Little Firms and Big Patents: The Incentives To Disclose Competencies

Wolfgang Gick*†

October 26, 2004

Abstract

This paper offers a theoretical treatment of information disclosure through patenting. We consider a signaling model in which two domestic firms disclose their competencies to a foreign firm. Conditions are discussed under which separating and pooling equilibria occur, together with a domination-based refinement. Depending on the payoff situation of the foreign firm, separating and semi-separating equilibria occur in which the firm with the higher competencies discloses. We show that subsidizing the costs of patent applications has no impact on the outcome.

JEL Classification: *D21, D43, L24, O31, O34.*
Keywords: *Patenting, Disclosure, R&D Cooperations, Asymmetric Information.*

Dartmouth Working Paper 04-3, Department of Economics.

*Department of Economics, Dartmouth College, 6106 Rockefeller Hall, Hanover, NH 03755, ph. (603) 646 0641, fax (603) 646 2122, e-mail w.gick@dartmouth.edu
†Center for European Studies, Harvard University.

1 Introduction

Recent contributions on open and voluntary information disclosure have delivered some insight into why firms may be interested in freely revealing technological knowledge to other firms and to technology users.[1] So far, this newly shaping literature has already characterized a variety of channels by which firms disclose information. While future empirical studies will reveal whether patents are substitutes or complements to other means of open knowledge disclosure, this topic is becoming of interest for theoretical research. In this paper, we follow Muller and Penin's (2004) broader idea that firms may want to disclose their knowledge through patent applications. We examine the incentives why and under which conditions firms signal their competencies to firms located in a foreign country, and under which conditions they don't. In a broader perspective, our paper connects back to the early patenting literature that highlights the informational role of patents together with patent scope. It also relates to some arguments on disclosure and enablement, in particular to the often-stated and insufficently illuminated fact that the patent system itself is a mechanism by which firms through patenting signal information to other firms and technology users (Wright 1983, Merges and Nelson 1990).[2]

After the 1998 surge in patenting in North America that can, by and large, explained by the reforms of the relative patent systems (Cohen et al., 2002, Gallini 2002, Kortum and Lerner 1999), it is worth to connect to arguments in the current policy debate on re-designing patent systems.[3] A well-known argument has been that small innovative firms do not file patent applications with a comparable frequency as large firms do, because the procedure is far too costly. In particular, the high costs of international filing procedures at the European Patent Office (EPO) have been a major concern for policymakers.[4] While an institutional reform is still pending, policymakers have tried to mitigate some disadvantages outlined above by offering subsidies that cover patent application fees, patent attorney services, and related expenses in order to encourage small firms to increase their patent portfolio beyond their home country. Current policy debates in the EU underline the priority given to the redesign of the patent system, strongly emphasizing its informational role.[5]

In this paper we argue that patent applications in large regions (Europe, U.S.) may become a signaling device for firms in specific regions and small countries to signal the quality to potential foreign R&D partners.

We offer a theoretical treatment of patent subsidies for a particular setting in which two firms, located in the same country, have already gained patent protection by a nationwide granted patent. Both firms need to decide whether to apply for a patent abroad. Whether it can be of any value to offer patent subsidies depends

[1] See e.g. Harhoff et al. (2003).

[2] For an overview, see Langinier and Moschini (2002).

[3] For an overview, see e.g. ECSC-EC-EAEC (2000).

[4] For a description see Grupp and Schmoch (1999, FN4).

[5] EU policymakers have not only set this topic on the European Union's "Lisbon Agenda," but currently conducts a series of hearings for patent users, pointing out that the "European patent system is seen by many as a model for successful international co-operation in the field of patents." (EPO 2004).

on the existence of private information, in particular regarding the relative quality of the innovation under consideration. We argue that a theoretical underpinning of the incentives to disclose through patenting is necessary, for the following reasons.

Empirical observations suggest that small firms are either not able or not willing to signal their competences via other channels, or that they at least have been unable to do so in the past. Whether a specific channel to disclose information can be the right means to use depends on how the disclosing firms may rely on this channel. Some channels of open knowledge disclosure may be regarded by receivers as lacking quality and reputation. One may doubt if a worldwide operating firm collects information from less renowned sources than from patent offices, both concerning patent applications and patented innovations. Moreover, patent information provided by EU member states is by nature less accessible than an EU-wide information source, not only because of language barriers. In particular, we argue that information connected to the patenting process is being seen of a certain quality by outside firms and technology users.

Moreover, information on internationally patented inventions is becoming increasingly available. The EPO's Open Patent Services initiative (EPO 2003) as a means to improve access to patent information furthermore backs our argument on distinguishing national from international patent data. Our paper takes this fact into account by treating patent applications as a signal of quality for specific technological competencies.

We argue that firms that already developed different technologies for a specific application may, although holding a patent in their home country, be reluctant to patent their result internationally, not because of facing potential infringement suits and of diminished chances of being granted an international patent, but because these technologies may, in other countries and for other users, not be seen as easily implementable, and this for a variety of reasons, such as technical or legal standards, norms, and the relative degree of fitness into other technology designs. This view is related to the the concept of "tacit competencies." Technological competencies are context-specific by nature since they reflect the result of research conducted by firms in their specific R&D network. Technological competencies therefore are the "knowledge of the particular circumstances of time and place".[6] To translate these competencies into other settings is difficult, costly, and sometimes impossible. The following questions spring to mind: What happens in the specific situation of a research network that ceases existing? How are firms limited by the tacitness of their knowledge when they on a sudden face a different environment? Can they immediately connect to new R&D partners? If they might want to, would they disclose through directly accessing new R&D partners or even freely disclose their knowledge to everybody? Should they refrain from directly accessing new networks because of quality issues, are their old competencies completely lost or are firms able and willing to adapt their R&D results to the need of other users? If so, what are the requirements to signal quality? In short: what are the *incentives* to signal competencies to outside actors, given the particular setting in which the firms operate, and given that firms, others than policymakers hold an informational

[6] Hayek (1945:521).

advantage over the quality?

Our starting point is that it is far from obvious that firms will patent any invention and innovation. This is known since Mansfield's (1986) empirical study and has been underpinned theoretically already in Horstmann et al. (1985). To analyze why firms may or may not disclose, we propose a signaling model with two domestic firms, both owning an invention that is already patented in their home country. This follows the motive of firms to appropriate the returns of their innovation where their markets are. We furthermore assume that because of language or institutional barriers, foreign technology users are not aware of the specific quality of an only domestically patented invention. Quality, in this view, is receiver-dependent in that it reflects the needs and the technology orientation of the foreign firm, which itself may be only incompletely known by the domestic firms. The key issue in our model is not a potential patent race in a first-to-file world. We instead suggest a viewpoint according to which a domestic firm with technological competencies that are closer to meet the specific quality preferences of a foreign firm is more likely to disclose, following its relatively lower variable costs of development.

