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THESE

de Doctorat de Sciences Economiques

Révélation ouverte de connaissances, information incomplète et formation de liens de collaboration en R&D

Open knowledge disclosure, collective innovations and incomplete information

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CONTENTS

RESUME EN FRANCAIS

REVELATION OUVERTE DE CONNAISSANCES, INFORMATION INCOMPLETE ET FORMATION DE LIENS DE COOPERATION EN R&D

Le sujet de cette thèse de doctorat porte sur la révélation volontaire et ouverte de connaissances. En particulier, nous nous intéressons aux motivations qui conduisent des entreprises à adopter de tels comportements : qu'est ce qui pousse des agents considérés comme rationnels à révéler sans aucune assurance de rémunération certaines de leurs connaissances à d'autres firmes et notamment à leurs concurrents ? Nous insistons particulièrement sur les effets de réputation qui découlent de la révélation de connaissances et qui facilitent, par exemple, la formation de liens de coopérations entre entreprises innovantes.

Le premier chapitre traite de l'endogénéisation des externalités de recherche. Il nous apparaît en effet que la littérature économique relative à la révélation volontaire de connaissances se situe dans le prolongement des travaux sur les externalités de recherche. Longtemps les économistes ont considéré les flux de connaissances à travers la théorie classique des externalités. S'inspirant des premiers travaux de Nelson (1959) et de Arrow (1962), l'innovation était ainsi supposée être un processus individuel, impliquant des agents isolés et connectés uniquement par des liens marchands et le produit de l'innovation supposée être un bien public.

La théorie traditionnelle suppose ainsi que les connaissances circulent « dans les airs » et sont accessibles à toutes les firmes au moindre coût. Dès qu'une firme innove, une partie des nouvelles connaissances lui échappe automatiquement et va accroître un stock mondial de connaissances dans lequel toutes les autres firmes peuvent puiser. L'externalité se traduit par un impact « tombé du ciel » des dépenses en recherche et développement (R&D) d'une firme sur les coûts, le profit ou la probabilité d'innover d'autres firmes sans qu'aucun des protagonistes ne contrôle quoi que ce soit. L'intensité des externalités de connaissances notamment est totalement indépendante, exogène aux comportements des agents, récepteurs ou émetteurs.

Au courant des années 1980 la théorie économique a commencé à mettre en cause cette vision des flux de connaissances en adoptant une position qui met davantage l'accent sur les propriétés de la connaissance et sur les structures d'interaction entre les agents (qui ne se limitent pas aux structures de marché). En un mot, les externalités de connaissances ne sont pas un phénomène automatique, inéluctable, sur lequel les agents n'ont aucune prise. Cette remise en cause de la vision traditionnelle repose sur trois points essentiels :

Tout d'abord, l'absorption de connaissances externes n'est ni libre ni gratuite. Il est impératif, afin d'exploiter les connaissances externes, que les firmes construisent et entretiennent une capacité d'absorption (Cohen et Levinthal, 1989).

En second lieu, et cette hypothèse est très importante pour comprendre l'idée développée dans notre thèse, le concept de stock de connaissances absorbables par une firme est également modifié. Les connaissances diffusées par une firme ne circulent pas « dans les airs », elles ne sont pas automatiquement et instantanément accessibles à toutes les autres firmes de l'économie. Elles circulent à l'intérieur de réseaux d'innovation, lors d'interactions complexes entre les membres de ces réseaux et ne sont accessibles qu'à ces membres. La connaissance est donc un bien collectif, un bien club et non un bien public.

Enfin, à l'instar de l'absorption, l'émission de connaissances est également endogène car les firmes peuvent souvent garder certaines de leurs connaissances secrètes sur une période de temps assez longue. Les connaissances ne s'échappent donc pas automatiquement de leur source créatrice et souvent les firmes peuvent choisir quand, comment et à qui les révéler, si elles choisissent de les révéler. Les firmes disposent ainsi de ce que nous qualifions, en écho aux travaux de Cohen et Levinthal (1989), d'une capacité d'émission des connaissances. A l'instar de Cohendet et Meyer-Krahmer (2001, p. 60), nous définissons cette dernière de la manière suivante : « the ability to tune the disclosure-secrecy dimension ». Si l'analyse économique relative à l'endogénéisation du processus d'absorption des connaissances remonte aux années 80, la prise en compte d'une capacité d'émission des connaissances est plus récente et les recherches à ce stade sont encore embryonnaires.

Le second chapitre a pour objectif d'établir une définition claire du concept de révélation ouverte de connaissances, de fournir des preuves empiriques de tels comportements et surtout de recenser les différentes explications de ces comportements que l'on trouve dans la littérature économique.

Il nous semble essentiel d'établir une distinction entre deux types de révélation de connaissances : la révélation de connaissances dite ouverte (open knowledge disclosure en anglais) et la révélation fermée ou restreinte. On parlera de révélation ouverte de connaissances lorsque l'émetteur ne peut pas s'assurer complètement de l'identité des récepteurs (une publication dans un journal par exemple). A l'inverse, on parlera de révélation restreinte lorsque l'émetteur connaît les personnes à qui il transmet ses connaissances (par exemple, un meeting privé au sein d'une entreprise ou une discussion informelle entre deux personnes). Cette distinction est importante car les motivations sous-jacentes à ces deux types de révélations sont très différentes, la révélation fermée s'apparentant plus à un échange de connaissances qu'à une révélation véritable (von Hippel, 1987, parle ainsi de « know how trading » plutôt que de « knowledge disclosure »).

Par révélation ouverte de connaissances, nous entendons ainsi une situation où une firme choisit délibérément de révéler ses connaissances, sans être directement rémunérée et sans pouvoir contrôler exactement les récepteurs. En un mot, trois dimensions comptent pour caractériser la révélation ouverte de connaissances : cette dernière doit être volontaire, gratuite et ouverte dans le sens expliqué ci-dessus. Nous recensons quatre types de vecteurs qui correspondent à cette définition et par lesquels une firme peut donc révéler ouvertement des connaissances : les publications dans des revues scientifiques (Allen, 1983 ; Hicks, 1995), la présentation de travaux de recherche à des conférences et colloques (Hicks, 1995), les brevets et Internet (exemple des logiciels libres). Par ailleurs, il existe des évidences empiriques tendant à montrer que chacun de ces quatre vecteurs sont utilisés en pratique.

La révélation ouverte de connaissances est une stratégie coûteuse (car elle implique notamment de communiquer des informations aux concurrents) et, par définition, non directement rémunérée. De tels comportements apparaissent donc comme un défi majeur pour les économistes qui ne peuvent pas se satisfaire d'explications en terme de motivation intrinsèque, de rationalité limitée ou d'altruisme. Ainsi, ces derniers se sont-ils efforcés d'identifier les mécanismes indirects de rémunération susceptibles de justifier les comportements de révélation ouverte de connaissances. La deuxième partie du deuxième chapitre est consacrée au recensement de ces différents mécanismes, desquels nous établissons ici une liste synthétique et non exhaustive.

Tout d'abord, une raison très souvent invoquée pour justifier la révélation ouverte de connaissances est la volonté des entreprises de garder les meilleurs chercheurs en leur sein. De même, des entreprises peuvent choisir de révéler ouvertement des connaissances afin de bénéficier d'externalités pécuniaires (Harhoff *et al.*, 2003), de déclencher des effets de réseaux ou d'accroître la demande de produit de la firme (Harhoff, 1996). Les comportements de révélation ouverte de connaissances peuvent également être expliqués à l'aide de la théorie des jeux répétés à l'infini (von Hippel, 1987). En dernier lieu, la révélation peut être motivée par un désir d'améliorer la réputation de la firme, ce qui peut lui être bénéfique pour plusieurs raisons, par exemple, en accroissant la demande qui s'adresse à elle, en lui facilitant l'accès au financement et l'embauche de jeunes chercheurs, en dissuadant les concurrents potentiels, etc.

Le troisième chapitre porte sur les effets de réputation et s'intéresse plus particulièrement à la révélation ouverte de connaissances comme signal de compétences permettant de faciliter l'intégration de l'entreprise dans des réseaux d'innovation. Pour développer cette idée, nous utilisons de manière complémentaire la littérature en économie de l'innovation et la littérature en économie de l'information et notamment de l'information incomplète.

Notre point de départ est la constatation, partagée par une majorité de chercheurs en économie de l'innovation, que l'innovation est un processus collectif lors duquel les agents impliqués (des entreprises, des laboratoires privés de recherche, des laboratoires publics, des capital risqueurs, des banques, des institutions publiques, des offices de brevet, etc.) doivent coopérer, échanger des connaissances, intégrer des projets communs de recherche. Les coopérations en R&D sont notamment très importantes afin de pouvoir accéder aux connaissances détenues par les partenaires et qui ne seraient pas accessibles autrement.

Cependant, des problèmes informationnels, concernant essentiellement l'identification des différents acteurs ainsi que l'évaluation des compétences des partenaires potentiels, compliquent le processus de formation de collaborations en R&D. Par exemple, comment une firme peut-elle repérer ses partenaires potentiels ? Comment peut-elle distinguer les firmes les plus compétentes des autres ? Ou encore, comment peut-elle être certaine avant de s'engager que ses partenaires ont les compétences nécessaires pour mener un projet commun à bien ?

Les firmes sont ainsi amenées à établir des stratégies afin de résoudre, ou tout au moins, de diminuer les risques dans le choix des partenaires. Entre autres, la révélation ouverte de connaissances joue un rôle important dans ce contexte de sélection adverse. Il est en effet bien connu en économie que le « signalling » est une stratégie efficace afin de briser les asymétries d'information (Spence, 1973). Il suit donc de ces développements que la révélation ouverte de connaissances, en permettant à l'émetteur de signaler ses compétences et ainsi de se distinguer par rapport aux autres firmes, peut constituer une stratégie efficace afin de faciliter la collaboration en R&D.

Dans un premier temps, nous illustrons les enjeux d'une stratégie de révélation ouverte de connaissances visant à intégrer des réseaux de production de connaissances en utilisant une formalisation analogue à celle de Cohen et Levinthal (1989). A la différence de ces derniers, nous supposons que les firmes ont le loisir de décider la quantité de connaissances qu'elles rendent publiques. Cette révélation ouverte de connaissances étant une façon d'envoyer des signaux vers les autres firmes, nous supposons qu'elle influence positivement le stock de connaissances absorbables de la firme émettrice car elle permet d'agrandir la liste de ses partenaires. Ainsi, dans ce modèle, les émissions de connaissances d'une firme déclenchent deux effets opposés sur son profit : d'une part, elles augmentent son stock de connaissances, et donc son profit, via un accroissement de son réseau de partenaires. D'autre part, elles augmentent le stock de connaissances des autres firmes ce qui, via un effet de rivalité, diminue le profit de la firme émettrice. Lorsque le premier effet domine le second, les conditions sont réunies pour que les firmes choisissent de révéler une part de leurs connaissances.

Dans un second temps, nous utilisons un modèle de signal issu de la théorie des jeux (Spence, 1973) afin d'expliquer le lien positif entre la révélation ouverte de connaissances d'une firme et le nombre de coopérations en R&D développées par cette firme. Nous considérons deux firmes (A et E) qui ont chacune le choix entre coopérer en R&D avec l'autre firme ou ne pas coopérer. La firme A peut être de deux types différents : soit elle est « compétente », soit elle est « moins compétente ».

Pour la firme *E*, la coopération avec *A* n'est rentable que si *A* est du type « compétent ». Cependant, *E* ne connaît pas le type de *A*. Son principal problème est donc de découvrir si la firme *A* est compétente ou non c'est-à-dire si la coopération avec cette firme est rentable ou non. Pour permettre à *E* de se faire une idée sur le type de *A*, nous supposons que cette dernière a la possibilité de révéler des compétences à *E* afin de lui envoyer un signal sur son type. Dans ce cadre, nous montrons que *A* est, sous certaines conditions, incitée à révéler une part de ses connaissances afin de permettre la coopération avec la firme *E*. Nous montrons notamment qu'en fonction de la technologie des firmes, de leur capacité d'absorption ou encore du degré de concurrence dans le secteur ou évolue la firme *A*, il peut exister un équilibre Bayésien parfait pour lequel la firme *A* révèle des connaissances.

Dans le quatrième chapitre, nous abordons à nouveau le thème de la révélation ouverte de connaissances dans le but de faciliter la collaboration en R&D mais, cette fois-ci, en utilisant l'outil des simulations numériques. L'objectif du chapitre est, d'une part, de développer un modèle théorique décrivant la formation de liens de collaboration en R&D entre firmes en insistant particulièrement sur le rôle de la révélation ouverte de connaissances et, d'autre part, de tester ce modèle à l'aide de simulations numériques.

Sans entrer dans les détails, le modèle se décompose de la manière suivante. Au commencement de la simulation, les firmes, symbolisées par des nœuds localisés sur un graphe vide, sont caractérisées par un certain niveau de connaissances générales (détenues par toutes les firmes) et privées (détenues par la firme et tenues secrètes pour les autres firmes) ainsi que par une stratégie de révélation ouverte de connaissances. Pour simplifier nous considérons seulement deux types de stratégies de révélation : des firmes qui révèlent une forte quantité de connaissances et d'autres qui révèlent une faible quantité. Le profit de chaque firme dépend positivement des connaissances privées détenues par cette firme.

La dynamique du modèle est la suivante : à chaque période, les firmes sont engagées dans la production de nouvelles connaissances privées. La probabilité pour une firme de produire de nouvelles connaissances dépend positivement de son stock global de connaissances. Les firmes décident ensuite de révéler ouvertement des connaissances privées afin d'accroître leur réputation. Les connaissances privées révélées deviennent automatiquement générales, c'est-à-dire qu'elles profitent à toutes les autres firmes. Enfin, les firmes décident d'établir des partenariats en R&D avec d'autres firmes, partenariats dont l'intérêt consiste essentiellement à pouvoir accéder à certaines connaissances privées détenues par les autres firmes. A ce stade, la quantité de connaissances révélées par une firme influence directement la réputation de cette firme et donc sa probabilité d'établir de nouveaux partenariats en R&D.

