy with the cost function (1), suppose that the innovation effort, K^I, and the probability of success, β, are linked by the relation $K^I = f(\beta)$, where $f(0) = 0$, $f'(\beta) > 0$, $f''(\beta) > 0$. We consider two opposite possibilities: unanticipated and anticipated concealability.

• *Unanticipated concealability*. Suppose that when deciding R&D expenses the innovator does not expect that some pieces of the technology to be discovered will be concealable without incurring the risk of losing patents' protection on the whole proprietary product. Only if and after the innovation has been achieved, this possibility becomes clear. This means that the innovator's expected rent is

$$R^I = \beta\left(T\frac{\pi_M}{r} + (1-T)\frac{\pi^I_{SD}}{r}\right) - f(\beta), \tag{5}$$

where π_M and π^I_{SD} are, respectively, the flow of monopoly profits granted by patents and the innovator's profit flow under symmetric-cost duopoly. Then, if R^I has an interior maximum, the privately optimal value of β will be determined by

$$f'(\beta) = T\frac{\pi_M}{r} + (1-T)\frac{\pi^I_{SD}}{r}, \tag{6}$$

from which $d\beta / d\theta = 0$.

If the inventive effort is successful and the entire technology is disclosed and patented, the present value of innovator's profits obviously will be $T\pi_M / r + (1-T)\pi^I_{SD} / r$. But if some relevant pieces of technology can be unexpectedly not disclosed in the patent filings, with probability $1-\gamma$ after patents' expiration the innovator will enjoy the flow of profit π^I_{AD} associated with the cost asymmetry granted by trade-secrets, so that the present value of innovator's expected profits will be $T\pi_M / r + (1-T)((1-\gamma)\pi^I_{AD} + \gamma\pi^I_{SD}) / r$. Since $\pi^I_{AD} > \pi^I_{SD}$, in this case, and in a certain sense, the innovator turns out to be over rewarded: while the expectation of monopoly profits during the patents' life and symmetric-duopoly profits after patents' expiration would be sufficient incentives to R&D effort in fact borne, with probability $1-\gamma$ the innovator will enjoy additional advantages from the non-disclosed information.

Since under the above assumptions the gains associated with concealability do not depend on programmed R&D expenses, the pieces of technology unexpectedly concealable can be analogized to serendipitous inventions. This implies that the incentive to innovate depends only on patents' duration, while the scope of trade secret law determines how much the patent-secret holder is potentially over rewarded with respect to the remuneration that would be sufficient to induce the R&D expenses actually incurred. So, in this case we can study the social effects of duplication activities in a comparable way with the relevant strand of literature that justifies (or does not justify) the existence of specific trade secrets laws on the ground of their ability to reduce private expenses in protection costs, while creating incentives to innovate is considered a very minor justification (Bone, 1998; Landes and Posner, 2003; Risch, 2007; Lemley, 2008).[13]

• *Anticipated concealability*. If the innovator knows in advance that some parts of the technology to be discovered will be protectable through trade secret, its expected rent becomes

$$R^I = \beta\left(T\frac{\pi_M}{r} + (1-T)\frac{(1-\gamma)\pi^I_{AD} + \gamma\pi^I_{SD}}{r}\right) - f(\beta), \tag{7}$$

so that the privately optimal β will be determined by

$$f'(\beta) = T\frac{\pi_M}{r} + (1-T)\frac{(1-\gamma)\pi^I_{AD} + \gamma\pi^I_{SD}}{r}, \tag{8}$$

from which, by using equation (4), $d\beta / d\theta > 0$.

In this case, unlike in the previous one, the scope of trade secret law affects the innovator's decisions −that is, the incentive to innovate depends now, besides on patents' duration, on the strength of trade secret protection. As we will see, this implies that the range of parameters over which a broad scope of trade secret law is socially efficient turns out to be expanded with respect to the case of unanticipated concealability.

3. Choosing the scope of trade secret law

In this section we first use our simple duopoly model to determine the optimal scope of trade secret law for a given patent length. In doing this we assume that, due to high transaction costs, trade secret licensing is not mutually convenient. Then we consider some special cases characterized by different market behaviors.