We hence exclude a situation in which a domestic firm applies for international patent protection with *exactly* the same invention that has already been granted a domestic patent. Both firms decide on whether to engage in costly incremental development to translate their invention into an international patent application. Whether they actually decide to disclose or not, depends on the expected profits of disclosure, but it also depends on their chances to gain such a profit, given the presence of a second domestic firm that may hold similar competencies.

Our paper may be of some interest from a game-theoretic perspective since it differs from standard monopoly signaling models. We use a real three-player game with two firms that send a signal; not only one sender that can be of different types.[7] Since the receiver always decides upon picking one firm only, this leads to a particular treatment of equilibria. To come full circle, our paper can be seen as complementary to the work of Anton and Yao (2004)). It differs from their main objective since we do not account for the impact of type-dependent costs effects on innovation size, imitation, market structure, and disclosure. Instead, we focus on the level of disclosure to receivers residing in a different country. The receiver, in our model, does not profit from actual disclosures being made, but uses the level of disclosure only to infer about the firms' types.

Our paper is organized as follows. Section two highlights some empirical facts and sets the stage for the model. Section three provides the theoretical analysis. Section four discusses the impact of patent subsidies, section five concludes.

[7]To our knowledge, the only field in which oligopoly models with two senders and one receiver are commonly applied to is the literature on price competition and advertising (Hertzendorf and Overgaard 2000, and 2001). The setup of our model differs however largely from theirs; and we reach different conclusions as to the existence of pooling equilibria and the applicability of refinements.

2 An empirical motivation[8]

While our paper offers a comprehensive treatment of cases, it is expedient to highlight that it traces back to the analysis of a very particular case of transition, namely the situation of East-German after the Germany's re-unification. This abrupt change has led both firms and policymakers into a situation in which standard explanations became obsolete and policy approaches lost their grip. Because of the unique change in history, policymakers have applied a large variety of instruments, including patent subsidies, designed to mitigate the costs of patent applications.

A few empirical facts illustrating the situation are worth being pointed out.

· **R&D activity.** The first years after 1990, East-German firms faced an overhang of research personnel. Following R&D input indicators in the manufacturing sector, R&D personnel relative to total employees has decreased until 1993. The situation has reversed since then, supported by public funding.

· **Regional concentration of R&D**. The two most innovative sub-regions of East Germany, Saxony and Thuringia, show a relative R&D personnel of 3.84% and 3.64%, respectively, compared to the total number of employees (manufacturing sector)in 1995. These values are close to the average sub-region in Germany and have been relatively stable since (Gick 1998). In 2001, East-German firms count for 8% of all firm-employed R&D personnel in the country (DIW 2003).

· **Domestic patent productivity.** This indicator showed a slightly encouraging picture. East Germany counted for 5-6 percent of all German patent applications from 1995-7 (1995: 5.51%, 1996: 5.57%, 1997: 5.78%, with values for Saxony of 2.3%, 2.18%, and 2.17% in this period, for Thuringia 1.27%, 1.32%, and 1.36%, followed by the town region of East Berlin of 1.22 and less, respectively).[9] This, in its sum, describes firms in this region to show a rather stable and slightly upward development since 1991. The percentage of product innovations compared to the total number is currently not lower than in West Germany (DIW 2003: 748); firms are prevalently pursuing R&D in local research networks, and the percentage of patents stemming from outside the business sector has decreased since 1993[10]

· **International patent applications.** The picture of a relatively weak but stable innovative behavior in this sub-region is disturbed by one particular indicator: the percentage of patent applications filed by firms in East Germany in more than one country. This figure has remained particularly low, compared to the rate that West-German firms showed during the same period (see *fig.* 1). While the rate itself shows an increase over time, the still low level of this activity throughout the documented

[8]Much of the spirit of this paper traces back to my activities as a Senior Researcher at the IFO Institute in Germany during the years 1998 and 1999. I thank Konrad Faust for having pointed me toward this interesting problem and having encouraged me to add to it.

[9]See Gick (1998).

[10]See Greif (1998). While the *direction* of innovative activity indeed shows an upward trend, its *level* in terms of patent productivity is still low, compared to West German sub-regions. Northrhine-Westphalia and Bavaria have reached a patent per R&D employee ratio of 0.19 and 0.13 during this time, while Saxony positioned itself in the upper mid-field within Germany with a level of 0.09. The majority of innovations were achieved in mid-technology fields of the manufacturing sector. Discouragingly, only 5% of East German start-ups belong to technology-intensive sectors (DIW 2003). Within these sectors, however, the new firms are remarkably high-technology oriented.

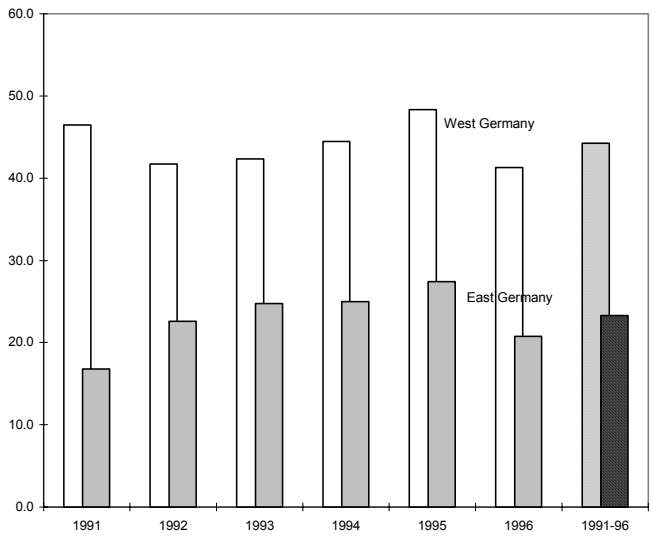

Figure 1: Percentage of patent applications in at least two countries compared to national patent applications in West and East Germany. Source: Gick (1998), data based on IFO patent statistics that has been closed since. The values for 1996 are incomplete (without U.S. data).

period remains a puzzle.[11]

This all suggests that firms in East Germany may have had particular reasons to not apply for international patent protection, since they clearly increased the numbers of *domestic* patent applications, and far-reaching subsidies were available.[12] Explanations that were given by researchers included the local and regional orientation of East German firms, which makes domestic patent protection the primary goal. Together with the fact that the high-tech sector is less pronounced in this region, it was commonly argued that firms in this regions were simply "not ready" to encompass international activities. Policymakers understood the latter strategy as being a next step, to be undertaken after a first phase of domestic consolidation would have been taken place.