Les entreprises font ainsi face au dilemme suivant : si elles décident de révéler beaucoup de connaissances elles accroissent fortement leur réputation et donc leur probabilité de trouver des partenaires mais en même temps elles diminuent leur stock de connaissances privées et donc leur profit immédiat. A l'inverse, si elles choisissent de révéler peu de connaissances elles préservent leur stock de connaissances privées mais n'accroissent pas leur réputation et, de ce fait, hypothèquent leurs chances d'innover dans le futur. En un mot, notre modèle tient compte du fait que la révélation ouverte de connaissances ne consiste pas seulement à offrir des connaissances aux concurrents, mais permet également d'améliorer la réputation de la firme ce qui lui permettra éventuellement de développer davantage de collaborations en R&D.

L'évolution globale des liens entre les firmes (comment, à partir d'une situation ou les firmes n'ont aucun lien entre elles, une forme particulière de réseau émerge) ainsi que le différentiel de performance entre les firmes qui adoptent des stratégies de révélation différentes sont étudiés à l'aide de simulations numériques dont voici, en résumé, les principales conclusions :

(i) La révélation volontaire de connaissances tend à augmenter le nombre de partenariats en R&D des firmes qui révèlent beaucoup; *(ii)* La révélation volontaire de connaissances est une stratégie risquée à court terme, les firmes qui révèlent beaucoup voyant leur profit décroître dans les premières périodes de la simulation quels que soient la fréquence de révélation et le nombre de firmes qui révèlent; *(iii)* Par contre, à plus long terme, la révélation ouverte de connaissances peut devenir une stratégie profitable pour les firmes qui ne révèlent pas trop de connaissances. Pour les autres, la révélation reste non profitable; *(iv)* Moins il y a de firmes qui adoptent une stratégie active de révélation, plus cette stratégie est payante en moyenne; *(v)* Par ailleurs, l'adoption d'une stratégie de révélation ouverte de connaissances raisonnable permet aux entreprises qui ont démarré la simulation

avec un stock de connaissances spécifiques faible de rattraper et de dépasser (en terme de profitabilité) les entreprises qui ont démarré avec un stock de connaissances plus important mais qui ont adopté une stratégie de révélation passive; *(v)* Enfin, il ressort du modèle que plus le différentiel initial de connaissances est faible, moins le temps nécessaire pour rattraper les firmes qui ont démarré la simulation avec un stock de connaissances spécifiques plus élevé est important.

Le cinquième et dernier chapitre s'intéresse plus particulièrement au rôle du brevet comme moyen de signaler des connaissances. La question à laquelle nous nous attaquons est la suivante : le brevet est-il simplement un instrument de limitation de la concurrence, conformément à la logique d'exclusion habituellement mise en avant dans les manuels d'économie, ou bien est-il aussi un outil facilitant les interactions avec les autres acteurs de l'innovation, s'inscrivant alors dans une logique de coordination, voire de coopération inter-organisations ? Si cette deuxième hypothèse devait être confirmée, quelle est alors l'importance des pratiques de « signalling » et notamment du brevet comme moyen de signalement ? En combinant des apports récents de la littérature économique sur le brevet avec l'étude de 18 entreprises de la Biovalley du Rhin Supérieur, notre travail fournit quelques premiers éléments de réponse à ces questions.

Le brevet détient une double fonction de protection et de divulgation des connaissances nouvelles. Traditionnellement les économistes se sont focalisés sur la fonction de protection du brevet, et sur le pouvoir de monopole, ou pouvoir d'exclusion, qui en découle. Cependant, notre conviction est que la fonction « révélation de connaissances codifiées » du brevet (qui s'opère à travers la publication automatique par l'office national des brevets d'un descriptif de l'invention) joue un rôle presque aussi important que la fonction « droit de propriété ». C'est le couplage de la protection et du signal, et non l'une ou l'autre de ces deux propriétés, qui donne au brevet toute sa dimension et son importance stratégique.

Ainsi, le brevet nous apparaît comme étant plus qu'une garantie de monopole. Parallèlement à son rôle classique d'appropriation de rente, émerge un rôle du brevet comme vecteur de coordination entre acteurs hétérogènes. Dans certaines industries où l'innovation est fortement systémique et le risque de chevauchement de brevets important (cas des semi-conducteurs notamment, mais aussi de plus en plus des biotechnologies), le brevet joue avant tout un rôle de coordination en facilitant les opérations d'échanges croisés de licences et de coopérations en R&D.

Afin de mieux juger de la pertinence de cette hypothèse et surtout d'évaluer le rôle du brevet comme moyen de signalement, afin également de comparer son utilisation à d'autres outils de signalement, nous avons mené, en parallèle à cette réflexion théorique, une étude empirique dans le secteur des biotechnologies. La synthèse des apports de cette analyse de terrain portant sur 18 entreprises de la Biovalley du Rhin Supérieur est la suivante.

Il apparaît que le brevet est perçu avant tout comme un moyen de protéger la connaissance détenue par l'innovateur. Cette protection est ressentie comme nécessaire aussi bien dans le but de limiter la concurrence que d'accroître le pouvoir de négociation du détenteur en cas de collaboration avec d'autres acteurs (scientifiques, technologiques ou financiers). En revanche, la fonction de signal de compétences, quoique mentionnée par une grande majorité de répondants, est perçue comme peu importante en moyenne, suggérant ainsi que le signalement de compétences n'est pas en tout état de cause la raison principale d'un dépôt de brevet. Toutefois, de nombreuses entreprises mentionnent que le brevet a joué un rôle important en amont de leurs collaborations avec d'autres acteurs, en leur permettant de se connaître, confirmant ainsi l'idée que la dimension de signal du brevet est importante dans le processus de collaboration. Enfin, concernant les autres moyens de signalement, la majorité des entreprises s'accordent à reconnaître qu'elles autorisent leurs chercheurs à publier dans des revues scientifiques ou à présenter leurs travaux lors de conférences. Bien qu'il soit évidemment très délicat de tirer des conclusions à partir d'un échantillon aussi restreint, ces résultats pris dans leur globalité donnent du poids à l'hypothèse de révélation ouverte de connaissances et à son rôle de signal afin de faciliter le processus de collaboration inter-organisations.

GENERAL INTRODUCTION

> "Essential feature of collective invention was the release of technical information to actual and potential competitors […] To the degree that economists have considered this behaviour at all, it has been regarded as an undesired "leakage" that reduces the incentives to invent. That firms desire such behaviour and that it increases the rate of invention are possibilities not yet explored. They should be."
>
> (Allen, 1983, p. 21)[1]

Although the firm is central to economics and has been the focus of a tremendous number of studies in the discipline, many questions regarding firms' behaviours still remain unanswered. In particular, it is still unclear why firms sometimes choose to disclose widely some of their knowledge that, once disclosed, benefits other firms including competitors. Yet, it is indisputable that behaviours of knowledge disclosure occur in reality and that firms often prefer to voluntarily disclose their knowledge rather than to keep it secret. This thesis aims at improving the general understanding related to knowledge disclosure and, more specifically, it aims at investigating the motivations that induce firms to adopt those behaviours.

It is hardly possible to argue nowadays, as Allen did 20 years ago, that economists did not consider the fact that rational firms may benefit from disclosing their knowledge. Knowledge disclosure has been the topic of notable economic studies during the past 20 years (Allen, 1983; von Hippel, 1987; De Fraja, 1993; Hicks, 1995; Harhoff, 1996; Harhoff, Henkel and von Hippel, 2003) but, overall, research in the field is still at an embryonic stage. Historically, the economic literature on knowledge disclosure has developed within the traditional economic theory of externalities.

[1] The preparation of a thesis usually gives young scholars the opportunity to present an overview of the literature surrounding the topic of the thesis. In order to preserve this mindset we have therefore chosen, as often as possible, to start each section with a quotation that, we believe, corresponds best to the issue that is treated in the section. Hopefully, this way of drawing links between our work and the existing literature may facilitate the reading of this thesis. But it is also a way to show that science is cumulative and that our researches are highly sensitive to prior researches in the domain.

Indeed, in the early days of the economic theory on innovation and knowledge, no voluntary transfer of knowledge among agents was assumed. The only transfers of knowledge were attributed to externalities. Following the seminal works of Nelson (1959) and Arrow (1962), once produced, knowledge was supposed to automatically and instantly leak from its creative source to profit other agents. Traditional economic theory assumes therefore that, in some sense, knowledge flows 'in the air'. Once produced by a firm, knowledge feeds a global stock of knowledge from which all the other firms can draw. A central point of this vision of knowledge transfer is that firms, those who generate externalities as well as those who benefit from them, are considered as exogenous. They control neither the rate of emission of their knowledge nor their absorption of external knowledge.

Taking a fresh look at this traditional vision leads directly to consider behaviours of voluntary knowledge disclosure. Specifically, the rethinking of the traditional view relies on three main points: First, an endogenous absorption capacity is introduced because firms cannot passively absorb external knowledge (Cohen and Levinthal, 1989). Second, the concept of external stock of available knowledge is modified. Once produced, knowledge does not feed a global stock of knowledge from which all firms can draw. Knowledge flows only within well-defined groups of agents, who know each other. We will hence refer to knowledge as a club good or a collective good in the sense that it is available only to members of the club in which it is embodied. Third, an endogenous emission capacity is introduced because most of the time knowledge does not automatically and instantly spill over. Firms can often control their knowledge, which means that they can decide when, how and to whom they want to disclose it, if they decide to disclose it at all. Following Cohendet and Meyer-Krahmer (2001, p. 60), we define firms' emission capacity as: "the ability to tune the disclosure-secrecy dimension".

Thus, the way that leads from the traditional theory of knowledge externalities to behaviours of voluntary knowledge disclosure is long but relatively straight. Our interest in this thesis lies in a particular kind of knowledge disclosure, namely open knowledge disclosure, which we distinguish from closed knowledge disclosure. More specifically, we investigate the motivations that rational profit seeking agents may find to adopt such behaviours of open knowledge disclosure. For instance, we explore why firms let their researchers publish in scientific reviews, why they let their researchers present their works during conferences, why they apply for patents while they do not intend to use the exclusive property rights associated with patents, why they release information on their web sites, etc.

We define open knowledge disclosure as a situation in which a firm chooses deliberately to disclose knowledge, without being directly remunerated for this disclosure and without being able to prevent a given agent from accessing the disclosed knowledge. In other words, open knowledge disclosure occurs when the sender cannot control exactly the population to which he discloses his knowledge (a publication in a journal for instance). Conversely, closed knowledge disclosure occurs when the sender knows the population of recipients (a private meeting inside a company, for instance, or informal discussion between employees). The distinction between open and closed knowledge disclosure is essential in this work because the motivations that induce firms to adopt these two kinds of behaviours are completely different, closed knowledge disclosure being more similar to knowledge trading than to pure knowledge disclosure.

By definition, open knowledge disclosure is not a direct remunerated activity. On the other hand, it is costly for firms, mostly because it means providing competitors with helpful knowledge that will enable them to compete more fiercely with the disclosing firm. At first sight common wisdom may therefore suggest that behaviours of open knowledge disclosure remain scarce and that firms always try to protect their new innovations either by keeping a strict secrecy on them or by applying for patents. It is not expected that firms would release precious information to competitors for free.

Yet, empirical evidence tends to demonstrate that, contrary to this first belief, firms often openly disclose knowledge through publications in scientific reviews, communications at conferences, patents, etc. Moreover, since at first sight firms can gain nothing by disclosing information to competitors for free, such behaviours of open knowledge disclosure were for long perceived as a major challenge for economists who, in the past, often attributed them to spillovers, i.e. to undesired knowledge leakages, to altruism or even to a kind of lack of rationality from the disclosing firms, thus considering that, from an economic point of view, disclosing firms make a mistake by releasing their knowledge for free.

However, in the last two decades wide ranges of indirect mechanisms that can make a strategy of open knowledge disclosure profitable for disclosing firms have been investigated. It has therefore been shown that there exist many reasons that can induce rational, profit seeking firms to openly disclose knowledge. For instance, the reputation stemming from open knowledge disclosure can ease the formation of R&D collaborations with other firms, thus increasing the R&D performances of the disclosing firms.

Indeed, the major point that we defend in this thesis is that behaviours of open knowledge disclosure can sometimes be interpreted as signals of competences aiming at easing the formation of R&D cooperation with other firms or with public institutions. Firms willing to collaborate in R&D may wish to disclose knowledge in order to increase their reputation, which in turn may facilitate the establishment of links with other agents.

Most scholars agree on the fact that innovation is a collective process that involves many types of agents (firms, universities, banks, patent offices, etc.). Firms who intend to be innovative must cooperate, exchange knowledge and develop innovation networks. R&D collaborations are especially important to access knowledge held by partners and which would not be available otherwise. Knowledge is indeed not a public good as traditionally argued in most economic textbooks. Once produced it does not become instantly and automatically available to other firms and it does not flow 'in the air'. Rather, knowledge usually flows within clubs and is accessible only to members of the club. Therefore, firms who want to access particular pieces of knowledge must develop collaborations with the owners of these pieces of knowledge, they must be granted access to the network of agents in which knowledge is flowing.

But the formation of R&D collaborations occurs in an environment of incomplete information. Firms do not know exactly the competences of potential partners and therefore they may not be able to infer whether or not a partnership is profitable. In other words, firms involved in the collective process of knowledge production may face adverse selection problems. For instance, how can a firm be certain to cooperate with the appropriate partners? How can she localise potential successful partnerships? How can she distinguish profitable partnerships from less profitable ones? These problems of adverse selection may severely damage the collective process of innovation (Akerlof, 1970).

Firms may therefore be induced to implement strategies in order to solve these problems of incomplete information and to decrease the risk of cooperating with inappropriate partners. And it is well known in economics of information that "signalling" may be an efficient strategy to solve adverse selection problems (Spence, 1973). Consequently, firms may decide to openly disclose knowledge in order to signal their competences to scientific and industrial communities, thus breaking the adverse selection problems regarding their own competences and facilitating R&D collaborations with other firms. In other words, we argue in this thesis that, by openly disclosing knowledge, firms may signal that they hold specific competences that have not been disclosed, therefore signalling other firms that collaborating with them may be profitable. This thesis is structured as follows:

The first chapter deals with the endogenisation of knowledge externalities. Indeed, it may be helpful to introduce behaviours of open knowledge disclosure by starting with a reminder of the classical theory of knowledge externalities because, as we already mentioned above, the economic work on knowledge disclosure finds its source precisely within this theory. It is by endogenising knowledge externalities that economic scholars came to deal with behaviours of open knowledge disclosure.