[13] Other related works are that which formalizes the social consequences of the private choice between patent and trade secret protection in the light of the contract theory of patents (Denicolò and Franzoni, 2004, 2008; Cugno and Ottoz, 2006). Even here, intellectual property laws are viewed exclusively in their role in incentivizing cost-saving.

3.1. Optimal scope

Let's indicate with Δ_M the stream of dead-weight loss associated with monopoly, with Δ_{SD} the stream associated with symmetric-cost duopoly, and with Δ_{AD} the stream associated with asymmetric-cost duopoly. With probability $1-\gamma$ firm E is not successful in the duplication attempt so that after patent expiration firm I will enjoy a production cost advantage. In this case the stream of dead-weight loss will be Δ_M during patent life and $\Delta_{AD} \leq \Delta_M$ soon after the expiration date. If, on the opposite, firm E is successful in the duplication attempt, after patent expiration the stream of deadweight loss will be $\Delta_{SD} < \Delta_{AD}$. This event has probability γ. The post-innovation expected social cost, SC, is the sum of the expected present value of dead-weight losses and of the present value of the cost borne by firm E to duplicate the secret. Then,

$$SC = T\frac{\Delta_M}{r} + (1-T)\left(\frac{\gamma\Delta_{SD} + (1-\gamma)\Delta_{AD}}{r} + \theta g(\gamma)\right), \tag{9}$$

so that the present value of expected social welfare turns out to be

$$SW = \beta(\overline{SW} - SC) - f(\beta), \tag{10}$$

where $\overline{SW}$ stands for the present value of social welfare that would prevail under perfect competition.

Maximizing SW with respect to θ and T under the constraints that the innovator and the duplicator choose R&D and duplication expenses in the privately optimal ways described above, we in general can determine the socially optimal combination of patent length and trade secret scope for innovations of the kind we are dealing with. As the choice of patent length is, nevertheless, relevant also for innovations whose components are all protectable only by patents, may be that policy makers whish to fix T in order to not penalize this second type of innovations. If so, the problem becomes that of verifying if a reduction in the scope of trade secret law, facilitating in prospect competitive entry, enhances social welfare. Propositions 1 and 2 below show that under certain conditions the opposite happens.

Before proceeding, it is useful to define the elasticity of probability of firm E's duplication success with respect to the expense for duplication. As we will see, this elasticity, given by $\eta = (d\gamma / dK^E)(K^E / \gamma) = g(\gamma)/ g'(\gamma)\gamma$, will turn to be crucial for our result.

Proposition 1. *Unanticipated concealability*. Suppose the innovator does not anticipate that some pieces of the technology to be discovered will be concealable. Then, the condition

$$\eta + \frac{d\eta}{d\gamma}\gamma > \frac{\Delta_{AD} - \Delta_{SD}}{\pi_{SD}^E - \pi_{AD}^E} \quad \text{for all } \gamma \in (0,1) \tag{11}$$

is sufficient and necessary for social welfare to be monotonically increasing in the scope of trade secret law .

Proof. Since in this case $d\beta / d\theta = 0$ (see equation (6)), differentiating SW in equation (10) we have $dSW / d\theta = -\beta(dSC / d\theta)$. By using equations (3), (4) and (9) we can verify that if

$$\frac{(g'(\gamma))^2 - g(\gamma)g''(\gamma)}{(g'(\gamma))^2} > \frac{\Delta_{AD} - \Delta_{SD}}{\pi_{SD}^E - \pi_{AD}^E} \tag{12}$$

this derivative is positive. (See the Appendix for details.) On the other hand, differentiating $\eta = g(\gamma) / g'(\gamma)\gamma$ and rearranging terms, we have

$$\frac{(g'(\gamma))^2 - g(\gamma)g''(\gamma)}{(g'(\gamma))^2} = \eta + \frac{d\eta}{d\gamma}\gamma . \tag{13}$$

Thus, inequality (12) corresponds to inequality (11). The statement immediately follows. ■

The rationale of Proposition 1 is that when condition (11) holds a high legal protection of trade secret allows society to save on duplication costs that would be otherwise borne by firm E: this saving may be sufficient to more than compensate the increase of the expected present value of dead-weight losses caused by the reduction of the probability that the duplication attempt is successful[14] Although it may seem odd that these social benefits can be more likely obtained just for high levels of the elasticity η, that is when at the margin duplication expenses are more likely to involve reductions in the present value of expected deadweight losses, the reason stays on the incentive effects of high levels of this elasticity. In fact, it is precisely a high marginal (expected) productivity of duplication expenses in terms of the probability γ that may create incentives to invest in duplication too strong from a social point of view. In other words, for η high and θ low private optimality implies investments in duplication too high relative to the expected benefits on social welfare.