We argue that this argument, as it stands, does not hold water. It lacks a sound explanation why and when firms do *not* patent internationally even if they could. What makes these firms choose to not undertake international activities? The fact that even today the situation has not improved suggests the need for a different explanation. Our view is in line with Kabla's (1995) general observation that propensity to patent depends on the patenting behavior of other firms operating in the same branch. Relatedly, Harabi (1995) has shown that small firms patent in order to protect their position against imitation, but also "as a means of entry into

[11] As a rule of thumb, firms in the most industrialized countries of Western Europe patent roughly 40% of their national patents abroad as well. This figure of course differs across industries.

[12] Since the beginning of the 1990s, a German national program (Patentförderung Ost) offered coverage of filing and application costs, including the costs for the patent attorney.

foreign markets (directly through direct investment and production or indirectly through granting a licensing agreement)."[13] In particular, Faust (1990) has argued that patent applications in foreign countries may be determined by profit expectations that a firm under consideration may hold. Only if the commercial value would compensate for the higher costs, a firm may want take international patenting into consideration.

Our paper follows this argument closely. It is both in line with Faust's (1990) view of international patents being a stake for future R&D partnerships, and with Hicks (1995) argument that firms signal tacit competencies through disclosing information, indicating the presence of additional knowledge. To illustrate, consider a product innovation, invented and implemented in an East German or Eastern European R&D network before 1990. With the end of the Soviet bloc, these networks dissolved, but as long as the innovation had a chance to be granted national patent protection in Germany after 1990, it was worth for the firm to apply for it. Will the firm now immediately patent this invention abroad? Leaving aside patent infringement considerations in our analysis[14], we need to examine the incentives to patent in a foreign country.

Example 1 *Assume that a domestic firm, labeled firm D1, holds a national patent on a high-tech carburator designed for a specific combustible engine.*[15] *What makes this firm presume that this patent will find enough attention of a foreign firm or of a foreign R&D network? The invention needs to be of a specific quality in its particular field. In our example, if the carburator cannot be of use for an engine that is to be produced by the foreign firm, or if the adaptation costs are excessively high, it will not help the domestic firm to enter an international R&D cooperation, despite the possible value of the invention as a masterpiece of engineering.*

Keeping the example, let us not extend the setting to include another domestic firm D2. Would the foreign firm still be interested in an adaptation of the carburator technology when firm D2 offers a better technological solution for the foreign firm, say in form of an already (nationally) patented injection pump?[16] *Firm D1, if the East-German firm, may face high costs of turning the already (nationally) patented carburator into a new design, adaptable to foreign standards, while firm D2 may face less costs to do so. Firm D1 in such a setting will rather refrain from patenting internationally, since the competitor's chances are anyway higher to be picked as an R&D partner by the foreign firm if it can utilize the same channel of disclosure. Firm D1, knowing that its technology may be improvable by incremental development to be a good fit, needs to level up with an R&D standard that is set by its (domestic) competitor.*[17]

[13] Harabi (1995:990).

[14] This makes sense for a broad range of cases in which the East German firm used a technology based on a different research field, compared to the technology used in Western countries.

[15] Given the rather high quality standards required by the German patent office, we may assume that an innovation, when granted a national patent, has a high chance to reach international patent protection as well (I owe this thought to Mark Schankerman).

[16] We assume in Section 3 that national patenting is solely undertaken to ensure the intellectual property rights in the domestic market and cannot convey information to outside firms.

[17] Note again that "quality" as defined here does not necessarily mean that the East-German firm's

Conversely, assume now that firm D1, has a cost advantage in that its development costs are lower that those of D2. As long it can assume that its technology includes specific properties that the foreign firm is looking for, it may decide to patent this innovation internationally, despite the presence of domestically known comparable R&D results.

This example motivates some thoughts that led to our model presented in the following section. As a caveat that applies to any stylized example, one should keep in mind that we do not necessarily argue that the foreign firm will hold priors that favor firm D2. Whether the priors are diffuse or inclined towared one of the firms, depends entirely on the situation under consideration.

Furthermore, we argue that a specific regional identity of the firms has no influence. We exclude e.g. the address of a firm to be a signal by which the foreign technology may infer the quality of the firm. Other than via patenting disclosure, D1 or D2 have no chance to find and to contact a potential foreign R&D partner.

3 The model

3.1 Basic setup

To capture the situation sketched above, consider a three-player signaling game with two senders and one receiver. There are two domestic firms that hold either high or low competencies in a specific field of application. A foreign firm, F, does not know which of the domestic firms is of high and which of low competencies, when randomly picking one as cooperation partner. To illustrate, we label the two firms i and j. The two firms may signal their competencies through disclosure. Disclosure is described by the variable $\delta \in [0, 1]$, which we normalize to 1 in the case of disclosing the highest possible quality. Last we assume that a domestic firm by choosing a disclosure level $\delta = 0$ does not incur any costs of incremental development, nor of the (fixed) costs through patent applications. Contingent on the observation of a disclosure pair (δ_1, δ_2), firm F updates beliefs and chooses a firm with which to form a partnership.

Let $\gamma(\delta_i, \delta_j) \in \{i, j, 0\}$ denote F's choice of partner, where $\gamma(\delta_i, \delta_j) = 0$ implies that F does not form an R&D partnership with either firm. Then, we may define firm i's revenue function as a function of F's choice as follows:

$$R_i\left(\gamma(\delta_i, \delta_j)\right) = \begin{cases} 0 \text{ if } \gamma(\delta_i, \delta_j) \in \{j, 0\} \\ R \ > 0 \text{ if } \gamma(\delta_i, \delta_j) = \text{i.} \end{cases}$$

Firm i's cost function $C_i(\delta_i) = C_f^p + c_i(\delta_i)$ cover the fixed patenting costs (patent fee etc.) C_f^P, and variable costs $c_i(\delta_i)$of incremental development, depending on the domestic firm's type. These variable costs can be linear or convex, which is specified in a later subsection.

invention has a lower value from a scientific perspective, but from the foreign firm $F's$ perspective as technology user it is less applicable.