The second chapter aims at providing an overview of the economic literature surrounding the topic of open knowledge disclosure. First, we give a precise definition of behaviours of open knowledge disclosure, as opposed to other kinds of knowledge disclosure. Then we display the empirical evidence that tends to show that such behaviours of open knowledge disclosure occur frequently in reality. Specifically, we identify and discuss four channels through which firms may openly disclose their knowledge, namely publications in scientific journals, presentations in conferences, application for patents and disclosure on firms' web sites.

In the second part of the chapter we present an overview of the different economic motives that have been treated in the economic literature and that may explain why firms often choose to openly disclose their knowledge. Here is a synthetic and non exhaustive list of the indirect mechanisms that can make open knowledge disclosure profitable and that are reviewed in this chapter:

Firms may want to openly disclose knowledge in order to keep their best researchers (who may value their scientific reputation and not only their pay) working in the firm. Also, firms may openly disclose knowledge in order to trigger reciprocity from other firms, to trigger pecuniary spillovers, to trigger network effects or to increase the size of the market in downstream sectors. Finally, and it is on this point that we insist in this thesis, firms, by openly disclosing knowledge, may wish to increase their reputation, which can be profitable in order to increase the demand addressed to the firm, to facilitate the granting of financing, to be able to hire young graduate students more easily, to deter potential competitors, etc.

In the third chapter, we develop the idea shortly introduced above of open knowledge disclosure as a device to find more easily partners with whom to cooperate in R&D. To tackle this point, we combine the literature on economics of information (and more specifically of incomplete information) and the literature on economics of innovation. We show that the presence of adverse selection problems at the early stage of R&D collaborations may induce firms to openly disclose some of their knowledge in order to signal their competences to potential partners, thus facilitating the formation of R&D collaborations.

We illustrate the stakes of strategies of open knowledge disclosure aiming at triggering R&D collaborations, first by using a formalisation analogous to the one developed by Cohen and Levinthal (1989) and second by using a formalisation taken from game theory under incomplete information. These two models allow us, among others, to demonstrate that there exist equilibria for which firms may decide to openly disclose knowledge and to identify the conditions under which behaviours of open knowledge disclosure may arise.

In the fourth chapter we develop a theoretical framework describing the formation of innovation networks of firms, with specific emphasis put on the role played by open knowledge disclosure on the formation of such networks. The model is then tested with numerical simulations (this chapter is based on a work realised in collaboration with Paul Muller).

The model of network morphogenesis works as follows. A population of firms is located on an empty graph. Firms differ both through their initial endowments of specific knowledge (knowledge held secret to other firms) and through their strategies of open knowledge disclosure: Some firms adopt an active strategy of knowledge disclosure and others a passive strategy.

At each time step, firms engage in R&D activity, which is aimed at building up new pieces of specific knowledge. The probability of producing a new piece of specific knowledge depends on the total level of knowledge a firm has access to. After having performed such an activity, each firm considers the decision whether to openly disclose or not part of the specific knowledge she holds which, if disclosed, would become public knowledge, i.e. knowledge available to all other firms. Such an action, although it decreases her current profit, allows the firm to improve her reputation. Then, periodically, a firm considers the decision of linking up with an other firm. The main interest of being connected with an other firm is to be offered access to part of the specific knowledge held by this firm. Connections therefore increase the stock of knowledge of connected firms, which in turn enhances the performances of their R&D. The connexion process is driven by reputation effects. Reputation mitigates the uncertainty associated with a first interaction, which means that firms aiming at connecting with an other firm are likely to give priority to firms enjoying higher levels of reputation.

Since firms are supposed to be knowledge intensive, specific knowledge constitutes their main source of profits. In other words, firms, when considering whether to openly disclose knowledge or not, face the following trade-off: On the one hand, open knowledge disclosure decreases their instant profit (since it decreases their stock of specific knowledge) but, on the other hand, it also increases their reputation and hence their probability to set up collaborations with other firms.

Some implications of our model have been investigated by using numerical simulations. Synthetically, the following results have emerged from these simulations: *(i)* Open knowledge disclosure tends to increase the number of R&D partnerships contracted by high disclosing firms. The less numerous the high disclosing firms, the higher the number of R&D partnerships they are involved in; *(ii)* In the short run, open knowledge disclosure is not profitable, whatever the frequency of the disclosure and the proportion of high disclosing firms; *(iii)* Conversely, in the long run, open knowledge disclosure can become a profitable strategy, provided that the frequency of the disclosure remains low (lower than 2%); *(iv)* Open knowledge disclosure is a more profitable strategy if fewer firms adopt it; *(v)* Open knowledge disclosure is a risky strategy in the short run, since it increases the probability of bankruptcy. The less numerous the high disclosing firms, the higher the probability that they go bankrupt; *(vi)* When the frequency of the disclosure for high disclosing firms is not too high (lower than 2%), adopting a strategy of open knowledge disclosure allows firms who started with low endowments of specific knowledge to catch up with and to outperform (in terms of profitability) firms who started with higher endowments of specific knowledge and who adopted a strategy of low knowledge disclosure. Furthermore, it also allows those firms to catch up with (but not to outperform) firms who started with higher endowments of specific knowledge and who adopted a strategy of high level of knowledge disclosure, tending to support the view that to explain firms' long run profitability the disclosure strategy counts more than initial endowments of specific knowledge.

Our model provides therefore a rationale to behaviours of open knowledge disclosure by showing that such strategies, although risky in the short run, may pay in the long run by enabling firms to access external sources of knowledge more easily.

The fifth and last chapter focuses specifically on the role of patents as devices to openly disclose knowledge (this chapter is based on a work realised in collaboration with Séverine Baverey, Rachel Levy, Sandrine Wolff and Antoine Bureth). By combining a theoretical discussion with the first elements of a case study in the field of biotechnologies we attempt to answer the following questions: Are patents only useful to protect their owners from competition or are they also devices that facilitate interactions and collaborations among agents involved in the innovation process? Furthermore, should this second hypothesis be confirmed, what is the importance of strategies of open knowledge disclosure in this coordination process and, more specifically, of patents as devices to openly disclose knowledge?

In theory, patents have a double function. They both protect an innovation and widely disclose the knowledge related to this innovation. Economists have focused essentially on the protection function associated with a patent. However, our conviction is that the function "disclosure of codified knowledge", which operates through the automatic publication of the description of the innovation by the national patent office, plays a role at least as important as the protection function. It is the combination of the disclosure and protection functions and not one single function taken separately that gives its strength and its strategic importance to a patent.

According to how these two functions are tuned, we show that patents can serve two different logics of utilisation: A logic of exclusion, which is traditionally put forward in economic textbooks, and a logic of coordination and even of cooperation among agents. Indeed, more than a simple guarantee of a monopoly position, in some industries where innovation is strongly systemic and the risk of patent overlap is high, patents can play a fundamental role of coordination in the innovation process, by easing the exchanges of knowledge and R&D collaborations for instance.

Empirically, we investigate the coordination role of patents and the importance of their open knowledge disclosure function with the help of a case study based on the answers to a questionnaire of 18 biotechnologies firms located in the Upper-Rhine BioValley. Overall, this case study confirms the strategic importance of patents in biotechnologies and not only in order to exclude rivals but also to improve firms' bargaining power, to ease access to financing and to signal competences.

Although firms, on average, report that they do not perceive the disclosure function of patents to be as essential as the protection function, some of them nevertheless consider it as important. Furthermore, biotechnologies firms in our sample report using the protection given by a patent in two different ways that seem equally important: To exclude rival firms and to improve bargaining power in negotiations. It also comes out that patents seem to play a role at all stages of R&D collaborations among firms and specifically before the collaboration, in order to help firms to locate their partners. Finally, we find that biotechnologies companies do use many methods to disclose knowledge and to signal their competences including the patent system, which is nevertheless not perceived to be as important as participations in conferences, publications in scientific reviews or the encouragement of informal relationships between employees.

CHAPTER I:

KNOWLEDGE EXTERNALITIES: ECONOMIC TRADITION AND RENAISSANCE[2]

[2] This chapter is based on my article “Endogénéisation des externalités de recherche: le rôle de la capacité d’émission des connaissances” (2003, *Revue d’Economie Industrielle*, vol. 102, pp. 7-28).

This thesis aims at studying behaviours of open knowledge disclosure. But in order to understand how this topic has emerged and evolved over time in the economic discipline it is worth making a preliminary detour by the theory of knowledge externalities. Such a detour is necessary because we believe that the economic literature on knowledge disclosure finds its sources precisely in the theory of knowledge externalities.

In the early days of economic theory on innovation, no voluntary transfer of knowledge among agents was assumed. Traditionally, scholars consider the problems of knowledge production and circulation through the lenses of the classical theory of public goods. Following the seminal work of Arrow (1962) and Nelson (1959) the innovation process is assumed to be an individual process that involves isolated agents connected only through market interactions and the outcome of this process, new knowledge, is considered as a public good. Once produced, knowledge is supposed to benefit automatically and instantly to other agents who did not participate in its production. Within this framework, all the transfers of knowledge between firms are reduced to externalities, meaning that firms are considered as passive and, among others, that the transfer of knowledge is undesired by the firm who initially held the knowledge (in line with the traditional theory of externalities knowledge transfer is exogenous to agents)[3].

[3] It would be unfair and naïve to argue that the first authors who worked on innovation adopted this view of knowledge transfer as being only externalities without any restriction. For sure they were conscious that knowledge flows were not only pure spillovers. However, this simple theoretical vision has endured because as Schumpeter puts it (1954, p. 136, t1): "In economy and elsewhere, we do not fight against man, things and idea as they really are, but against the caricature that we draw from them" (taken from the French edition. The translation is mine). This method of ideal type has always proved necessary to ease the understanding of a given problem.

It is only in the 1980s that economic theory began to question this rather naïve view of knowledge circulation and considered a more competence based approach, which puts more weight on learning, competences and on the structure of interactions between the agents. The circulation of knowledge is not a process in which firms are passive, as argued by the traditional approach of knowledge spillovers. Mechanisms that depend, among others, on the properties of knowledge and on the structures of interactions of agents allow controlling the circulation of knowledge.

Basically, the rethinking of the traditional vision of knowledge externalities rests on three main points: *(i)* The consideration of knowledge as a collective good rather than as a pure public good and of the innovation process as a collective process involving non market interactions and collaborations rather than as an individual process that involves isolated agents connected only through market interactions; *(ii)* the introduction of a knowledge absorption capacity (Cohen and Levinthal, 1989); *(iii)* the introduction of a knowledge emission capacity. Thus, we see that the road from the traditional approach of knowledge externalities to behaviours of open knowledge disclosure is long but relatively straight.

In the first part of this chapter we present the traditional approach of knowledge externalities. Then we describe how this view has evolved by revisiting the central hypotheses, regarding the properties of knowledge as well as the mechanisms of interaction among agents, on which this traditional vision relies. But let us begin our way along the road that leads to open knowledge disclosure by a brief reminder of the early economic literature on externalities.

I.1. The traditional approach of knowledge exernalities

I.1.1. The general economics of externalities

"The concept of external economies is one of the most elusive in economic literature"

(Scitovsky, 1954, p. 143)

The fatherhood of the theory of externalities is generally granted to Marshall (1920) and Pigou (1932). The term "spillovers" or "externalities" or "external economies" (or diseconomies) is purely economic. It makes some sense only in this field because it is narrowly correlated with the notion of market. In other words, the concept of externalities can be apprehended only relatively to the market.

Classical economics assumes that all transactions take place on a market, meaning that things done by a given agent affect other agents' well being exclusively through their impact on market prices. There is no other interdependence between agents than the ones that occur through market mechanisms. In a fictitious, perfect economy all the interactions between agents occur on a market and there exists a market for each commodity. Graphically, market relationships can be illustrated by assuming that all agents are located on a star shaped graph with the auctioneer located in the middle of the star. In such a graph it appears clearly that agents have no direct links, their only relation being the one that goes through the auctioneer, i.e. through the price mechanism. However, this assumption that there exists a market for each commodity is strong and this has led economists to consider the problem of non-market interdependences between agents.

Generally speaking the word externalities encompasses all the exchanges that do not occur on the market, meaning that these exchanges are not regulated by the price mechanism. Externalities are direct interdependences that do not operate through the market. In other words, the absence of a market is the major characteristic of externalities.

This absence may have two sources: Technical and financial. Sometimes it is technically impossible to implement a market for a good due to some specific properties of this good. This is the case, for instance, when dealing with pure public goods such as the air we breath. Such goods cannot be made appropriable. It is technically impossible to exclude an individual from enjoying them. Thus, it is not possible to implement a market to exchange these goods because a necessary condition for markets to work is the possibility for both parts to control the transaction. Each party must have the possibility to end the transaction whenever he wants. If control is not possible for a least one part of the transaction, either the seller or the buyer or for both parts, then a market for the good cannot exist. The absence of control of at least one part is therefore an important feature of externalities, since it undermines the possibility to market the good.

Externalities may also emerge in cases in which it would be technically possible to implement a market for the good but it would be too expensive to do so. Here sources of externalities are to be found within the Transaction Cost theory that was initiated by Coase (1937) and developed and popularised by Williamson (1975). The main contribution of these authors to the classical market theory is the statement that market interactions are not free, that agents must support a transaction cost. This cost is essentially due to bounded rationality (agents do not have a complete information, which might generate situations of adverse selection or moral hazard) and to opportunistic behaviours. These two factors, when they are associated, increase the negotiation and monitoring costs of the transaction (Coriat and Weinstein, 1995). Therefore, due to high transaction costs it is sometimes too expensive to settle a market for a given good and to internalise the spillovers.

Externalities can be divided into two groups: Externalities of consumption and of production. The former occurs when the consumption of one agent affects directly the well being of another agent, while the latter arises when the activity of a firm affects the welfare of other agents without this effect occurring through the market. Here are a few examples of different kinds of spillovers: Negative consumption externalities may be, for instance, when the tenant of an apartment plays the guitar loudly. The music affects the neighbourhood negatively without the latter being able to ask for compensation, since there is no market for having the right to play music in one's own apartment. Conversely, positive consumption externalities may occur, for instance in the previous example, if at least one neighbour enjoys the music. Similarly, a famous example of positive production externalities, taken from Meade (1952), is when an orchard is located close to hives. In this case, the honey and the fruit producers both benefit from positive spillovers, since it is not feasible to settle a market to regulate the passage of the bees into the orchard. Finally, the classical example of negative production spillovers is environmental pollution.