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[14] It is worthwhile noticing that the hypotheses we have formulated on the relation between γ, k and θ are crucial for the above result. Other models assume that the probability of success in duplicating the secret technology is equal to 1 provided that the entrant invests a given amount of resources for that purpose and that there exists a positive probability (obviously smaller than 1) of total leakage of the secret. (See Denicolò and Franzoni, 2008; see also Gallini, 1992, where the duplication cost of the secret doesn't play any role, but there is a probability of total leakage and a probability equal to 1 of non infringing patent imitation if the imitator invests for that goal a sufficient sum.) In these circumstances, if the probability of total leakage is negatively affected by the scope of trade secret law, it would be always optimal to adopt a policy of minimum trade secret protection. In fact, as duplication expenses do not depend on policy makers' choices, it would be advisable to get the maximum probability of total leakage.

Proposition 2. *Anticipated concealability*. If the innovator anticipate that some part of the technology to be discovered will be concealable, the range of parameters over which social welfare increases with the scope of trade secret law is broader than that identified in Proposition 1.

Proof. Some calculations involving equations (7), (8) and (10) show that in this case $dSW/d\theta = -\beta(dSC/d\theta) + (1/\beta)(SW - R^I)(d\beta/d\theta)$. The statement follows from the facts that: (i) $SW > R^I$ (besides the expected innovator's rent, expected social welfare comprehends the expected entrant's rent and consumer surplus); (ii) $d\beta/d\theta > 0$ (see equation (8)); and (iii) under the assumption underlying Proposition 1 $dSW/d\theta$ is positive if and only if $-\beta(dSC/d\theta) > 0$. ■

Obviously, the above result is due to the effects on the incentive to innovate that a broad scope of trade secret law has in the case of anticipated concealability but not in the opposite case. Under anticipated concealability, a broadening in the scope of trade secret law increases R&D expenses, but the positive effects through the probability β overweighs this increment in costs, enhancing social welfare for any given SC. Then, condition (11) of Proposition 1 is no longer necessary, but only sufficient, for social welfare to be increasing in the scope of trade secret law.

3.2. Reverse engineering, protection costs, and rent dissipation

In Samuelson and Scotchmer (2002) the authors argument that "When a particular means of reverse engineering makes competitive copying too cheap, easy, or rapid, innovators may be unable to recoup R&D expenses. If so, it may be reasonable to regulate that means. Anti-plug-mold laws … are an example. Using a competitor's product as a "plug" to make a mold from which to make competing products permits competitive copying that is so cheap and fast that it undermines the incentives to invest in designing an innovative product. Restrictions on plug-molding may restore adequate incentives to make such investments". Provided that the cost of reverse engineering is high enough, according to the authors the innovator can prevent it entirely, especially if a licensing strategy for preventing unlicensed entry is adopted. In this case, licensing will be on terms that permit the innovator to recoup its R&D expenses, while at the same time constraining the exercise of market power in order to dissuade other potential entrants. As a consequence, society saves on wasteful duplication costs.

Since regulation of reverse engineering can be viewed as equivalent to a broadening in the scope of trade secret law, our result partially parallels the above arguments. We show, however, that society can gain from making duplication more difficult even when, due to high transaction costs, licensing is not an option. Note moreover that these social gains are independent of any possible reduction in innovator's expenses on protection against misappropriation caused by a broadening of trade secret law. If we were considering the arguments in Risch (2007) and Lemley (2008) that information-owners' expenses to prevent illegal appropriation efforts diminishes as the strength of legal trade-secret protection increases, our result would be reinforced in that the range over which a broad scope of trade secret law is efficient would be expanded.