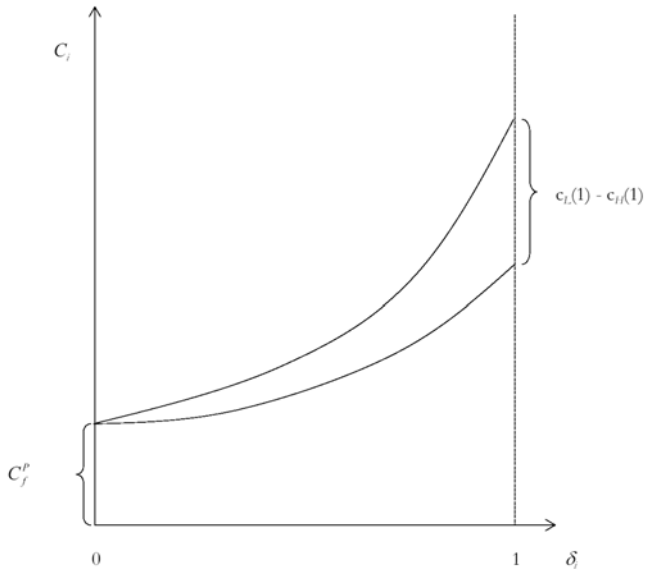

Figure 2: The domestic firms' total costs of disclosure as a function of their type.

To reach a specific quality level of disclosure, δ_i, firm i invests in development, innovates by spending the type-dependent variable development costs $c_i(\delta_i)$, plus pays the fixed patenting costs C_f^p. here. For simplicity, we label the type dependent variable costs c_L and c_H, which permits us to illustrate the cost function $C_i(\delta_i) = C_f^p + c_i(\delta_i)$ as follows (see $fig.$ 2).

We are now able to define firm i's profits as functions of (δ_i, δ_j) and F's decision rule, γ :

$$\Pi_i(\delta_i, \delta_j; \gamma) = R_i(\gamma(\delta_1, \delta_2) - C_i(\delta_i).$$

Let now $\mu^i(\delta_i, \delta_j)$ be firm F's assessment that firm i, when disclosing δ_i, holds competencies belonging to type i. The quality of the knowledge stock of firms i and j are perfectly negatively correlated, with $\mu^i(\delta_i, \delta_j) = 1 - \mu^j(\delta_j, \delta_i)$. This permits us to simplify the setting by using the following notation that we keep for the rest of the paper: Nature flips a coin and creates the following two exclusive events:

- *Event HL:* Firm 1 is of type H , firm 2 of type L
- *Event LH:* Firm 2 is of type H , firm 1 of type L.

F holds prior beliefs such that event HL occurs with probability ν, and consequently that event LH occurs with probability $1 - \nu$. This assumption comes without loss of generality.

To illustrate, F when choosing firm 1 picks type H with probability ν. In the trivial case of diffuse priors with $\nu = .5$, F picks firm 1 randomly, but only if its profit expectations permit so: although differing in their competencies, the type of firms H and L is not known to F. The only information source firm F has about the quality of firm H stems from disclosure through international patenting. Unless we deviate from the assumption of diffuse priors in Case 2b, we require that $\mu(\delta, \delta) = \frac{1}{2}$. We furthermore assume that F does not produce for the domestic market of the two competitors, nor does it attempt to enter the domestic market after an R&D cooperation with one of the domestic firms. Similarly, none of the domestic firms is envisaging international patenting in order to reach a stake in the foreign market that permits either of them to compete with F in the latter's country, but to reach higher profits resulting from a research partnership with the foreign firm.

We define the payoff ranking of firm F. Whenever denoting F's profits, the superscripts L and H indicate F's cooperation partners; N stands for non-cooperation:

$$\Pi_F^H > \Pi_F^N > \Pi_F^L.$$

Firm F's profits itself do not depend on the level of disclosure of either domestic firm but on the type of the firm with which it is cooperating. To motivate why the foreign firm is strictly worse off when cooperating with L we assume that the cost of cooperating with L are higher because of its lower competencies, leading to a negative net value of cooperating with firm L. Under full information, F picks firm H as cooperation partner. If F is not informed about the state of nature, asymmetric information affects the result. Thus, by disclosing information, the domestic firm(s) mitigate the problem of asymmetric information.

3.2 Timing

The timing of the game reads as follows:

Nature determines the competencies of L and H	L and H decide on investing in incremental development	One/both domestic firms develop and disclose through patenting abroad	F observes the signal and picks either L or H as R&D partner	Outcome and payoffs.

A few explanations are in order. For simplicity and without loss of generality we exclude decisions on domestic patenting but assume that at $t = 0$ each domestic firm already holds a national patent that protects its intellectual property rights in the home country. Incremental development reaches a possible quality increase for F, compared to the existing patent, but the disclosed innovation through patenting is never a completely finished solution that can already be licensed to F, it is rather that F needs to win the better domestic firm for joint R&D. Although our model is compatible with licensing, we do not further refer to this issue in our exposition.

3.3 Equilibria

We now determine F's *ex-ante* payoff $\nu\Pi_F^H + (1-\nu)\Pi_F^L$ from cooperating with firm 1 and compare this expected value with the payoff under noncooperation Π_F^N, which leads us to two general cases that determine the behavior of firm F, given that F holds priors that HL occurs, with $\nu \geq .5$. There are two relevant payoff cases:

• **Payoff Situation 1:** The payoff when not cooperating exceeds the expected payoff of cooperation: $\nu\Pi_F^H + (1-\nu)\Pi_F^L < \Pi_F^N$. In the case is case, F will choose to not cooperate with either firm.

• **Payoff Situation 2:** The foreign firm has expected profits that exceed the default payoff of $\nu\Pi_F^H + (1-\nu)\Pi_F^L \geq \Pi_F^N$. Cooperation is much more likely in this situation: Under diffuse priors, firm F randomizes, under priors of $\nu > .5$ it picks firm 1 as its cooperation partner if no additional information is available.

Definition 2 *A Perfect Bayesian Equilibrium (PBE) is a strategy profile* $(\hat{\delta}_H, \hat{\delta}_L)$ *together with a system of beliefs* μ *such that*

(i) $\hat{\delta}_H = \arg\max_{\delta_H} \Pi_H(\delta_H, \hat{\delta}_L; \gamma)$,
(ii) $\hat{\delta}_L = \arg\max_{\delta_L} \Pi_L(\delta_L, \hat{\delta}_H; \gamma)$,

and a system of beliefs such that consistency with strategies is fulfilled:

(iii) $\mu^i(\hat{\delta}_L, \hat{\delta}_H) = 0$ *and* $\mu^j(\hat{\delta}_H, \hat{\delta}_L) = 1$ *if* $\hat{\delta}_L \neq \hat{\delta}_H$ (consistency),

(iv) $\mu^1(\delta, \delta) = \nu$ *for all* δ (consistency).