Scitovsky (1954) drew a distinction between two different kinds of production externalities. He explains that one must differentiate production externalities in a perfect competition environment and pecuniary production externalities that occur within a non-perfect competition framework. Externalities in a perfect competition framework were, for instance, treated by Meade (1952). They refer to the classical, commonly used definition given above, namely interdependences among agents that do not occur through market mechanisms.

But, Scitovsky also points out another class of spillovers, which occur through market mechanisms: “This latter type of interdependence may be called pecuniary external economies to distinguish it from the technological external economies of direct interdependence” (Scitovsky, 1954, p. 146). Such externalities arise because markets are not perfectly competitive and therefore the price of a transaction may not always reflect the value of the good. We will come back to the distinction between pure and pecuniary externalities later, when considering the case of knowledge externalities, which will help us to understand better the differences between these two concepts.

Externalities have important consequences on the outcome of market mechanisms. Since there is no market, externalities mean services (and disservices) that are rendered for free by one agent to another. They are interactions that are not remunerated. Therefore, externalities are considered as one cause of market failure, meaning that in the presence of externalities the first welfare theorem does not hold: The market equilibrium is not a social optimum.

In case of negative externalities, which are effects harmful for other agents, the private return of the production or consumption of the good is higher than its return for society. It follows that market forces lead to a level of production of the good that spills over too high as compared with the desirable level for society. Conversely, but for similar reasons, in case of positive spillovers the private return is lower than the social return and thus market forces lead to an under production or consumption of the good that spills over as compared with an ideal.

In the presence of externalities the market does not lead to a social optimum. It is therefore necessary to implement policies to assist the market and to orient it toward a social optimum. Different methods to internalise spillovers have been underlined in the economic literature but before mentioning them, we wish to say a word about the work of Coase (1960) who suggested that the problem of externalities can sometimes be solved automatically, without any external intervention.

First, Coase insists on the reciprocal nature of externalities, which involve at least two agents (a sender and a recipient). Then, Coase suggests that both agents may have an interest to directly negotiate and to find an agreement to solve by themselves the problem caused by spillovers. Indeed when the economy is not at a social optimum, by definition, there is an opportunity to increase the gains of each agent. And Coase stresses that rational agents would never miss such an opportunity to increase their profits and hence have an interest to negotiate in order to internalise externalities.

For instance, let us consider a world with one factory that pollutes a river in which fishermen work. Here, the problem of externalities should lead to a situation in which there is too much pollution from a social point of view. But, following Coase, if the law states that the factory is allowed to pollute, then it is in the interest of the fishermen to pay the firm in order that she decreases her pollution. On the other hand, if the fishermen have the right to prevent the factory from polluting then it may be in the interest of the firm to pay the fishermen in order to be allowed to pollute. In both cases Coase shows that pollution will decrease until it reaches its optimal level from a social point of view.

Therefore, all a government has to do is to ensure that the rights are well defined. The choice of who holds the rights affects the problem of which part must pay the other but not the outcome of the market. In the above example, whether it is the firm who is allowed to pollute or the fishermen who have the right to stop pollution the equilibrium is the same. To sum up, the Coase conjecture states that no matter who has the rights, in the absence of transactions costs, even when there are externalities the market leads to a social optimum[4].

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[4] A recurrent reproach addressed to the Coase conjecture is that it is nothing more than a tautology. Indeed, all it states is that if there is no transaction costs then market mechanisms lead to a social optimum. Put it differently, this means that 'if the market is perfect then the market is perfect'.

However, most of the time it is costly to localise all the agents affected by externalities and negotiations are also time consuming and costly. And when there are transaction costs then the problem remains basically the same, i.e. externalities are a cause of market failure. In such cases, methods to internalise the spillovers may be implemented by a government concerned with the global welfare.

A first and radical solution is to merge the agents affected by the spillovers. Indeed, when the sender and the recipient are merged into one single entity, then the problem of spillover is automatically solved, since the sender is now induced to take into account the effect of his decision on other firms (since after the merger those firms are part of the same organisation). Therefore, the merger makes it possible to force the sender to include in his decision the effects of this decision on the agents who are affected by it. A solution less radical than the pure merger of the sender and the recipients is to encourage agents to make cooperation agreements that could allow the internalisation of the externalities.

Another solution suggested by Pigou (1932) is to tax agents who emit negative spillovers and to grant subsidies to those who are at the source of positive spillovers. In order to force the sender to include in his computation all the spillovers he releases, the amount of the tax or subsidy, for each unit of production (consumption), must be equal to the marginal effect of this production (consumption) on society as a whole. It is worth noticing that in order to implement such a tax or subsidy, a government must enjoy perfect information regarding the situation, which is rarely the case.

A last solution is to implement a market for the goods that spill over. Since the lack of a market is the main characteristic of externalities, the implementation of a market solves the problem of external effects. This solution was tested, for instance, in the United States in the case of environmental pollution with the implementation of permits to pollute, which are permits that allow their holders to produce a certain amount of pollution and that can be exchanged on a market.

The concepts mentioned here should become clearer in the next section in which they are illustrated with the case of knowledge externalities.

I.1.2. The case of knowledge externalities

> "Good work is rightly appreciated, inventions and improvements in machinery, in processes and the general organization of the business have their merits promptly discussed: If one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas"
>
> (Marshall, 1920, p. 225)

This section, which aims at using the theory of knowledge externalities as a departure point in order to introduce behaviours of open knowledge disclosure, should be concerned only by pure knowledge externalities. However, to avoid confusion between two really different phenomena we think it necessary to explain also what pecuniary knowledge externalities are.

I.1.2.1. Pecuniary knowledge externalities

Following the definition given by Scitovsky (1954), pecuniary knowledge externalities occur through market transactions. This definition may appear quite obscure, but it takes all its meaning when applied to knowledge. For instance, let us consider a firm who makes an innovation that enables her to improve tremendously the products she is selling on the market. Consider that this firm cannot appropriate the entire surplus generated by this innovation due, for instance, to her inability to price discriminate, to the existence of substitute goods or to the potential entry of competitors. In this case, the innovation benefits not only the firm but also her customers, to whom a fraction of the surplus generated by the innovation is transmitted under a pecuniary form. Purchasers can obtain a better quality input for less than their reservation price.

It follows that pecuniary knowledge externalities always flow from upstream to downstream sectors. Since these externalities are embodied in goods that are exchanged on the market, one can expect them to be strictly correlated with the intensity of the exchanges. The more a firm buys from an innovative supplier, the more this firm should benefit from pecuniary spillovers. This point is illustrated in a paper of Coe and Helpman (1995), for instance, who tried to assess the intensity of knowledge externalities between countries by using data on 21 OECD countries. To measure this intensity, they weight the external stock of knowledge that can be absorbed by each country by a measure of the intensity of the commercial relations that this country has with all the other countries. By doing so, they take into account the fact that more open countries are more likely to benefit from knowledge externalities. The idea here is clearly that knowledge externalities are functions of commercial relations between countries.

Conversely, as it will be shown below, pure knowledge externalities have no reasons to be conveyed exclusively through commercial transactions. It is even likely that firms who benefit most from pure knowledge spillovers are firms who do not have commercial relationships but who work on similar technological programs (although commercial transactions may also be a way to convey knowledge since agents may learn from the products they are buying). To quote the example given by Griliches (1992, p. 36), the photographic equipments industry and the scientific instruments industry may not buy much from each other but may be, in a sense, working on similar things and hence benefiting much from each other's research.

I.1.2.2. Pure knowledge externalities

In order to introduce pure knowledge externalities and to help distinguish them from pecuniary knowledge spillovers, let us start by a simple example drawn from Branstetter (1998): The emergence of new technologies that improve the performances of the oil industry may first involve a sharp decrease in oil prices, which means that every economic sector benefits from these new technologies through pecuniary forms. But firms in other sectors may also use these new technologies in order to improve their own technologies. This second effect is what we mean by pure knowledge externalities: Ideas that flow from firms to other firms, who in turn use these ideas to generate further ideas, that flow to other firms, etc.

Traditionally, economists consider knowledge circulation through the lenses of the traditional theory of externalities, which is presented in the previous section. Thomas Jefferson, the third President of the United States, illustrates this statement perfectly. He explained that:

> "If nature has made any one thing less susceptible than all others of exclusive property, it is the action of the thinking power called an idea […] he who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper at mine, receives light without darkening me".
>
> (Jefferson, 1813, p. 333)

Clearly, following Jefferson knowledge has the two properties that characterize a public good: Non-rivalry and non-appropriability. Non-rivalry means that any additional individual enjoying the benefits of the knowledge can do it at a zero marginal cost. It follows that even if one could exclude someone from enjoying the benefits of knowledge, it would be socially undesirable to do so because there is no marginal cost to sharing these benefits. Further, while knowledge non-rivalry property states that no one should be excluded from the enjoyment of this knowledge, its non-excludability property implies that no one can be excluded.

Actually, some forms of knowledge can, to some extent, be appropriated and therefore knowledge is often considered as an impure public good (Callon, 1993). Furthermore, it is still unclear among scholars whether knowledge should be considered as a local or as a global public good. In the former case only neighbours in the geographic space profit from the knowledge while in the latter case every single agent in the economy benefits from this knowledge. Empirical studies tend to confirm the assumption that knowledge is a local public good (Jaffe, Trajtenberg and Henderson, 1993; Audretsch and Feldman, 1996) but the concept of knowledge as a global public good has not been given up yet (Stiglitz, 1999a and 1999b[5]). However, either pure or impure, knowledge is still perceived by economists of innovation as a public good and as such it is supposed to be a source of externalities.

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[5] Stiglitz in his famous 1999 paper "Knowledge as a global public good" claims that knowledge must be thought of as a global public good because a mathematical theorem is as true in Russia as it is in the United States, in Africa as it is in Australia and because scientific truths are universal by nature.

Let us consider, for instance, the knowledge about the properties of a raw material that is embodied within a marketable good. This knowledge is non-appropriable since, once the good is sold on a market, the innovator cannot prevent other agents from learning these new properties. Moreover, it is clearly non-rival because the fact that others also know these properties does not decrease the knowledge of the innovator. This knowledge can be shared by many people without decreasing its value.

Therefore, once produced, new knowledge is thought as being impossible to appropriate fully by its inventor. Knowledge flows to others through reverse engineering, scientists' mobility, informal exchanges between scientists, etc. This means that new knowledge benefits people who, although they did not share the cost of production of this new knowledge, share a part of its benefits without having to pay for this. Since there is no market to regulate these knowledge flows[6], one can indeed refer to them as pure knowledge externalities.

Moreover these knowledge spillovers are positive in the sense that they benefit other firms. Indeed, it is widely acknowledged nowadays that knowledge is an input in the production function of firms. All other things being held equal, the more a firm holds some knowledge, the higher her profit. Furthermore, knowledge is considered as a cumulative good. The more an agent holds some knowledge the higher his probability to generate further knowledge. This cumulative property is brightly illustrated by a famous quotation of lord Isaac Newton, who answered modestly a question about how he managed to discover so many central things in the following manner: "If I have seen so far it was because I was standing on the shoulder of giants" (Scotchmer, 1991, p. 29). The giants being metaphorically all the researchers before him. Therefore, knowledge spillovers, by increasing the understanding of other agents, increase their probability to generate further knowledge. It means that

[6] Arrow (1962) explains why it would be hard to implement a market to trade information. He points out that if the seller does not disclose the information then no buyer will ever want to buy it since they do not know the value of it. But once it is disclosed then the buyer has acquired it at no cost. A famous illustration of this problem is given by Tirole (2003, p. 23) who tells us the story of Robert Kearns, the inventor of the windshield wiper. Having no possibilities to commercialise alone his invention Robert Kearns proposed a collaboration to Ford, to which he disclosed the idea and some of the technical aspects. Ford refused the collaboration and some time later introduced on the market a similar product with only slight technological differences.

the existence of technological spillovers profits other agents through two channels: Higher knowledge, i.e. higher current profit, and higher probability to innovate, which means higher future profits.

At this stage, before mentioning the consequences that knowledge externalities may have on society, we wish to raise an important issue: To what extent do knowledge spillovers really matter in practice? Have such unintended flows of knowledge already been observed and measured empirically? Without entering into too many details, it must be known that a tremendous number of econometric studies were devoted to this problem and if conclusions are not always convergent, the general impression remains unambiguous (Jaffe, 1986; Cincera, 1997; Branstetter, 1998). As summarized by Griliches (1992, p. 29): “Taken individually, many of the studies are flawed and subject to a variety of reservations, but the overall impression remains that R&D spillovers are both prevalent and important”. It is therefore necessary first to assess the consequences that knowledge spillovers may have on the economy and second, to implement policies to solve the possible problems that may arise.

I.1.2.3. Consequences of the existence of knowledge externalities

Under very specific conditions, market mechanisms optimally allocate the resources of an economy. In a perfectly competitive economy the first welfare theorem teaches us that market forces always lead to a social optimum. But this conclusion holds only in a perfect environment with, among others, no external effects, no uncertainty and no increasing returns. Unfortunately, the knowledge production process is confronted with these three problems.

Consequences of knowledge externalities on the level of investments in knowledge production are relatively straightforward according to the traditional approach of externalities. Two different situations must be considered but both of them lead to a similar conclusion: Knowledge spillovers imply that market forces lead the economy to a level of investments in knowledge production lower than the level necessary to reach a social optimum. Firms do not invest enough in knowledge production from a social point of view.

To illustrate this point, let us assume an economy with two competing firms *A* and *B*. If there are technological spillovers, a fraction of the R&D investments of firm *A* benefits instantly firm *B*. This, in turn, decreases firm *A*'s own profit through a rivalry effect and therefore it decreases her incentives to invest in R&D. To put it plainly, within a competitive environment, new knowledge profits competitors, which affects the inventor negatively due to the effect of competition. It follows that knowledge spillovers have a disincentive effect on R&D investments and this leads to under investments in knowledge production as compared with the optimal level for society.

This disincentive effect of knowledge externalities on R&D investments is well known in economic theory but what is less known is that even without assuming that the two firms compete together, knowledge spillovers still lead to under investments in knowledge production as compared with what is required to reach a social optimum. Indeed, even if there is no disincentive effect, firms, in computing their optimal level of knowledge production, do not take into account the positive effect of their R&D on other firms' profits, since this effect is not remunerated. But this positive effect enters into the computation to determine social optima. Hence, knowledge spillovers lead to a divergence between the social and the private returns of R&D, implying that R&D investments are more important at the social optimum than at the private equilibrium.