Finally, note that in terms of the rent dissipation theory our result can be reed as follows. At the patent expiration, duplicator's entry implies a decrease in producer surplus (because joint duopoly profits are less than monopoly profits) and increases consumer surplus. Moreover, the entrant firm will spent some money in attempting duplication of trade-secrets. Thus, if the sum of duplication expenses plus the reduction in joint profits outweighs the increase in consumer surplus, at the social level we have a (partial) post-invention rent dissipation – the second type of rent dissipation envisaged by Grady and Alexander (1991). Under condition (11) in Proposition 1, this type of rent dissipation is minimized when the scope of trade secret law is at a maximum.

3.3. Some special cases

To gain more insights into the meaning and relevance of condition (11) in Proposition 1 it is useful to consider different market behaviors under linear output demand and constant marginal costs. Assume therefore the inverse demand function $P = a - Q$, where P is market price and Q is total output. Also assume that, with respect to the superior technology which allows to produce at constant marginal costs equal to zero, the inferior technology implies a constant cost disadvantage equal to ε.[15] Under the above linearity assumptions and the additional hypothesis that the function $g(\gamma)$ is iso-elastic ($d\eta / d\gamma = 0$), condition (11) can be written

$$\eta > \frac{\Delta_{AD} - \Delta_{SD}}{\pi_{SD} - \pi_{AD}} = \frac{(1/2)(P_{AD})^2 + \varepsilon q_{AD}^E - (1/2)(P_{SD})^2}{P_{SD} q_{SD}^E - (P_{AD} - \varepsilon) q_{AD}^E}, \tag{14}$$

[15] No loss of generality is implied by setting marginal costs associated with the superior technology equal to zero. If these costs were supposed positive, the demand function could simply be rescaled to produce the same results.

where q_i^E, $i = SD, AD$, stands for firm E's output.[16] In what follows we will examine Cournot competition (integrated with limit pricing), Stackelberg competition with the incumbent firm acting as the quantity leader, collusion, and incumbent's post-patent monopoly. In this way we can obtain approximate numeric information about the pairs (η, ε) for which, given the market behavior, condition (11) in Proposition 1 is fulfilled.

• *Cournot competition*. Suppose $\varepsilon < P_M = a/2$, where P_M stands for monopoly price. Under Cournot duopoly, where each firm chooses a quantity to produce that maximizes its profit flow given the expectation that the rival firm maintains its output level fixed, firm E's outputs and market prices are given by $q_{SD}^E = a/3$, $q_{AD}^E = (a-2\varepsilon)/3$, $P_{SD} = a/3$, $P_{AD} = (a+\varepsilon)/3$. Then, condition (14) becomes

$$\eta > \frac{8a - 11\varepsilon}{8a - 8\varepsilon}.$$

Since the ratio $(8a - 11\varepsilon)/(8a - 8\varepsilon)$ decreases as ε increases, approaching the value of $5/8$ as ε tends to the point $a/2$, at which and above the incumbent firm enjoys full monopoly power even after patent expiration, a necessary condition for inequality (14) to be satisfied is $\eta > 5/8$. For $\eta > 5/8$ inequality (14) can be fulfilled provided that ε is sufficiently high (see the shaded zone in Figure 1, panel *i*).[17] In particular, this event is the more likely the more relevant is the secret part of technology in terms of production costs and the more productive is at the margin the expense for duplication, that is for high levels of ε and η. This is due to the fact that for any θ duplication becomes more attractive as ε and η increase, so that a strong trade secret protection permits the society to save resources whose amount exceeds the expected present value of dead-weight losses associated with no duplication.

[16] Since Pareto-optimal output is equal to a, deadweight-loss triangles are given by $(1/2)P_i(a - Q_i) = (1/2)(P_i)^2$, $i = SD, AD$. When $i = AD$, we must add the total extra cost born by firm E, that is εq_{AD}^E.

[17] Note that the elasticity η is upper bounded at 1 because the assumptions $g''(k) < 0$ and η = constant are incompatible with $\eta \geq 1$.