F's equilibrium strategy is

(v) $\hat{\gamma}(\delta_i, \delta_j) = i$ *if* $\mu^i(\delta_i, \delta_j) = 1$ *and* $\hat{\gamma}(\delta_1, \delta_2) = 0$ *if* $\mu^1(\delta_1, \delta_2) = \nu$ (Payoff Situation 1),

(vi) $\hat{\gamma}(\delta_1, \delta_2) = 1$ *if* $\mu^1(\delta_1, \delta_2) = \nu$ (Payoff Situation 2).

We now use the foreign firms beliefs at out-of-equilibrium disclosures to check which different kinds of equilibria are supported by the out-of equilibrium beliefs.

First, consider a situation in which F maintains its prior beliefs independent of the firms disclosures. Then, an equilibrium exists in which neither firm discloses, since disclosure is costly and cannot influence F's decision. This equilibrium is trivial. It exists because of firm F's refusal to update. We therefore rule out these beliefs. We will maintain the following out-of-equilibrium beliefs throughout the remainder of the paper.

Definition 3 ***Out-of-equilibrium Beliefs:***

For any out-of-equilibrium disclosure pair (δ_i, δ_j) :

(i) $if\ \max(\delta_i, \delta_j) < \hat{\delta}_H$, *then* $\mu^1(\delta_1, \delta_2) = \nu$,

(ii) $if\ \max(\delta_i, \delta_j) \geq \hat{\delta}_H$, *then* $\mu^i(\delta_i, \delta_j) = \begin{cases} 1\ if\ \delta_i > \delta_j, \\ 0\ if\ \delta_i < \delta_j,\ and\ \mu^1(\delta, \delta) = \nu. \end{cases}$

If both firms disclose less than $\hat{\delta}_H$, F retains its prior beliefs, while if at least one firm discloses at least the level $\hat{\delta}_H$, F believes that the firm disclosing the most is of type H. This is intuitive since the H-type firm has a lower cost of disclosure for all levels of disclosure. In the same setting, whenever the domestic firms disclose the same amount, the prior is maintained.

Under these out-of-equilibrium beliefs, the two domestic firms may affect F's decision, provided they disclose a sufficient amount. The overall picture offers the consistent view that F punishes low disclosures whenever believing the firm under consideration is of type L. However, since F cannot believe that *both* are of type L, it resorts to its prior belief in this case.

This now permits us to examine the conditions for equilibrium outcomes in the following cases:

3.3.1 Case 1: $\nu\Pi_F^H + (1-\nu)\Pi_F^L < \Pi_F^N$ and $\nu \geq .5$ [18]

This case represents the first of two intuitive cases. It refers to the situation in which the foreign firm is not completely uninformed and may holds prior beliefs in favor of firm 1.

This case best motivates why signaling is needed according to F's payoff condition $\nu\Pi_F^H + (1-\nu)\Pi_F^L < \Pi_F^N$ together with the condition for the priors $\nu \geq .5$ without loss of generality. Here, F needs a separating signal to tell the two firms apart. Otherwise, the belief structure will render cooperation impossible.

Existence. We now analyze under which conditions the domestic firms are willing to send these signals. Whenever speaking of the domestic firms' payoffs, we use the notation (δ_H, δ_L), in this sequence. The superscript used for the domestic firms' payoff denotes the putative mode of cooperation, with C denoting cooperation between F and the firm under consideration, O indicating cooperation between F and the domestic competitor, and N, as before, non-cooperation. Given that firm F picks one firm only, separating requires three IC constraints to hold, one for firm H,

$$\Pi_H^C(\delta^*, 0) \geq \Pi_H^N(0, 0) \qquad \text{(IC H)}$$

and two for firm L :

$$\Pi_L^O(\delta^*, 0) \geq \Pi_L^N(\delta^*, \delta^*). \qquad \text{(IC L}^N\text{)}$$

[18] For other priors, the foreign firm switches from case HL to LH because of symmetry.

$$\Pi_L^O(\delta^*, 0) \geq \Pi_L^C(\delta^*, \delta^* + \varepsilon), \qquad \text{(IC L}^C\text{)}$$

for any $\varepsilon > 0$.

Solution. (i) (IC H). Without loss of generality we may set $\Pi_H^N(0,0) = 0$. This reduces the observation to $\Pi_H^C(\delta^*, 0) \geq 0$. Since $\Pi_H^C(\delta^*, 0) = R - (C_f^P + c_H(\delta^*))$, we may state that (IC H) holds if and only if $R \geq C_f^P + c_H(\delta^*)$, in words, if H's expected cooperation benefits R at least cover its patenting plus development costs.

(ii) (IC L^N). As long as L cannot benefit from an increase in its rival's cost of disclosure, we can assume that $\Pi_L^O(\delta^*, 0)$ is zero. The R.H.S. however is negative since $\Pi_L^N(\delta^*, \delta^*)$ entails signaling costs of $C_f^P + c_L(\delta^*)$. Under reasonable assumptions, (IC L^N) is always fulfilled.

(iii) (IC L^C). For the same reason as in (ii), let us set $\Pi_L^O(\delta^*, 0) = 0$. (IC L^C) holds if and only if $R \leq (C_f^P + c_L(\delta^* + \varepsilon))$. Since $\lim_{\varepsilon \to 0} (c_L(\delta^* + \varepsilon)) = c_L(\delta^*)$,the L-type firm wouldn't find it profitable to overshoot δ^* even if, by doing so, it could ensure F's cooperation.

Proposition 4 *Under the given assumptions on belief structure and payoff conditions, the game has a continuum of separating PBE, in which H discloses exactly the disclosure level δ^*, and L discloses 0, with δ^* satisfying $C_f^P + c_H(\delta^*) \leq R \leq C_f^P + c_L(\delta^*)$.*

Note that the set of δ^*defined according to this proposition is non-empty because $c_H(\delta^*) < c_L(\delta^*)$ for all $\delta > 0$.