Furthermore, the under investment in knowledge production is not solely due to the presence of spillovers. The knowledge production process involves three of the most currently mentioned causes to explain market failure: A strong uncertainty, increasing returns of scale and externalities. For instance, the strong uncertainty inherent to the knowledge production process was emphasised by Schumpeter (1942, p. 127) who compared the forecasting of R&D outcomes to the exercise of: "shooting at a target that is not only indistinct but moving (and moving jerkily at that)". And, economic theory has extensively stressed how uncertainty may affect the level of production of a good negatively.

To summarize, due among others to the presence of knowledge spillovers the market does not lead to an optimal level of knowledge production as compared with an ideal. This conclusion calls for the implementation of non-market mechanisms in order to increase firms' incentives to invest in knowledge production.

However, the case is more complex than this simple problem of restoring incentives to invest in R&D. The innovation process is confronted not only to a problem regarding the production of knowledge but also to a problem regarding the distribution of the produced knowledge. On the one hand the lack of appropriation of knowledge leads to under optimal knowledge production levels, as it was explained above, but, on the other hand, if it was possible to dismiss spillovers by allowing inventors to appropriate their new knowledge perfectly the situation might not be improved from a social point of view because the distribution of knowledge among individuals would not be optimal. Indeed, knowledge is not only a non-appropriable good, it is also a non-rival and a cumulative good. And these properties of non-rivalry and cumulativeness are hardly compatible with the property of appropriation.

First, non-rivalry means that any additional individual enjoying the benefits of the knowledge can do it at a zero marginal cost, meaning that in a perfectly competitive economy the optimal price of any given piece of knowledge must be zero. Everybody must be allowed to access knowledge for free, which is of course not compatible with the property of appropriability that gives market power to owners and hence that leads to prices higher than zero.

Second, the fact that knowledge is a cumulative good implies that knowledge is not only an input to produce a marketable good, it is also an input to produce further knowledge (Scotchmer, 1991). Hence, the more an agent holds knowledge, the higher his probability to invent and to generate further knowledge. The corollary of this observation is that a society must allow a wide distribution of knowledge among its members in order to be innovative, which again is hardly compatible with appropriability.

There is an obvious opposition between the two views presented here, between the optimal distribution of knowledge within an economy and the optimal level of incentives to produce this knowledge. This opposition was first explained in details by Arrow (1962):

> “To sum up, we expect a free enterprise economy to under invest in invention and research (as compared with an ideal) because it is risky, because the product can be appropriated only to a limited

> extent and because of increasing returns in use […] Further, to the extent that a firm succeeds in engrossing the economic value of its inventive activity, there will be an under utilization of that information as compared with an ideal allocation."

Arrow (1962, p. 619)

In other words, without externalities (if knowledge is appropriable) incentives to produce new knowledge are strong but this knowledge is not well distributed among agents. On the other hand, when spillovers are strong (under a regime of weak appropriability) agents have few incentives to invest in knowledge production.

This dilemma between the optimal level of knowledge production and distribution leads to the conclusion that the true problem is not so much the presence of knowledge externalities as the lack of incentives to invest in knowledge production. For instance, Spence (1984) shows that the system performs better with than without externalities with the incentives appropriately restored. Non-market mechanisms must therefore be implemented not only to increase incentives to invest in knowledge production but also to ensure a wide diffusion of the produced knowledge. Knowledge distribution must be a central concern of innovation policies, since it is at least as important for social welfare as providing incentives to invest in knowledge production.

I.1.2.4. Policy devices to internalise knowledge externalities

The above conclusion calls for the implementation of non-market mechanisms in order to restore a social optimum or at least to close the gap between it and the market equilibrium as much as possible. Here, we want to insist once again on the fact (which is too often forgotten by policy makers) that non-market mechanisms must be targeted not only to increase incentives to produce knowledge but also to preserve knowledge spillovers and to increase the distribution of the new knowledge among the economy. Public policies to internalise knowledge spillovers can be gathered into three different classes that David (1993) names the three P's : "public Patronage (prizes, research grants, subsidies…), state Procurement (or Production) and the legal exclusive ownership of intellectual

Property". Moreover, the promotion of R&D cooperation and of research joint ventures deserves to be added to these three policy devices since, as it was shown by D'Aspremont and Jacquemin (1988), R&D cooperation can solve, under specific conditions, the problem of knowledge spillovers.

It is also important to mention here the solution suggested by Coase, who argues that in some cases, for which transaction costs are not too high, agents may solve the problems of external effects by themselves, through direct bilateral negotiations. This mechanism of auto-endogenisation of spillovers relies on the fact that agents are induced to negotiate, to trade information, to form research joint ventures, etc. However, due for instance to the difficulty to localise the agents affected by the externalities or to set up agreements during negotiations, the solution proposed by Coase, although elegant, is likely to work imperfectly, implying that there is a need to implement non-market interventions.

(i) Public production of knowledge. A first possibility is to substitute a centralized solution to the market solution. The government may, for instance, directly manage knowledge production and distribution. By doing so, the regulator, who of course is omniscient, would be able to include all the knowledge externalities into his computation. Hence, the level of knowledge production decided by this central regulator would be equal to what is socially optimal. Public universities and public laboratories are examples of such a public production of knowledge.

The efficiency of this solution is of course dependant on the fact that the government is really interested in reaching a social optimum and has the ability and the needed information in order to reach this purpose. This strong assumption regarding the distribution of information implies that, nowadays, the market, since it is a decentralized solution, is more and more perceived as preferable to centralized solutions. Without denying this point, it seems to us that universities are in many cases not substitutable but complementary to other policy devices. According to the traditional approach that goes back to Nelson (1959) and Arrow (1962), the innovation process is linear and can be divided into two main steps: Basic research, which aims at producing fundamental knowledge, and applied research, which uses basic research in order to produce innovations that can be patented. Following this view, the patent system aims at increasing the production and diffusion of applied knowledge whereas universities are devoted to the production and diffusion of basic research, which cannot quickly result in a patent. This view, which assumes an efficient division of labour in the innovation process, may have evolved slightly but it is still believed to be valid in most cases (Nelson, 1992; Rosenberg and Nelson, 1994). Policy makers should therefore be very cautious before condemning university research and substituting it by private research driven by a patent system[7].

(ii) Public patronage. Instead of implementing a centralized solution to produce and distribute knowledge, it is possible to assist the market by a system of R&D subsidies, R&D credit taxes, *ex post* rewards, patent buyouts, loans with low interest rates, etc. There is a wide range of policy devices that can help, at least in theory, to orient the market toward a social optimum.

For instance, it is possible to grant subsidies to firms who invest in R&D in order to increase their incentives to produce knowledge. Theoretically, when the amount of the subsidies for a given amount of R&D investments is fixed so that it equals the benefits of this R&D for society as a whole, then the private and public goals are perfectly balanced and the outcome of the market mechanisms assisted by such a system of subsidies are socially optimal.

However, it immediately comes out that such a system of *ex ante* subsidies is subject to moral hazard problems since firms, once they are granted a subsidy, have fewer incentives to succeed in their research. R&D *ex ante* subsidies would therefore have the same effect on knowledge producers as insurances have on their contractors. They decrease the incentives to do well since, in case of failure, the profits are nevertheless increased by the subsidy. Another problem stemming from the fact that the firm is helped before she innovates is that there is a risk that subsidized firms take the grant but do not do research. In order to overcome this risk, policy makers can be tempted to target as much as possible the firms to help (i.e. to adopt a policy of "picking winners"), for instance by establishing a list of requirements that innovators must meet in order to be helped or by helping only firms who have already projects well-advanced, in order to be absolutely certain that innovators will successfully use public money. But we see here that another problem may arise: The more targeted the help, the more

[7] This complementary role of patents and universities was analysed in more depth in an other paper (Pénin, 2003d).

likely the innovator will use the money for R&D purpose but also the less he may have needed this help in order to innovate, implying that the help did not trigger any further research.

A solution to these problems may be to reward innovators not before they innovate but after, with a system of patent buyout for instance. Under such a system of patent buyout governments would buy patents to their owners in order to put them into the public domain and hence, to make them accessible freely by all without having to pay an exploitation license (Polanyi, 1944; Wright, 1983; Taylor, 1995; Kremer, 1998; Llobet, Hopenhayn and Mitchell 2001; Shavell and Ypersele, 2001; Pénin, 2003c). An equivalent system is to grant *ex post* rewards to innovators. Such a system of *ex post* recompenses would solve, at least in part, the problems of moral hazard mentioned above. Another very important advantage of this system of patent buyout as compared with R&D subsidies or credit taxes is that the produced knowledge is automatically disclosed (since it is patented). Whereas in the case of subsidies, firms usually do not have to disclose their innovation. They can keep it secret.

However, a major drawback of all these centralised solutions is that they can work only provided that the central planner (the policy maker) has access to almost perfect information. Indeed, in order to implement such systems, the central planner must be able to compute the optimal (from a societal point of view) amount of the subsidy, price of the patent buyout or amount of the reward, which will be most of the time impossible.

For instance, in the case of *ex post* rewards the ideal amount of the reward (from a social point of view) must encompass all the benefits the innovation generates for society, including all the spillovers either positive or negative. In other words, without taking any equity concept into account, the ideal reward is equal to the social value of the innovation. Only then can policy makers be sure that all the profitable innovations, from a social point of view, and only those innovations, are implemented. Indeed, when the remuneration is more than the social surplus, there is a risk that some innovations with a social cost higher than the benefit they generate for society are implemented. Conversely, when the reward is less than the social surplus, some innovations profitable for society (with a social cost lower than the social benefit) may not be implemented. Thus it is only when the reward for an innovation equals the social surplus of this innovation that the social and private goals are perfectly balanced[8].

We see therefore that policy makers will be, in most cases, unable to gather all the information that would enable them to compute the optimal reward or subsidy. These informational problems that are encountered by all the centralized solutions provide patents with a fundamental advantage over the other *P*s of David. Indeed, following the economic studies that have documented the topic, information and its distribution are major elements in the rationale for the patent instrument. The patent system is decentralized and as such: "Patent leaves nothing to anyone discretion; because the reward conferred by it depends upon the invention's being found useful and the greater the usefulness, the greater the reward" (J.S Mill, 1872, cited in Shavell and Ypersele, 2001, p. 527). The special advantage of patents arises from the Hayekian argument that private researchers have far more information concerning their own inventions than any central authority and the patent system exploits this private information by letting the market determine the value of an innovation. It follows that when information is complete it may be advisable to implement a centralized solution, such as R&D subsidies or *ex post* rewards, but when information is incomplete the patent system, being decentralized, appears to perform better[9].

(iii) The patent system. Now that we have explained what the fundamental advantage of patents over other policy devices is (following a traditional approach), let us say a word on the patent system itself, which is the third *P* mentioned by David (see also chapter V). Schumpeter (1942, p. 88) used to introduce the patent system by arguing that: "Motorcars are travelling faster than they otherwise would because they are provided with brakes". Patents are supposed to have the same

[8] It can be argued that policy makers are not obliged to give the entire social surplus generated by an innovation to the innovator. They could, for instance, give him only an amount equal to the cost of his innovation plus a bonus. However, in such a case, our argument still holds since policy makers must know the social value of the innovation in order not to give more than this value to innovators, which would induce the production of socially undesirable innovations.

[9] In another paper we have developed an alternative view of the debate between patents and more centralized innovation policy devices. We proposes that the fundamental advantage of patents may not arise from informational concerns but rather from the fact that patents are central devices in order to reduce the coordination failure that impedes the innovation process by signalling knowledge and by facilitating R&D cooperation (Pénin, 2003c).

impact on the innovation process that brakes have on car speed. They provide incentives to invest more in R&D as brakes provide incentives to drive faster. Indeed, a patent gives its holder an exclusive exploitation right over the patented innovation on a given territory and for a limited time (20 years from the filing since the Trips agreements[10]) (Deffains, 1997). This exclusive right is expected to increase innovators' profits and therefore to increase firms' incentives to invest in knowledge production.

At the same time, patents are also supposed to increase the circulation of knowledge, which is one of the most important and controversial points regarding patents. Theoretically, a patent does not directly provide a property right on a new piece of knowledge itself, but only on the marketable artefacts that are issued from this new piece of knowledge. Indeed, when applying for a patent an innovator must define a set of claims about the different applications of his idea. If the patent is granted, it protects the claims made by the innovator and not the idea itself. For instance, if someone discovers a new medicine, this inventor may be granted a patent on this medicine and benefits from a monopoly position for the sale of this medicine in every country where the patent holds. But this inventor cannot be granted a property right on the knowledge underlying this new medicine (why it works, etc.). Therefore, everybody is allowed, and even encouraged, to use this knowledge in order to produce further medicines or other products. With the aim to encourage the cumulative process of knowledge production, the patent system even tries to ensure a wide diffusion of the knowledge (codified) underlying the patented innovation. Indeed, when an inventor applies for a patent he must give a description of his invention that allows a person knowing the state-of-the-art to reproduce it. Once the patent is granted, or in some countries even if the patent is not granted, this description is published and everybody has free access to it. This led Mazzoleni and Nelson (1998, p. 278) to

[10] Trips = Trade-Related aspects of Intellectual Property rights (Adpic in French = 'Aspects des Droits de Propriété Intellectuelle qui touchent au Commerce'). The World Trade Organisation's agreement on Trips, negotiated in the 1986-94 Uruguay Round, came into force on January 1st, 1995, and must be respected by all the WTO members, who have until 2005 to make it comply with the law (see Mfuka, 2002, for more in depth details). Trips agreements introduced intellectual property rules into the multilateral trading system for the first time. They establish minimum levels of protection that each government has to give to the intellectual property of fellow WTO members (the minimum rights that a patent owner must enjoy). Among these minimum rights is the obligation to provide a 20-year patent protection.

conclude: "patents encourage and provide a vehicle for disclosure and, more generally, generate quick and wide diffusion of the technical information underlying new inventions".