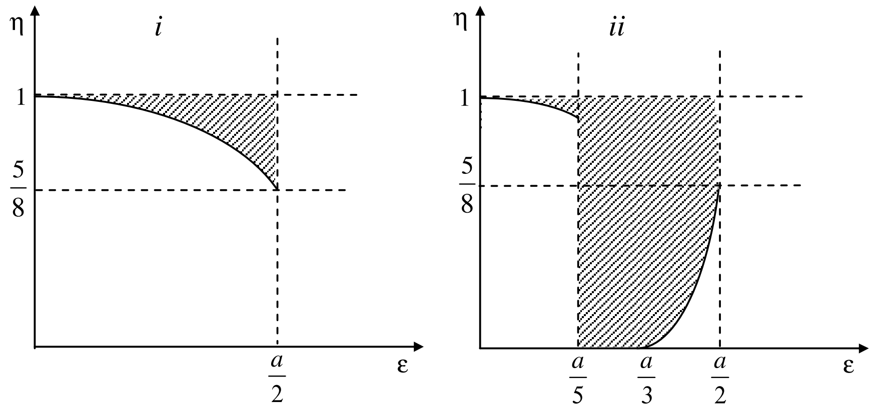

Figure 1. Condition (14) under Cournot competition (panel *i*) and limit pricing (panel *ii*).

• *Cournot competition and limit pricing*. In considering the above kind of competition we have ignored that when firm E fails in its duplication attempt the incumbent can prefer to deter entry by resorting to a limit pricing strategy, that is by setting the price at $P_{AD} = \varepsilon$. Specifically, comparing the value of the incumbent's profit flow under limit pricing with the corresponding value under asymmetric-cost Cournot duopoly, we can verify that limit pricing turns out to be a superior alternative for the incumbent if $a/5 < \varepsilon < a/2$.[18] Suppose then that the two firms compete à la Cournot when the entrant succeeds in duplicating the secret technology or, if it does not succeed, when $\varepsilon < a/5$. Otherwise, the incumbent adopts a limit pricing strategy, so that if the entrant firm fails the duplication attempt and $a/5 < \varepsilon$, its output will be zero. Then, since for $a/5 < \varepsilon < a/2$ we have $q_{SD}^{E} = a/3$, $q_{AD}^{E} = 0$, $P_{SD} = a/3$, $P_{AD} = \varepsilon$, while for $\varepsilon < a/5$ the results for Cournot competition hold, condition (14) becomes

$$\eta > \begin{cases} \dfrac{8a - 11\varepsilon}{8a - 8\varepsilon}, & \text{for } \varepsilon < \dfrac{\text{a}}{5}, \\ \dfrac{9\varepsilon^2 - a^2}{2a^2}, & \text{for } \dfrac{a}{5} < \varepsilon < \dfrac{a}{2}. \end{cases}$$

Contrary to what happens in the case illustrated in panel *i* of Figure 1, the right-hand part of the inequality $\eta > (9\varepsilon^2 - a^2)2a^2$, starting from negative levels for $\varepsilon = a/3$, increases with ε

[18] The incumbent's profit flow under asymmetric-cost Cournot duopoly is given by $(a+\varepsilon)^2/9$. Comparing this value with the profit flow under limit pricing, $\varepsilon(a-\varepsilon)$, it follows that limit pricing turns out to be a strictly superior alternative for the incumbent if and only if $10\varepsilon^2 - 7a\varepsilon + a^2 < 0$, which implies $a/5 < \varepsilon < a/2$.

until reaching the value of $5/8$ at the point $\varepsilon = a/2$, at which entry is no more a problem for the incumbent. This is explained by the fact that under limit pricing, while Δ_{AD} increases with ε as under Cournot competition, π^E_{AD} is null for all ε. It follows that $a/5 < \varepsilon < a/3$, or $a/5 < \varepsilon < a/2$ together with $\eta > 5/8$, are sufficient conditions for inequality (14) to be fulfilled (see the shaded zone in Figure 1, panel *ii*). In these intervals, expected deadweight losses associated with no duplication are so small, or duplication is so attractive, that a strong trade secret protection which allows to save duplication expenses turns out to be beneficial for society.