Equilibrium Refinements.[19] The continuum of separating PBE however occurs as long as firm F does not update its beliefs for the necessary minimum level of δ^*. Suppose there is an equilibrium in which firm F would hold the new unreasonable belief structure:

$$Prob \text{ (firm 1 is of type H } \mid \delta_1, \delta_2) = \begin{cases} 1 \text{ if } \delta_1 = \delta^* + \alpha \text{ and } \delta_2 \neq \delta^* + \alpha \\ \nu \text{ if } \delta_1 = \delta_2 \\ 0 \text{ otherwise.} \end{cases}$$

Under this belief structure, any signal less than $\delta^* + \alpha$ will be interpreted by firm F as stemming from L. Firm H would be willing to disclose within the interval $[\delta^*, \delta^* + \alpha]$, while firm L would not. In other words, to signal within this interval would constitute an equilibrium-dominated strategy for L. This can be checked as follows:

[19] This equilibrium-domination based refinement concept follows the exposition of the more general case described in Mas-Colell et al. (1995:471).

Assume first that by sending such a signal, firm L makes F believe that it is of type L, then it would not have been necessary at all to send this signal, since a lower disclosure would have led to the same result at lower costs.

Second, if firm L by sending such a signal would make F believe that its type is H, then this disclosure would be at too high a level. L would need to behave optimally after, and would not want to mimic H. Thus, any signal in the interval $[\delta^*, \delta^* + \alpha]$ would be equilibrium dominated for firm L.

Note that in none of the two cases firm F would assign any positive probability to a signal observed in the interval $[\delta^*, \delta^* + \alpha]$ stemming from firm L if F has a reasonable belief structure. Therefore the separating PBE described in case 1 cannot be a sensible prediction as long as firm F maintains the new belief structure. Since we need to limit our observations to equilibrium responses and to reasonable beliefs should our separating PBE be a sensible prediction, we can drop the assumption that firm F will maintain any belief structure of this kind.

We therefore have narrowed down our case to a unique separating PBE that involves the lowest amount of disclosure for the type-H firm that is consistent with (IC L^C): that is, δ^*defined by $R = C_f^P + c_L(\delta^*)$.

Nonexistence of Pooling Equilibria.

Proposition 5 *No pooling equilibria can exist given our maintained belief structure.*

Proof. First, consider a candidate for a pooling equilibrium involving $\delta \geq \delta^*$. Both firms are incurring costs of disclosure but neither receives a contract with F. Thus, either firm would do strictly better by defecting to no disclosure.
Next, consider a candidate for a pooling equilibrium involving $\delta \leq \delta^*$, including $\delta = 0$. Similarly, neither firm is receiving a contract, but firm H would do strictly better by defecting to δ^* and reaching cooperation with F. ■

3.3.2 Case 2: $\nu\Pi_F^H + (1-\nu)\Pi_F^L \geq \Pi_F^N$

Case 2a: $\nu = .5$

• Separating equilibria.

Whenever observing $\delta_1 = \delta_2$, firm F is indifferent between choosing firm 1 or 2 as its cooperation partner. Since firm F 's payoff does not depend on δ, there is no rational reason why firm F should not cooperate with either firm after observing $\delta_1 = \delta_2$, even if this would be below some threshold value $\overline{\delta}$ that can be reached by L. This threshold value can be close to zero.

F in this case sets its priors and thus chooses firm 1 with probability .5 as its partner when observing $\delta_1 = \delta_2$. Any positive probability of choosing firm 1 is a credible threat for firm 2 and vice versa, punishing the domestic firms' out-of equilibrium actions.

The conditions for which $(\delta^*, 0)$ forms a separating PBE are now reading

$$\Pi_H^C(\delta^*, 0) \geq .5 \cdot \Pi_H^C(0,0) + .5 \cdot \Pi_H^O(0,0), \qquad \text{(IC H')}$$

$$\Pi_L^O(\delta^*, 0) \geq .5 \cdot \Pi_L^O(\delta^*, \delta^*) + .5 \cdot \Pi_L^N(\delta^*, \delta^*), \qquad \text{(IC L}^{N\,\prime}\text{)}$$

$$\Pi_L^O(\delta^*, 0) \geq \Pi_L^C(\delta^*, \delta^* + \varepsilon). \qquad \text{(IC L}^{C\,\prime}\text{)}$$

(i) (IC H'). Since H does not face reduced profits due to domestic competition, we can rewrite the constraint into $.5R \geq C_f^P + c_H(\delta^*)$. In words, the total costs of patenting and development need to stay below half of H's expected cooperation benefit. This makes (IC H') harder to fulfill than (IC H).

(ii) (IC $L^{N\prime}$). We assumed in 3.1 that in the absence of domestic competition $\Pi_L^O(\cdot, 0) = 0$. Then, the R.H.S. becomes $-(C_f^P + c_L(\delta^*))$, which is always fulfilled.

(iii) (IC $L^{C\prime}$). Note that the R.H.S. reads $\Pi_L^C(\delta^*, \delta^* + \varepsilon)$ since by overshooting, firm L leads to an inference of H, which means that F will cooperate with L. Note also that (IC $L^{C\prime}$) and (IC L^C) are the same constraints and can be re-expressed into $R \leq C_f^P + c_L(\delta^*)$.[20]

Assumption. *(i)* Development costs $c_H(\delta)$ and $c_L(\delta)$ are linear. In this case we restrict our attention to the situation in which $c_L - 2c_H > C_f^P$. From this follows that $\frac{C_f^P}{c_L - 2c_H} < 1$, and any $\delta^* \in \left[\frac{C_f^P}{c_L - 2c_H}, 1\right]$ can be used to signal quality H.

(ii) Development costs $c_H(\delta)$ and $c_L(\delta)$ are convex, $c_H(\delta) - 2c_L(\delta)$ is increasing in δ and $c_L(1) - 2c_H(1) > C_f^P$. We define $\bar{\delta}$ by $c_L(\bar{\delta}) - 2c_H(\bar{\delta}) = C_f^P$. Then, any $\delta^* \in \left[\bar{\delta}, 1\right]$ can serve as signal of type H.

Proposition 6 *Under the given assumptions on belief structure and payoff conditions, the game has a continuum of separating PBE, in which H discloses exactly the disclosure level δ^*, and L discloses 0, with δ^* satisfying $2[C_f^P + c_H(\delta^*)] \leq R \leq C_f^P + c_L(\delta^*)$.*

Equilibrium Refinements. Applying the same domination based equilibrium refinements, we can narrow down the continuum of separating PBE to one unique equilibrium in which the smallest equilibrium disclosure δ^* is chosen. The exposition follows very closely the one described in the previous case.

• Pooling equilibria: Existence.