Hence, we see that in theory the patent system manages both to restore incentives to invest in knowledge production and to ensure the necessary distribution of the research results. This performance explains why patents are often considered as an ideal system and why this system is widely used all around the world. However, the patent system, by granting innovators a monopoly position limited in time, also triggers a static monopoly dead-weight loss as compared with a situation of perfect competition. During the time the patent holds, social welfare is not maximized because the monopoly pricing penalizes consumers more than it favours producers. A monopoly situation penalizes consumers because some of them, who value the good above its marginal cost (and hence who could afford to buy it in a situation of perfect competition), do not consume it at the monopoly price. For this reason it is often argued that the patent system leads to sacrificing the static efficiency of the economy in order to ensure the dynamic efficiency. Today's welfare diminution, due to the monopoly price distortion created by patents, leads to an increase of tomorrow's welfare, because higher incentives to invent mean further innovation in the future[11].

I.1.2.5. The hypotheses underlying the traditional approach to knowledge externalities

Following the traditional approach, when a firm invests in knowledge production, a part of the investments spills over and benefits instantly other agents. These spillovers generate market

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[11] It is worth mentioning quickly the other "embarrassment of an exclusive patent" (Jefferson, 1813, p. 335) (See also Andersen, 2003):

- Patents do not align private and social goals perfectly. They increase the incentives as compared with perfect competition but they still do not provide enough incentives to reach a social optimum since they do not offer the entire social surplus to innovators.
- Patents do not take into account the collective and cumulative nature of the innovation process.
- Patents are hardly available to small firms (see chapter V).
- *Ex ante*, patents generate a duplication of the resources dedicated to invention, due to patent races. Plant (1934) wondered, for instance, whether patents would not encourage too many innovations of the "wrong kind".
- Patents do not allow the diffusion of all types of knowledge (see chapter V).

inefficiencies and call for non-market interventions in order to assist market mechanisms. However, this traditional vision of knowledge spillovers rests on strong hypotheses about the properties of knowledge and the way in which agents interact. It is possible to detail these hypotheses in seven points (Cohendet and Meyer-Krahmer, 2001, p. 59-61):

(1) Knowledge is treated as pure information (Cohendet and Llerena, 1999);

(2) The only incentive that matters for the producer of knowledge is to experience the full ownership over the new piece of knowledge;

(3) The producer of knowledge is a solitary one;

(4) The producer of knowledge is facing the 'market';

(5) The producer of knowledge is not supposed to have knowledge disclosing capabilities;

(6) All the agents have a full absorptive capacity[12];

(7) The epistemic content of knowledge does not matter.

These seven assumptions can also be reduced in two main points (Cohendet, Foray, Guellec and Mairesse, 1999):

(H1) Knowledge is viewed as pure information, meaning that it is assumed to be perfectly codified and disclosed, such as patents and publications in scientific newspapers. Thus, knowledge cannot be kept secret for long and other firms who have not invested in its production can use it without any limitation.

(H2) No explicit non-market interactions are considered. Interactions between agents occur either through competitive markets or are reduced to spillovers. There is no other interaction, such as neighbourhood relationships or informal discussions between employees. The knowledge producer is solitary and faces the market represented by an infinite number of anonymous agents, meaning that agents do not know each other. Therefore, there cannot be any direct bilateral negotiations between them in order to reduce the problem of spillovers. If knowledge producers were not supposed to face

[12] Which is in some sense equivalent to assume that the revealed knowledge is completely generic and that firms do not have to engage costs in order to adapt external knowledge to their specific environment. Hirshleifer (1971) gave a pioneer critic of this hypothesis and as such was one of the first to question the value of information for society.

an infinite number of anonymous agents then there would be room for bilateral negotiations in order to solve the problem of externalities, as suggested by Coase (1960).

These assumptions lead the traditional theory to assume that knowledge is a public good, that it flows 'in the air'[13]. Like military dissuasion provided by the possession of nuclear weapons or security granted by the police, knowledge, once produced, is supposed to benefit other agents in the economy instantly. Once a firm invests in knowledge production, a part of the new knowledge automatically and instantly spills over and feeds a common stock of knowledge or even, if knowledge is a global public good, a "world stock of knowledge" (Cowan, David et Foray, 2000, p. 226), which is composed of spillovers emitted by all the firms in the economy. In return, this stock of knowledge affects positively these firms, who can draw from it and hence who can increase their own stock of knowledge.

This theoretical approach of knowledge in terms of public good can be found, for instance, in many endogenous growth models, in which a global stock of knowledge is included into the production function of firms. For instance, in its 1986 seminal paper, Romer assumes that the production function of each firm has the following form: $Y_i = f_i\left(L_i, C_i, K_i, \sum_{j \neq i} K_j\right)$, in which Y stands for firms' production, L for the quantity of labour they use, C for the capital and K for the knowledge. It is explicit here that firms' investments in knowledge are supposed to feed a world stock of knowledge which, in return, has a positive effect on the production of all the firms.

This vision of knowledge in terms of public good and of the innovation process as an individual process involving isolated agents connected only through market interactions calls for one important remark: In line with the traditional economic theory of externalities, knowledge transfers between firms are seen as completely exogenous. Firms are considered as passive in front of knowledge spillovers, which occur such as a *deus ex machina*, meaning that they appear to fall from the sky. The sender cannot try to limit his knowledge leakage and the recipients do not have to do

[13] Alfred Marshall in the eighth edition of his *Principles of Economics* (1920) describes the mechanisms of knowledge spillovers by arguing that: "The mysteries of the trade become no mysteries; but are as it were *in the air*, and children learn many of them unconsciously" (p. 225, *it.* are mine).

anything, do not have to feed an absorption capacity for instance, in order to absorb this external knowledge. Furthermore, this view of knowledge leads to considering the transfer of knowledge between agents as undesired and often as harmful for firms who initially held the knowledge.

This traditional vision of knowledge was finally perceived as hiding "a naïve portrait of the channels along which knowledge flow" (Breschi and Lissoni, 2003, p. 6) and gave place recently to a more competence based approach, which puts more weight on learning, competencies and on the structure of interactions between the agents (Le Bas, 1999). Indeed, to assume that knowledge flows 'in the air' is equivalent to neglecting largely the channels through which knowledge is conveyed. Innovation cannot be correctly apprehended by the traditional approach in terms of public good, market and spillovers, first because knowledge is something far more complex than simple information and second because non-market interactions among firms cannot be neglected or reduced merely to exogenous spillovers. The changes brought by this new vision, which was initiated in the 1980s, are presented in the next section.

I.2. Toward the endogenisation of knowledge externalities

The circulation of knowledge is not an exogenous process in which agents are passive, as argued by the traditional approach of knowledge spillovers. Mechanisms that depend, among others, on the property of knowledge and on the structures of interactions of agents, allow the control of the circulation of knowledge. Basically, the rethinking of the traditional vision of knowledge spillovers rests on three main points: The introduction of a knowledge emission capacity, the introduction of a knowledge absorption capacity and the consideration of knowledge as a collective good and of the innovation process as a collective process involving non market interactions and collaborations.

I.2.1. Firms' knowledge emission capacity

First of all, and this point will be extensively developed in the next chapters, firms have an emission capacity of knowledge. Of course, due to reverse engineering or to the mobility of researchers a fraction of the knowledge held by firms always leaks to other firms. But, for many reasons, firms can most of the time control their own knowledge, meaning that they can often keep it secret over very long spells of time.

This being first because the outcome of research activities is something far more complex than pure information. It takes various forms such as human capital, organisational rules, databases, drawings and models, etc. It cannot be reduced to a single output perfectly codified and disclosed (publication and/or patent). Knowledge is the result of cognitive, learning processes and very often it takes a tacit, not easily transferable form.

Tacit knowledge concerns all the knowledge embodied into a human support, as the know-how, the know-who, the beliefs and the mastering of a language. For instance, Polanyi (1958, p. 195) noticed that in each human being: “there is present a personal component, inarticulate and passionate, which declares our standards of values, drives us to fulfil them and judges our performance by these self set of standards”. In 1966 Polanyi also referred to the existence of tacit knowledge by noting that we all know more than we can write. Similarly, Arrow (1994, p. 16) noticed that: “we can know how to do things, without necessarily being able to describe how to do it". Often, the holder of tacit knowledge is not even fully aware of the existence of this knowledge. As Polanyi explains: "The aim of a skilful performance is achieved by the observance of a set of rules which are not known as such to the person following them" (1958, p. 49). It can even be argued that this knowledge is valuable because it remains unconscious[14].

A direct consequence of the existence of tacit knowledge is that knowledge does not spill over as easily as it was assumed by the traditional view. Tacit knowledge is sticky. Even if its owner wants to disclose it, it can do it only after a long and often costly effort of codification. So in cases in which the owner does not want his knowledge to be disclosed it is easy to imagine how hard it is for other firms to access this knowledge.

Moreover, even under a codified form, knowledge does not automatically generate spillovers. Codified knowledge is knowledge systematic enough to be explained in a language, written down and stored on an artificial support, independently of its human support. To codify knowledge means to extract it from the human support in which it was embodied and to store it on another support, a book or a floppy disk for instance. It is thus easy to understand that one of the main benefits of codification is to facilitate the circulation of the knowledge, since under a codified form knowledge can be transferred through the Internet, for instance, or by mail[15].

Therefore, according to innovators' purpose, codified knowledge can be disclosed or kept secret. If by definition tacit knowledge is sticky, it is not because knowledge is codified that it becomes leaky and that it escapes from its holder more easily. For instance, whether it is strictly codified or tacit, the organization of a laboratory, its way to solve specific problems, does not easily

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[14] Polanyi (1958, p. 56) gives the following example: "If a pianist shifts his attention from the piece he is playing to the observation of what he is doing with his fingers while playing it, he gets confused and may have to stop. This happens generally if we switch our focal attention to particulars of which we had previously been aware only in their subsidiary role […] The particulars of a skill appear to be unspecifiable in the fact that the performance is paralysed if we focus our attention on these details […] We may describe such a performance as logically unspecifiable, for we can show that in a sense the specification of the particulars would logically contradict what is implied in the performance or context in question".

[15] We do not enter into the details of the discussion around codification and tacitness because the purpose of this work is not to give an exhaustive presentation of this very rich literature (the reader interested in such a discussion may rather consult the following papers on which we built our understanding of this issue: Cowan and Foray, 1997; Mangolte, 1997; Cowan *et al.*, 2000; Cohendet and Meyer-Krahmer, 2001; Johnson, Lorenz and Lundvall, 2002).

spill over if the members of the laboratory do not want it to spill over. Similarly, knowledge about new processes or new materials, which are not explicitly embodied in the artefact sold by the firm, are not subject to reverse engineering and thus can be kept secret during very long spells of time.

Furthermore, even when it is disclosed knowledge can sometimes still be considered as secret. Indeed, the process of diffusion involves the use of a language. When everybody can understand this language the secret is broken. But if the language is kept secret, the disclosure of knowledge can be a way to communicate this knowledge only to a given, well specified group of persons while the others, who do not know the language, cannot access this disclosed knowledge. The alchemists of the Middle Ages used to disclose their knowledge in this way, writing books in languages that were understandable only by a few initiates. Hence, their knowledge was free but protected because the language they used was secret. The same could be argued nowadays about economic science: The number of publications in this domain is booming, which should indicate that the public stock of economic knowledge is increasing, but the language in which it is disclosed (complex mathematics) prevents the knowledge from being understood by everybody.

Hence, organisations and individuals can often appropriate their knowledge during very long spells of time. But empirical studies also point out that many firms often decide to voluntarily disclose widely some of their most precious knowledge, making therefore this knowledge available to other firms, including to their competitors. The traditional approach, which assumes that knowledge circulation is exogenous and undesired by firms, gives therefore place to this new vision of knowledge flows in which firms may wish to disclose knowledge. De Fraja (1993) resumed this point clearly:

> "The novelty of the present approach is to be found in the fact that the rate of spillovers is a strategic variable, endogenously determined by the optimising behaviours of the players rather than being imposed exogenously as in the rest of the literature […] This change leads to ask "Would a firm want to reveal part of what it discovers?" rather than "How does a firm behave, given that part of what it discovers will be revealed?" ".

(De Fraja, 1993, p. 139-140)

Knowledge does not always leak automatically and instantly from its creative source but is often voluntarily disclosed. Firms have an emission capacity in the sense that they are not forced to let their knowledge spills over but they can choose whether or not to disclose it (the term emission capacity refers obviously to the work of Cohen and Levinthal on firms' absorption capacity). Following Cohendet and Meyer-Krahmer (2001, p. 60), we define firms' emission capacity as: "the ability to tune the disclosure-secrecy dimension". It must also be noticed that the existence of firms' knowledge emission capacity casts some doubts on the empirical studies that underline the existence and the scope of knowledge spillovers. What is measured by econometric studies may not be the intensity of an externality coming from unintended spillover flows, but rather the impact of knowledge that has been voluntarily revealed.

The study of knowledge disclosure behaviours is the main purpose of this work, which means that we will come back to this point in the next chapters. Before, we would like to say a word about the two other points on which the traditional approach of knowledge spillovers has evolved: The introduction of an absorption capacity and the fact that the innovation process is a collective process and that knowledge is a collective good.

I.2.2. The need to build an absorption capacity to use external knowledge

> "The firm cannot passively assimilate externally available knowledge […] a firm's assimilation of outside knowledge is constrained by its absorptive capacity"
>
> (Cohen and Levinthal, 1989, p. 572-573)

An important drawback of the classical vision of knowledge externalities is that firms cannot absorb external knowledge automatically, without doing anything and without costs. To say that a given piece of knowledge is available, meaning that the owner cannot or did not want to keep it secret, does not mean that other firms directly absorb it. It only means that it is susceptible of being absorbed, providing that other firms have the competences to do so. Indeed, to internalise external knowledge involves important monetary and organisational investments. A firm who wants to use external knowledge must first build what Cohen and Levinthal (1989; 1990) call an absorption capacity. Hence, we see that recipient firms play clearly an active role in the process of knowledge transfer, which cannot be assumed to be exogenous. When a piece of knowledge is disclosed, its effect on other firms depends on these firms' ability to detect, understand and then use this knowledge.

The economic theory attributes the fatherhood of this concept of absorption capacity (or at least of the formalisation of this concept) to Cohen and Levinthal (1989). Indeed, these two authors underlined two functions for R&D investments, arguing that these investments serve not only to produce new knowledge but also to absorb more easily knowledge produced by other firms. Hence, Cohen and Levinthal introduced an absorption capacity by assuming that the extent to which a firm benefits of the R&D realised by other firms is an increasing function of this firm's own R&D investments.