• *Stackelberg competition*. Suppose again $\varepsilon < P_M = a/2$. Under Stackelberg competition, with firm I being the quantity leader, firm E maximizes its profit flow treating firm I's output as given. In turn, firm I maximizes its profit anticipating firm E's reaction. The equilibrium firm E's quantities and market prices are $q^E_{SD} = a/4$, $q^E_{AD} = \max[(a-3\varepsilon)/a, 0]$, $P_{SD} = a/4$, $P_{AD} = \min[(a+\varepsilon)/4, a/3]$. Then, condition (14) becomes

$$\eta > \max\left[\frac{10a - 23\varepsilon}{12a - 18\varepsilon}, \frac{7}{18}\right].$$

As under Cournot competition, there exists a level of η below which inequality (14) cannot be fulfilled. Since for $\varepsilon \geq a/3$ firm E's output is zero, this level is now $\eta = 7/18$. As ε decreases in the interval $0 < \varepsilon < a/3$, the ratio $(10a - 23\varepsilon)/(12a - 18\varepsilon)$ increases, until reaching the value $5/6$ at $\varepsilon = 0$. Thus, condition (14) turns out to be more likely fulfilled under Stackelberg than under Cournot competition (see the shaded zone in Figure 2). The reason for this is that in the ideal passage from Cournot to Stackelberg competition, for each $\varepsilon < a/3$ both the differences $\Delta_{AD} - \Delta_{SD}$ and $\pi^E_{SD} - \pi^E_{AD}$ decrease, but $\Delta_{AD} - \Delta_{SD}$ decreases more than $\pi^E_{SD} - \pi^E_{AD}$.[19]

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[19] Under Stackelberg competition there exists no $\varepsilon < a/3$ such that limit pricing is a privately superior alternative. This can be viewed by comparing the incumbent's profit flows under asymmetric-cost Stackelberg duopoly, given by $(a+\varepsilon)^2/8$, with the profit flow under limit pricing, that is $\varepsilon(a-\varepsilon)$. For $a/3 < \varepsilon < a/2$ limit pricing and Stackelberg solutions coincide.

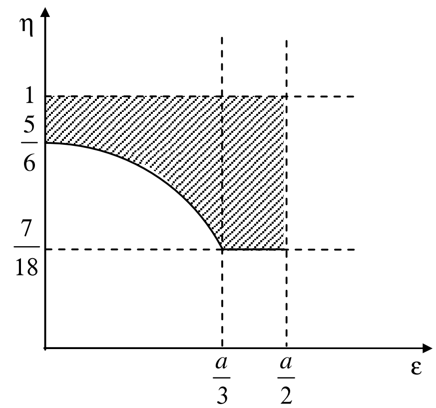

Figure 2. Condition (14) under Stackelberg competition

• *Collusion*. Antitrust notwithstanding, it may be that the two firms collude, in the sense that firm I pays firm E a fee, negatively related to the cost differential, and firm E stays out of the market. If this is a real possibility, condition (14) is surely respected: in fact, since $P_{SD} = P_{AD} = P_M$ and $q_{AD}^E = 0$, condition (14) reduces to $\eta > 0$, that is, it is fulfilled for any relevant pair (η, ε).[20]

• *Incumbent's post-patent monopoly*. Until now we have assumed that $\varepsilon < a/2$. If $\varepsilon \geq a/2$ and firm E fails its duplication attempt, firm I continues to enjoy full monopoly power beyond the date of patent expiration. In this case, when the two firms compete à la Cournot if the duplication attempt succeeds, market prices and firm E's outputs in condition (14) will be $q_{SD}^E = a/3$, $q_{AD}^E = 0$, $P_{SD} = a/3$, $P_{AD} = P_M = a/2$. Then, condition (14) reduces to $\eta > 5/8$. When, instead, the incumbent can act as a Stackelberg quantity leader, we have $q_{SD}^E = a/4$, $q_{AD}^E = 0$, $P_{SD} = a/4$, $P_{AD} = P_M = a/2$, and condition (14) becomes $\eta > 3/2$, which cannot hold.[21] Summing up, when entry does not occur because of a cost differential greater than the monopoly price and η is constant, condition (14) can be fulfilled under potential Cournot competition but not if the incumbent firm is able to act as a Stackelberg leader.

[20] Note that under collusion π_{SD}^E and π_{AD}^E are given by the fees paid by firm I in the two situations.
[21] See footnote 17 above.