We check whether under the given system of beliefs there exist active pooling equilibria. This is the case if the following IC conditions hold:

[20] Note again that $\lim_{\varepsilon \to 0} (c_L(\delta^* + \varepsilon)) = c_L(\delta^*)$.

$$.5 \cdot \Pi_H^C(\delta^*, \delta^*) + .5 \cdot \Pi_H^O(\delta^*, \delta^*) \geq \Pi_H^O(0, \delta^*), \qquad \text{(IC H P)}$$

$$.5 \cdot \Pi_L^C(\delta^*, \delta^*) + .5 \cdot \Pi_L^O(\delta^*, \delta^*) \geq \Pi_L^O(\delta^*, 0), \qquad \text{(IC L P)}$$

$$.5 \cdot \Pi_H^C(\delta^*, \delta^*) + .5 \cdot \Pi_H^O(\delta^*, \delta^*) \geq \Pi_H^C(\delta^* + \varepsilon, \delta^*) \qquad \text{(IC H}^C \text{ P)}$$

(i) Since $\Pi_H^C(\delta^*, \delta^*) = R - (C_f^P + c_H(\delta^*))$, (IC H P) rewrites into $.5R \geq C_f^P + c_H(\delta^*)$.

(ii) Similarly, we assume for firm L that $\Pi_L^O(\cdot, 0) = 0$. Then, (IC L^{o}P) reads, analog to (IC H P):$.5R \geq C_f^P + c_L(\delta^*)$.

(iii) The third IC condition ensures that the H type would rather pool than outbid L and win the contract with certainty. As in (i), the L.H.S rewrites into $.5R - (C_f^P + c_H(\delta^*))$, while the R.H.S. now reads $R - (C_f^P + c_H(\delta^* + \varepsilon))$. Since $\lim_{\varepsilon \to 0} (c_H(\delta^* + \varepsilon)) = c_H(\delta^*)$, (IC H^{C}P) rewrites into $.5R \geq C_f^P + c_H(\delta^*)$.

Proposition 7 *The game has no pooling equilibrium.*

Proof. Suppose there exists a δ that leads to pooling. In this case, both firms win a cooperation with equal likelihood. Both firms receive $.5R - C_f^P - c_k(\delta)$,with k $\epsilon\{L, H\}$.
Either type would be better off by moving from this given δ to $\delta + \varepsilon$ and getting the contract with probability 1. ■

Case 2b: $\nu > .5$ The game also has equilibria under $\nu\Pi_F^H + (1-\nu)\Pi_F^L \geq \Pi_F^N$. The case $\nu > .5$ provides firm 1 with a natural advantage: F chooses firm 1 whenever the two firms disclose the same amount. This leads to the general picture that firm 1 does not need anymore to outbid firm 2 to get the contract; matching becomes a sufficient strategy to win the contract.

Recall *Definition 4* on the out-of-equilibrium beliefs. Using the same beliefs, we can now specify a particular δ^* in this case to be defined by $R = C_f^P + c_L(\delta^*)$. Then, for any out-of-equilibrium disclosure pair, F's beliefs can be written as follows:

(i) if $\max(\delta_i, \delta_j) < \delta^*$, then $\mu^1(\delta_1, \delta_2) = \nu$,

(i) if $\max(\delta_i, \delta_j) \geq \delta^*$, then $\mu^i(\delta_i, \delta_j) = 0$ if $\delta_i < \delta_j$, and $\mu^i(\delta, \delta) = \nu$.

Proposition 8 *This game has a semi-separating equilibrium in which firm 2 discloses δ^* in the event LH and F awards the contract to firm 2, and both firms disclose 0 in the event LH and F awards the contract to firm 1.*

Proof. First, consider event LH. Firm 1, of type L, would never disclose more than δ^*[21] since this would yield negative profits for L even if it is awarded the contract. Firm 2, the H-type discloses $\delta^* + \varepsilon$ in order to win it. Therefore, firm 1 chooses to not disclose, while firm 2 discloses chooses $\delta^* + \varepsilon$ in equilibrium.

Next, we consider event HL. Firm 2, now of type L, would never disclose more than δ^* since this would yield negative profits, even when the firm is awarded the contract. Note that firm 2 can never win the contract as long as firm 1 can reach the disclosure level $\delta^*$and win the cooperation with certainty. Given the new belief structure, firm 1 has no incentive to disclose either since it receives the contract independent of the disclosure, thus it sets $\delta = 0$. In equilibrium, neither firm discloses and firm 1 is awarded the contract. ■

4 Subsidies

We have described three cases that characterize our extended setting. Case 1 as the most realistic setting involves a situation in which firms have a strong incentive to reveal. For obvious reasons, we need to exclude Case 2b from being of any interest for the policymaker. We now characterize how generalized patent subsidies influence the decisions on disclosure.

Assumption *Government is not informed about the domestic firms' type. It offers patent subsidies of $S = C_f^P$ to both firms. This is known to the firms at their decision stage.*

Proposition 9 *(Separating PBE, Case 1, 2a):*
Subsidies do not change the outcome of separating equilibria. Since there is no reason to assume that either domestic firm will keep its level of disclosure δ^* constant under subsidies, subsidies lead to wasteful competition in that both firms could now increase their level of disclosure. This, per unit of increase, is less costly for firm H. H will now disclose a higher level δ^*, depending on the additional level of disclosure that firm L can gain by receiving $S = C_f^P$. L will not disclose and the firms again separate. Subsidizing has no effect on the outcome and is wasteful. Total welfare is decreased.

Proof. Recall that the optimum disclosure level at which the firms separate was found at $R = C_f^P + c_L(\delta^*)$. Subsidies covering $S = C_f^P$ lead to separation under $R = c_L(\delta^{**})$, with $c_L(\delta^{**}) > c_L(\delta^*)$ and $\delta^{**} > \delta$. ■

[21] Note that the incentive structure follows case 1. Thus, δ^* solves $R = C_f^P - c_L(\delta^*)$

5 Conclusion

This paper has aimed at shedding some light on the following two questions. Why is it that some firms disclose information through international patenting, while others in the same country don't? Can patent subsidies induce firms to disclose, and are they an efficient policy instrument?
Our main result shows that under realistic assumptions firms disclose if their invention is of sufficient quality for the foreign firm, compared to the level of competencies that can be reached by the domestic competitor. Our findings link the decision to patent of firms to their knowledge of their specific situation, given their knowledge on the presence of domestic innovators. Firms use the patent system to reveal their knowledge. Keeping in mind that firms are usually better informed about their specific technological competencies and the usefulness of their inventions for specific applications than policymakers, this particular implication of the model is indeed of some value.