The idea underlying the concept of absorption capacity is very simple: It is assumed that in order to assimilate a given piece of knowledge one needs to already possess some fundamental knowledge. The more one already knows, the easier it is to learn more. For instance, a biotechnology firm can hardly learn anything from a semiconductor firm if she does not already hold competences related to the electronic field. In order to learn knowledge from the electronic field, the biotechnology firm will have to develop some basic electronic competences. At the very least she must learn the language specific to electronics.

Cohen and Levinthal formalised this idea by assuming that, at each period, the increase of the knowledge held by a given firm *i* is a function of two things: The R&D investments realised by the firm herself and the external knowledge that the firm is able to absorb. Let z_i be the augmentation of firm *i*'s knowledge at a given period. It follows that:

$$z_i = RD_i + \gamma_i \left(\theta \sum_{j \neq i} RD_j + T \right)$$

in which RD_i reflects the R&D investments realised by firm *i*, *T* the extra industry stock of knowledge, θ $(0 \leq \theta \leq 1)$ the degree of knowledge spillovers emitted by firms located in firm *i*'s industry and γ_i firm *i*'s absorption capacity. $\theta \sum_{j \neq i} RD_j + T$ represents the external knowledge that can be absorbed by firm *i* if only she has the absorption capacity to do so.

θ, the spillover coefficient, is assumed to depend only on exogenous factors, i.e. firms are not supposed to have emitting capacities, they do not control their spillover parameters. Moreover, Cohen and Levinthal do not consider that all the knowledge held by a given firm automatically spills over. Only a fraction θ of this knowledge does. And other firms can only absorb this fraction, since firms cannot assimilate what is not spilled out.

Once knowledge has spilled out, it becomes instantly available to other firms who can absorb it depending on their absorption capacity. Cohen and Levinthal assume that the absorption of external knowledge is constrained by γ_i, the firm's absorption capacity, which depends positively on firm's own R&D investments. It is indeed assumed that: $\gamma_i = \gamma(RD_i, \beta)$, in which β is the nature of the knowledge to be absorbed, such as:

$$\frac{\partial \gamma(RD_i, \beta)}{\partial RD_i} > 0, \frac{\partial^2 \gamma(RD_i, \beta)}{\partial^2 RD_i} < 0, \frac{\partial \gamma(RD_i, \beta)}{\partial \beta} < 0, \frac{\partial^2 \gamma(RD_i, \beta)}{\partial RD_i \partial \beta} > 0$$

The authors consider two dimensions of knowledge: The degree of complexity and the degree of generality (it is assumed that β increases with knowledge complexity and generality). The more complex or general (in the sense of not targeted toward a precise application) the knowledge to be absorbed, the harder it is to absorb it, but the more important is the effect of the firm's own R&D on the absorptive capacity.

Within this framework, Cohen and Levinthal are able to compute the private level of R&D investments for a given level of θ (see chapter III). By doing so, they obtain conclusions quite different from the one predicted by the traditional theory of knowledge externalities. First, they observe that their model encompasses the traditional model with no absorption capacity, since when it is assumed that $\partial \gamma / \partial RD_i = 0$, we have the traditional spillover model, which predicts that knowledge spillovers have always a dissuasive effect on R&D investments. But when an endogenous absorptive capacity is considered, the model predicts that knowledge externalities may have a positive effect on the level of R&D investments.

Indeed, the effect of knowledge externalities on firms' profit is twofold: On the one hand, knowledge spillovers have a disincentive effect, since they mean that R&D investments increase competitors' stock of knowledge. But on the other hand, it is also assumed that R&D investments increase firms' own absorption capacity. And the stronger the spillovers, the more important the external stock of knowledge to be absorbed and therefore the stronger the incentives to increase R&D investments to benefit from this external knowledge.

Hence when the intensity of the spillovers increases it does not automatically imply a drop of R&D investments. The effect of the absorption capacity may dominate the leakage effect. Firms may be encouraged to increase their R&D investments in order to improve their absorption capacity and their ability to absorb external knowledge because, since appropriability is weaker, the stock of external knowledge may have increased tremendously. It is therefore possible to identify cases for which stronger spillovers lead to more investments in knowledge production. Furthermore, even in cases for which the disincentive effect dominates the positive effect stemming from the absorption capacity, the introduction of an absorption capacity always reduces the negative effect that spillovers may have on R&D investments. When an endogenous absorption capacity is considered, spillovers have a slighter negative effect on R&D investments than when the absorption capacity is considered as exogenous.

The work of Cohen and Levinthal, as it was briefly presented here, calls for four short remarks. First, the authors do not mention any relation between the degree of codification of the absorbed knowledge and the absorption capacity. This may be due to the fact that, at the time the article was written, the debate around codification and tacitness was not as developed as it is nowadays. However, it can be advanced without too many risks of distorting the thinking of the authors, that the degree of codification of the absorbed knowledge is likely to have a negative effect on β, meaning that the more codified the knowledge, the easier it is to absorb this knowledge.

Second, the activity of codification may also help to improve firms' own absorption capacity. Indeed, the act of codification of a piece of knowledge is a learning process. It involves the creation of a language and of a model in order to articulate the knowledge that the firm wants to codify. The codification process is therefore not only a process of conversion that consists in the transformation of tacit knowledge into codified knowledge. Agents may learn a lot from the activity of codification. For instance, a tennis player may improve his game tremendously by trying to articulate all the movements he is making when he plays. As such, the act of codification may increase firms' own competences[16].

Third, Cohen and Levinthal specify the absorption capacity as being a function only of the current R&D investments of the firm. This specification, as the authors themselves acknowledge, does not reflect the long run characteristics of the absorption capacity but was technically necessary in order to allow an analytic resolution of the model. However, the construction of an absorption capacity is a learning process and as such, time should play an important role in this process, i.e. the absorption capacity should rather be a function of weighted current and past R&D investments.

For instance, Llerena and Oltra (1999) used a dynamic specification, which is rendered possible by using simulation methods rather than analytical methods of resolution. By using computer algorithms rather than trying to compute equilibrium values (see chapter IV), simulations allow the characterisation of the evolution of a system over a very long horizon. Llerena and Oltra specify the following function for firms' absorption capacity: $\gamma_{it} = 1 - \frac{2\beta}{\sqrt{\overline{R}_{it}}}$ in which β reflects the nature of knowledge as in Cohen and Levinthal's model and $\overline{R}_{it}$ is a weighted sum of current (R_{it}) and past R&D investments such as $\overline{R}_{it} = \alpha_R \overline{R}_{it-1} + (1 - \alpha_R) R_{it}$. It is straightforward to observe that this function verifies all the hypotheses specified by Cohen and Levinthal and that it also reflects the long run dimension of the absorption capacity.

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16 This idea was taken up by Maret (2003), who used the degree of knowledge codification to endogenise both sides of the externalities. For the emission side, she assumes that firms can choose the amount of knowledge that spills over by controlling their activity of codification (she assumes that the more codified the knowledge, the more easily it spills over, which is a controversial point still vividly debated among scholars). For the absorption side, she assumes that firms can also improve their absorption of external knowledge through their activity of codification.

Our last remark deals with one important result that comes from the work of Cohen and Levinthal: The introduction of an absorption capacity may explain behaviours such as a high level of private R&D investments in situations of weak knowledge appropriability. Among other things, it may explain why firms carry out basic research whereas the marketable benefits of such research are often unpredictable and the appropriability is weak (Rosenberg, 1990). Basic research is at least necessary to build an absorptive capacity and to develop the ability to absorb external knowledge.

I.2.3. Collaborations vs. isolated agents, non-market interactions vs. market, collective good vs. public good

> "Reality is complex and most knowledge is neither completely public nor completely private. The knowledge base is fragmented and constituted by semi-public "pools" to which access is shared regionally, professionally and through networking".
>
> (Johnson and Lundvall, 2001, p. 12)

The third shortcoming of the traditional approach of knowledge externalities is that the innovation process cannot be correctly apprehended in terms of market, isolated agents and public goods. Innovation is not a linear and individual process and its outcome is not a pure public good. The move toward a vision that considers interactions in an explicit way leaves little room for market and externalities. Agents are not anonymous and they do not face the market. They live in a world of complex interactions, a world composed of many "small worlds" or networks. Hence, the conclusion we adopt here, which is in line with many recent studies, is that innovation must be thought of as a collective and networking process and knowledge must be thought of as a collective or club good. To reach this conclusion it is necessary to rethink the two main hypotheses *H1* and *H2* on which the traditional view of knowledge spillovers relies (see section I.1.2.5. above).

First, (H2) is questioned because innovation is a group of activities involving interaction and knowledge exchange between people and organizations. It is the result of interpersonal and inter organization interactions, which take place continuously and everywhere. Markets are far from being the only mechanism through which agents interact and develop links. Most of the time agents are not anonymous, they know each other, they exchange information, etc. Actors involved in this networking process are private firms (competitors, suppliers, customers), private go-between actors (such as venture capital firms, banks, consulting firms, etc.) and public institutions (such as university labs, institutions that aim to promote innovations, patent offices, etc).

One of the first authors that stressed this collective and complex (by opposition with the linear and individual view assumed by the traditional approach) aspect of knowledge production is Gibbons and his collaborators in their famous 1994 book. Gibbons explained that the vision economists have of the knowledge production process has switched from a “mode 1” to a “mode 2”. In mode 1, he says, knowledge production is the fact of isolated individuals, it is a linear process initiated in universities and developed in firms and it is bounded by disciplines. While in mode 2 knowledge production is a social and collective process (that involves many individuals and firms), it is non linear and not hierarchical (it involves constant interactions between the actors of this process and it is not always initiated in universities) and it is multi-disciplinary or even trans-disciplinary (it goes far beyond the frontier between scientific disciplines).

In other words, innovation is a collective process. In order to be innovative economic agents must cooperate, must set up formal research joint venture (RSV) or more informal innovation networks, in which they exchange some of their knowledge and share specific competences. Actors of the innovative process are far from being isolated individuals connected with other individuals only through market interactions. At the contrary, firms involved in the knowledge production process are members of innovation networks, in the sense that they develop a reasonably stable set of partners with whom they collaborate. Without such partnerships one can even argue that innovation could hardly occur[17].

Following Kogut (2000, p. 407): “A definition of an economic network is the pattern of relationships among firms and institutions. In this definition, an idealised market is a polar case of a

[17] This claim cannot be viewed as new or original. As emphasized by Breschi, Lissoni and Malerba (2003), to say that networks matter for innovative activities is nowadays almost to state the obvious.

network in which firms transact at spot prices and are fully connected in potential transactional relations but are disconnected through their absence of cooperative agreements. Few markets exist of this type. Rather most markets consist of sub-sets of firms and institutions that interact more intensely with each other on a long-term basis. These patterns of interactions encode the structural relationships that represent the network". Specifically, an innovation network can be defined as: "a set of reciprocal, reputational or customary trust and cooperation based linkages among actors that coalesces to enable its members to pursue common interests, in this case on respect of innovation" (Cooke, 2001, p. 953; see also Maskell and Lorenzen, 2003).

Hence, firms involved in innovative activities develop a set of links and connections with other firms and with public institutions and these links go most of the time beyond the anonymous and hostile market relationship (Guellec, 1999, p. 53). Among others, firms build relationships that resist through time. Bach and Lhuillery (1999, p. 350) illustrate the fact that agents develop non-market interactions by making a clear reference to the work of Coase (1960). They argue that the economy of R&D has followed the evolution of the theory of the firm and the evolution of the classical theory of externalities by embarking into a 'coasian slide'.

In other words, firms do not face an infinity of anonymous agents, they do not face the market, as it is assumed by the traditional theory of externalities, but they face a web of well identified firms, they evolve into a world of complex market and non market interactions among known and unknown agents (Granovetter, 1985).

This vision of knowledge production as a collective process involving many informal and non-market relationships has completely supplanted the view in terms of individual innovators, market, and externalities. Formal collaborations may involve suppliers, customers, rival firms, who may all collaborate within a research joint venture for instance, while informal collaborations may be materialized by relationships between employees of different firms (who built contacts through neighbourhood relationships, meetings at conferences, old classmates, etc.) who exchange knowledge and help each other to solve specific problems (von Hippel, 1988; Schrader, 1991). These informal links are often well known and even encouraged by the executive board of the firm.

Examples of such formal and informal R&D collaborations are many. The interested reader may consult Hagedoorn (1995), for instance, who made an in depth analysis of the links and R&D partnerships that have been developed among firms in the automotive, aviation/defence, chemical and heavy electrical instruments industries. High-Tech consortia are also examples of R&D partnerships between many, sometimes very different, firms and organisations (Cassier, 2002, Cassier and Foray, 1999a and 1999b; see also the examples of Sematech, MCC or CEPH given below). Industrial clusters such as the Silicon Valley in California, Route 128 near Boston (Saxenian, 1994) or NorCOM in Northern Denmark (Dahl and Pedersen, 2003) are also prominent examples of collective forms of innovation and illustrate, among others, the importance of spatial proximity for R&D collaborations.

It would be possible to give a very long list of examples of collaborative processes of innovation but to avoid repetition let us focus only on one last example, which is drawn from the work of Dahl and Pedersen (2003) regarding the communications cluster in Northern Denmark (NorCOM) and which stresses the importance of knowledge trading through informal links between employees. The starting point of the work of Dahl and Pedersen was the observation that an intense disclosure of detailed knowledge seemed to occur between firms of the cluster. With the help of a questionnaire addressed to engineers of firms of the network, Dahl and Pedersen were able to test this assumption. For instance, they stress that three quarter of the engineers who answered have built informal contacts with one or more employees in another firm of the network. Further, almost half of these engineers who have built informal contacts confess that these contacts have led to the acquisition of knowledge that has been useful in their current job. However, the authors also confess that their study does not teach a lot about the benefits that this intense knowledge disclosure may yield to firms.

To summarize, *(H2)* must be modified in order to take into account the collective and collaborative dimension of the innovation process, which requires the cooperation of many actors who develop links that go beyond market relationships. Furthermore, *(H1)* is also questioned. Knowledge is not a pure public good. Once produced, knowledge does not automatically flows ‘in the air’, it does not accumulate into a world stock of knowledge that is accessible to all firms as it is assumed by the traditional theory of knowledge externalities. Rather knowledge flows within a well-defined web of agents. It is accessible only to some specific agents who know where to look for it and who are allowed to access it.