3.4. The elasticity of duplication probability

We have seen that under Cournot competition a necessary condition for inequality (14) to hold is $\eta > 5/8 = 0.625$. Likewise, under Stackelberg competition inequality (14) cannot be fulfilled if η does not exceed the value $7/18 = 0.388$. As there is no empirical evidence on the value of η −which measures the elasticity of individual probability of duplication success with respect to the individual expense for duplication− the only thing we can say is that likely it varies greatly according to the innovation type, in the same way as the elasticity of the supply of inventions −which can be viewed as the elasticity of the aggregate probability of invention success, empirically proxied by the number of patent applications, with respect to aggregate research expenses− appears to vary greatly across sectors and over time (see Denicolò, 2007, and the literature cited therein).[22] Since something similar seems to hold for the cost differential ε, the only conclusion we can sensibly drawn is that there may exist particular market situations where fulfillment of condition (14) cannot be excluded. Obviously, at the present no policy implication can be deducted, either for the aggregate or for specific sectors.

4. Conclusion

We presented a simple model in which an incumbent firm owns a proprietary product protected by a mixture of patents and trade secrets. At the patents' expiration date an entrant tries to duplicate the secret part of the incumbent's technology, with a probability of success depending on the amount of resources devoted to this aim and on the quantity of usable knowledge spilled out of the incumbent firm, which in turn depends on the scope of trade secret law. Then, when the patent will expire the competitor will enter the market at the same production cost as the incumbent if duplication is successful, or higher costs if the duplication attempt fails. We showed that in this context, under some conditions a broad scope of trade secret law may be socially beneficial, either if the innovator, when deciding R&D expenses, anticipates that some pieces of the technology to be discovered will be concealable, or if concealability becomes a serendipitous opportunity after the innovation has been achieved.

[22] Available estimates of the elasticity of the supply of inventions range from about 0.3 to about 1, depending on data sets and estimation methods. This great variability of estimates just suggests that the true elasticity may vary across sectors and over time.

For example, in a linear Cournot duopoly a sufficient condition for a strong trade secret protection to be socially beneficial is that the secret part of technology is rather relevant in terms of production costs and the probability of duplication success is sufficiently elastic with respect to the expenses for duplication. This result holds for a wider range of parameters when the incumbent firm can act as a Stackelberg leader or adopts a limit pricing strategy or colludes with the entrant. In any case, independently of the innovator's forecasting ability, a strong trade secret protection may be collectively efficient in that it allows society to save on duplication costs that would otherwise be borne by the entrant firm: such saving may be sufficient to more than compensate the relatively high expected present value of dead-weight losses associated with a low probability that the duplication attempt is successful.

Appendix

Differentiating equation (10) with $d\beta / d\theta = 0$ we have

$$\frac{dSW}{d\theta} = -\beta \frac{dSC}{d\theta} = \beta(1-T)\left(\frac{\Delta_{AD} - \Delta_{SD}}{r} \frac{d\gamma}{d\theta} - \theta g'(\gamma) \frac{d\gamma}{d\theta} - g(\gamma) \right),$$

that is, by using equations (4) to eliminate $d\gamma / d\theta$ and rearranging terms,

$$\frac{dSW}{d\theta} = -\beta \frac{dSC}{d\theta} = \beta \frac{1-T}{g''(\gamma)} \left((g'(\gamma))^2 - g(\gamma) g''(\gamma) - \frac{\Delta_{AD} - \Delta_{SD}}{r\theta} g'(\gamma) \right).$$

At this point it is easy to verify that $dSW / d\theta$ turns out to be positive if and only if

$$\frac{(g'(\gamma))^2 - g(\gamma) g''(\gamma)}{g'(\gamma)} > \frac{\Delta_{AD} - \Delta_{SD}}{r\theta},$$

that is, by using equation (3), if and only if

$$\frac{(g'(\gamma))^2 - g(\gamma) g''(\gamma)}{(g'(\gamma))^2} > \frac{\Delta_{AD} - \Delta_{SD}}{\pi^E_{SD} - \pi^E_{AD}},$$

which is inequality (12) in the proof of Proposition 1.

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