Second, we have set up different scenarios, following different profit expectations of the foreign firm. In a world in which cooperation profits would not beat non-cooperation in expectation, only disclosure can lead one of the domestic firms to cooperation, while in a relaxed setting, the priors that the foreign firm may hold, may ease the situation of the firm under consideration. Our general result is that the two firms separate according to their competencies and that pooling equilibria do not exist.

Third, our result shows no indication for patent subsidies that would cover the fixed costs of patenting. Even in the most realistic case 1, patent subsidies cannot help firm L to increase its chances to win a partnership. In all cases, patent subsidies are wasteful. This, at least, should suggests to policymakers to rethink commonly used instruments that aim at correcting existing patent systems toward their particular needs. A patent system, even if flawed in its design, still has its value as a mechanism to reveal information.

While capturing all possible relevant payoff cases, the richness of the model leaves space for extensions and for future research. Our results are rather robust; our main focus was on the incentives that govern international patenting decisions of firms that already hold a national patent and decide on whether or not engage in incremental development in order to patent internationally. We found this setting plausible, given the empirical observation that we took as our starting point. The model developed in section three captures a far broader scenario. In order to keep our setting simple and tractable, we refrained from adding further modeling options, such as the influence of R&D partnerships on domestic competition. Future research may be worthwhile to capture an extended setting.

6 Acknowledgments

I am greatly indebted to Jennifer Reinganum, Hideki Konishi, Corinne Langinier, and Helena Poon for their repeated suggestions and discussions and their helpful support. I furthermore thank Jesse Giummo, Mark Schankerman, John Scott, Chris

Snyder, and the participants of the 2004 IIOC Conference in Chicago for further comments on an earlier draft. All remaining errors are mine.

7 Bibliography

Anton, J., Yao, D. (2004) Little Patents and Big Secrets: Managing Intellectual Property, in: RAND Journal of Economics 35,1:1-22.

Cohen, W. M., Nelson, R. R., Walsh, J. P. (2000) Protecting Their Intellectual Assets: Appropriability Conditions And Why U.S. Manufacturing Firms Patent (Or Not), NBER Working Paper #7552, Cambridge, MA.

ECSC-EC-EAEC (2000) Enforcing Small Firm's Patent Rights, ETAN Expert Report, Brussels-Luxembourg.

EPO (2003) Europe's industry needs patent information more than it realises, in: EPIDOS News 3/2003, European Patent Office, Munich.

EPO (2004) The Future of the European Patent System, Munich,
(available at http://www.european-patent-office.org/news/info/hearings/index.htm)

Faust, K. (1990) Early identification of technological advances on the basis of patent data, in: Scientometrics 19, 5-6: 473-480.

Faust, K. (1994) Sächsische Forschung und Entwicklung im Spiegel der Patentstatistik [R&D in Saxony following Patent Statistics], in: IFO Dresden berichtet, 1, 3: 34-45.

Gallini, N. (2002) The Economics of Patents: Lessons from Recent U.S. Patent Reform, in: Journal of Economic Perspectives, 16 :131-154.

Gick, W. (1998) An der Sicherung der technologischen Basis für Innovationen muß gearbeitet werden, Teil 1 [Ensuring a technological basis for innovation, part 1], in: IFO Dresden berichtet 2: 39-45.

Grupp, H., Schmoch, U. (1999) Patent statistics in the age of globalization: new legal procedures, new analytical methods, new economic interpretation, in: Research Policy 28:377-396.

Harabi, N. (1995) Appropriability of Technical Innovations: An Empirical Analysis, in: Research Policy 24: 981 - 992.

Harhoff, D., Henkel, J., von Hippel, E. (2003) Profiting from voluntary information spillovers: how users benefit by freely revealing their innovations, in: Research Policy 32: 1753-1769.

Hayek, F. A. (1945) The Use of Knowledge in Society, in: American Economic Review 35: 519-30.

Hertzendorf, M.N., Overgaard, P.B., 2000,. Will the High-Quality Producer Please Stand Up? A Model of Duopoly Signaling, mimeo (available at http://www.econ.au.dk/vip_htm/povergaard/pbohome/webpapers/duosig5.pdf).

Hertzendorf, M.N., Overgaard, P.B., 2001, Price Competition and Advertising Signals - Signaling by Competing Senders, in: Journal of Economics and Management Strategy 10: 621-662.

Hicks, D. (1995) Published Papers, Tacit Competencies and Corporate Management of the Public/Private Character of Knowledge, in: Industrial and Corporate Change 4: 401-424.

Horstmann, I., MacDonald, G.M., Slivinski, A. (1985) Patents as Information Transfer Mechanisms: To Patent or (Maybe) Not to Patent, in: Journal of Political Economy 93, 5: 837-858.

Kabla, I. (1996) The Patent as Indicator of Innovation, in: INSEE Studies, vol 1, 1996, p. 63.

Kortum S., Lerner J. (1999) What is Behind the Recent Surge in Patenting? in: Research Policy, 28, 1-22.

Langinier, C. (2004) Using patent to mislead rivals, Working Paper #04009, Department of Economics, Iowa State University.

Langinier, C., Moschini, G. (2002) The Economics of Patents - An Overview, Working Paper 293, Center for Agricultural and Rural Development, Iowa State University.

Lerner, J. (1994) Patenting in the shadow of competitors, in: Journal of Law and Economics 38: 463-496.

Mansfield, E. (1986) Patents and Innovation: An Empirical Study, in: Management Science 32:173-180.

Mas-Colell, A., Whinston, M., Green, J. (1995) Microeconomic Theory, New York: Oxford University Press.

Merges, R. P., Nelson, R. R. (1990) On the Complex Economics of Patent Scope, in: Columbia Law Review 90: 839 - 916.

Muller, P., Pénin, J. (2003) Why Do Firms Disclose Knowledge And How Does It Matter? mimeo (available at http://www.economie.uqam.ca/Muller%20Penin.pdf)

Pénin, J. (2003) Open knowledge disclosure: A signal to enter innovation networks, mimeo
(available at http://www.economie.uqam.ca/PDF/ Voluntary%20know.%20dis.%2081.doc).

Scotchmer, S., Green, J. (1990) Novelty and Disclosure in Patent Law, in: RAND Journal of Economics 21,1:131-146.

Schmoch, U. (1998) Impact of international patent applications on patent indicators, Report to the OECD, Fraunhofer-ISI, Karlsruhe.