Knowledge must be thought of as a collective good or a club good, since it can often be appropriated during very long spells of time by the collectivity that produced it. As argued by Gibbons (1994), in a collective form of knowledge production, knowledge production and knowledge appropriation are likely to converge (see also the quotation of Johnson and Lundvall in introduction of this section). R&D consortia are perfect examples of collective forms of knowledge production in which knowledge flows are limited to the members of the club, as illustrated by the following examples:

According to Cassier and Foray (1999a, p. 14) Sematech, a US consortium created in 1987 in the field of semiconductors, worked as follows: "Results of research undertaken by Sematech had to be granted to all members on the basis of a two years exclusivity license, and then made available to all US firms on condition they pay copyright fees". MCC, another US consortium created in 1982, worked according to a similar rule: Participants were the only beneficiaries of the technology licenses for three years. Only then had non-members access to the researches (Cassier and Foray, 1999a).

Another example to illustrate that knowledge usually flows only within clubs is given by the "Centre d'étude du polymorphisme humain (CEPH)", which is a French private research foundation. Cassier (2002, p. 104-105) explains that CEPH developed at the beginning of the eighties an original system of collective research in order to build the map of the human genome. The CEPH network established a policy of diffusion of its results in two concentric circles: First, the results of its research are gathered into a private database, which is available only to the members of the network. Then after two years, they become available to the entire scientific communities as they are put into a public database.

Hence, clearly knowledge cannot be considered as a public good which, once produced, becomes instantly available to others. To adopt this view is equivalent to expressing an absolute lack of consideration of how knowledge is transferred among individuals and organisations. Knowledge is embodied in physical, material supports, the movements of which are limited by material contingencies. It follows that knowledge flows are also limited.

For instance, we already mentioned above that knowledge takes often a tacit form and as such it is hardly transferable without physical contacts. Tacit knowledge can only be transmitted through master-apprentice relationships. Since tacit knowledge is embodied in the individual or group who masters it, only people who develop privileged contacts with the owner of a given piece of tacit knowledge may have a chance of accessing this knowledge. Or people who know people who know these people, etc. Organisational knowledge, for instance, is often tacit and as such is available only to members of the organisation or to agents who have close relationships with these members. Hogdson (1993, p. 174) wrote that: "organizational knowledge becomes manifest only through the interactive practice of the members of the group. It is both learned and transmitted in a group context only". Similarly, when knowledge is embodied in the mind of a researcher, only colleagues who know this researcher, who have personal contacts with him, have an opportunity to learn this knowledge. And still, they will have to count on his willingness to reveal this knowledge to them. We see that most of the time tacit knowledge remains within the club in which it was produced.

Yet, even codified knowledge released in books or patents can, in some sense, be considered as a collective good. When it is released, codified knowledge is still embodied in a material support, either a patent, or a book, or an industrial artefact. Hence, the circulation of a given piece of codified knowledge is always limited by its support and there cannot be any knowledge transfer without a connection between the agents (Callon, 1999, p. 412-413). For instance, if knowledge is released via a note internal to a given organisation then only the members of this organisation and their relatives, and the relatives of their relatives, etc., may be given a chance to access this information. If knowledge is released in a scientific journal, only agents who read this journal or who know someone who reads it, etc., may be given a chance to access this information.

Therefore, we see that there cannot be any spillovers without connections between the agents. Knowledge is not a pure public good like the air we breathe. Even the most widespread knowledge, the one embodied in books or diffused on the web, is not directly accessible and therefore not really public. People must first know where it is located and then must often make an effort to access it. For instance, in the case of a firm who wants to access knowledge released on the Internet, the firm must first look for it among all the relevant or not information on the web, which is not an easy search. In the case of a book, the recipient must know that this book has been printed and then must buy it. We see that knowledge, even in its more public form, is not a pure public good, since once produced it is not automatically and instantly available to other agents.

We will thus refer to knowledge as a club good or a collective good in the sense that knowledge does not flow in the air but is embodied within a given set of agents, a club or a network. New knowledge does not spill over from its source to feed a public pool of knowledge. It flows only within networks or clubs and it is available only to members of those clubs. Such clubs may be quite large, as in the case of knowledge embodied in a book or a patent, but in some cases they may also be quite small, as in the case of knowledge held only by the members of a laboratory team. There does not exist something like a world stock of knowledge, which all the individuals can automatically use depending on their absorption capacity. Rather, knowledge is accessible only to some specific agents who know where to look for it and who are allowed to access it.

To summarize, the outcome of the innovation process, new knowledge, is a collective good or a club good. Knowledge circulation is limited to a precise set of agents and the access to this knowledge is forbidden to non-members of the club. The unique way to access the knowledge embodied within a given network, to be granted access to the semi-public pool of knowledge, is to become oneself a member of the club (see also chapter III).

The corollary of this observation is clearly that some firms may find it profitable to implement specific strategies in order to develop R&D collaborations with other firms and therefore to benefit from the competences of their partners. One purpose of this thesis is to show that open knowledge disclosure may be one of these strategies. But the choice of a geographic location can also be interpreted as such a strategy. Indeed, since contacts are easier when partners are neighbours, the choice of a geographic location and the decision to openly disclose knowledge may be complementary strategies aiming at entering innovation networks and at developing R&D collaborations with other firms.

The analogy with the choice of a location in the geographic space

Most of empirical works underline that knowledge circulation is often localised geographically and that firms are more likely to innovate if they are located in a region in which many other knowledge intensive firms are situated (Jaffe, Trajtenberg and Henderson, 1993; Audretsch and Feldman, 1996; Branstetter, 1998; Capron and Cincera, 1998; Baptista and Swann, 1998; Aharonson, Baum and Feldman, 2003)[18]. Traditionally, this feature is explained by the fact that knowledge externalities are localised in space, meaning that only neighbour firms benefit from spillovers emitted by a given firm. Yet, as we have seen above, knowledge is not a public good and does not generate externalities, even localised one. Therefore, one way to explain the empirical finding that knowledge flows are localised in space is to consider that knowledge is a collective good and that the club in which it is flowing admits a local dimension. This point is underlined by Breschi and Lissoni (2003), who find out that spatial effects vanish when knowledge flows are controlled for any network relationship, suggesting that if knowledge transfers appear to be sometimes limited in space it is only because the clubs in which knowledge is flowing are geographically limited.

Why should R&D partnerships and other clubs be limited in space? Reasons for this spatial limitation are multiple. First, social interactions are strongly local. Furthermore, researchers, although hired by different firms, may have a common belief in the long run interest of a region. Also, geographic proximity favours trust between firms and this trust is necessary for the good functioning of innovation networks. Finally, many factors make long distance contacts harder: Taxes prevent an easy circulation of merchandises, difference of languages prevents communication between researchers, etc. All these reasons tend to explain why contacts are easier to make with neighbours than with people living 10,000 km away.

To put it plainly, what really matters for knowledge flows is social proximity and not spatial proximity (Amin and Cohendet, 2004). When we say that spatial proximity matters for knowledge

[18] However, as Massard et Riou (2001) mentioned it, econometric studies usually show that geographic proximity has a positive effect for firms when externalities are inter-sectoral and not when they are intra-sectoral, since in this latter case the negative effect of rivalry softens the positive effect of externalities.

flow we are not wrong but we miss an important step. We forget to mention that it is social proximity that matters and if spatial proximity seems to matter it is only because it influences social proximity. But why does this distinction between spatial and social proximity matter? We believe that it is important to draw this distinction because it may have many repercussions on firms' strategies.

For instance, as soon as knowledge is regarded as a local public good, firms have an incentive to cluster, to gather on the same territory[19]. Marshall (1920) already stressed this point. He identified three reasons that can explain firms' spatial concentration: (1) The pooling of demand; (2) The development of specialised intermediate goods industries and the concentration of raw materials among a given territory; (3) The existence of localised knowledge spillovers.

If knowledge circulation is limited to a given region, firms may find some incentives to agglomerate in this region in order to benefit from the knowledge that flows within it. This idea was formalised, among others, by Long and Soubeyran (1998) who demonstrated how the fact that geographic proximity affects the circulation of knowledge may be a key element in the decision of firms to form industrial clusters, although this proximity also exacerbates the competition between firms. In other words, according to this view all that is needed to access external knowledge is to set up a new factory in a given region where this knowledge is flowing, which is a rather passive vision of knowledge flows.

But as soon as knowledge is viewed as a collective good, it may not work for firms willing to absorb knowledge to only set up a factory in a given territory. Firms must rather develop social links with other firms, they must enter clubs in which knowledge is flowing. Spatial proximity may facilitate the construction of social links but it is only one strategy among others to do so. In order to be granted access to R&D collaborations firms must also set up other complementary strategies, such as strategies of open knowledge disclosure for instance.

[19] The geographic concentration of firms on a given territory was underlined, for instance, by Krugman (1991, p. 5) who wondered what is the most striking feature of the geography of economic activity? For him, the answer is straightforward: "The short answer is surely concentration […] Product is remarkably concentrated in space". To refer to such a concentration of firms on a limited geographic space Porter (1990) used the term "industrial clusters".

It is hence possible to draw a remarkable analogy between firms' decision of a geographic location and their decision to openly disclose knowledge. Both decisions may be triggered by the willingness to form formal or informal collaborations in R&D. As argued by Aharonson, Baum and Feldman (2004, p. 20): "The location and the formation of alliances may be best considered as strategic decisions that provide a means for firms to succeed at innovation". As such, models explaining firms' agglomeration in a given territory, such as the one of Long and Soubeyran (1998), may be especially useful to explain the rationales of open knowledge disclosure behaviours, since it may be the same basic forces that drive the choice of a location and the decision to openly disclose knowledge.

To conclude, it was argued here that innovation is a collective process and that the outcome of this process, new knowledge, is a collective good. This change in our vision of the innovation process may have important repercussions on our understanding of firms' strategies. We saw above that it may help to explain why firms choose specific locations in space and we will see in next chapters that it may explain why firms openly disclose knowledge. But it may also help to develop more appropriate public innovation policies.

I.2.4. Consequences of this new vision of innovation on innovation policies[20]

Here we would like to say a word on the consequences that the vision of the innovation process developed above have on innovation policies. We want to do so because, although this topic is not central to our work, we have treated innovation policies when dealing with the traditional approach and hence we would like to complete what was said then. Furthermore, this discussion will be helpful to understand the issues tackled in chapter V.

Within the traditional framework there cannot be any diffusion and coordination problems since it is assumed that knowledge circulates perfectly, that once produced it flows freely to

[20] This section is based on my paper "Patent policy: A need to solve both appropriation and coordination failures" (Pénin, 2003b).

everybody. As a matter of fact then, the main purpose for policy makers is to increase incentives to innovate (incentives that are assumed to be sharply reduced by the presence of spillovers) even if the price to pay is a decreased diffusion of the produced knowledge. This traditional vision is at the source of most of the current innovation policies, which almost all focus on appropriation concerns while neglecting the coordination side. Everywhere, governments implement tax cuts for R&D investments, reinforce the system of intellectual protection rights, but few actions are undertaken to facilitate cooperation between agents.

However, policies that focus mainly on appropriation concerns may be misleading. It was indeed argued in this chapter that knowledge is not a public good, that it can often be appropriated at least in part, that when it is released it is not available to everybody and that even when it is available to other firms it does not profit freely to them but only after they realize important investments to absorb it. The corollary of these observations is that the lack of incentives to invest in R&D is probably not as important as assumed by the traditional vision of knowledge. This statement is still strengthened by the fact that firms have many incentives to invest in knowledge production even under a weak appropriation regime:

(i) For instance, Cohen and Levinthal (1989) showed that even with strong spillovers firms may have strong incentives to invest in R&D in order to build an absorption capacity and to be able to absorb knowledge that spilled over; Contrary to what is traditionally assumed, in such a case, spillovers may therefore encourage R&D investments; *(ii)* Firms' investments in R&D may also be triggered by the willingness to remain on the technological frontier of the industry. As Schumpeter argued: "In capitalist reality as distinguished from its textbook picture, it is not price competition which counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization [...] This kind of competition is a much more effective than the others as a bombardment is in comparison as forcing a door" (Schumpeter, 1942, p. 84-85). In this context, to invest in R&D is a survival necessity in a world in which competition is a matter of innovation. When a firm stops being innovative it is sure to be kicked out of the market within a more or less short spell of time; *(iii)* Firms, by performing R&D, may be willing to acquire a reputation as innovators, which may lead to profitability at a more or less long time horizon even if the firm does

not capture the full benefit of its R&D; *(iv)* Finally, a last reason that explains why innovations may frequently emerge on the market even without a strong appropriation regime, is the consideration of the creative pleasure, the man's desire to understand. Nowadays, there still remain cases for which innovations are initiated by individual inventors, although such cases are more and more isolated. These individual inventors probably welcome being rewarded for their innovation but certainly do not live in the expectation of such a reward and therefore the absence of monetary incentives does not decrease their willingness to invent.

The arguments seen so far suggest therefore that the deficit of incentives to invest in knowledge production have probably been over estimated, that the appropriation concerns are widely exaggerated within the traditional framework. On the other hand, the need to achieve coordination between agents involved in the knowledge production process, the need to allow a wide circulation of the produced knowledge is surprisingly neglected, whereas it appears that coordination problems that occur between firms involved in the innovation process may be as damaging, if not more damaging, than the appropriation failure.

Indeed, it was emphasised earlier that knowledge production is a collective, multi-disciplinary, and cumulative process. But this collective process may be impeded by strong coordination problems, which may complicate cooperation and knowledge circulation between agents. First, the innovation process takes place in an environment of incomplete information. And the presence of strong asymmetries of information regarding firms' competences may sharply decrease the volume of exchanges between firms. Adverse selection and moral hazards problems may decrease firms' willingness to cooperate because they fear to be betrayed.

Second, the circulation of knowledge is slowed down because firms do not have the same competencies, the same language, and even when they do, the knowledge can just be tacit, meaning that it is very hard to transfer. These problems, mainly the existence of tacit knowledge and of asymmetries of information, may impede severely the collective and cumulative process of knowledge production.

This new vision of the knowledge production process strongly contrasts with the traditional view. Within a competence-based framework a policy oriented to solve only appropriation problems at the detriment of the coordination problems would be misleading. Even if firms can perfectly appropriate their knowledge (and hence if the incentives to invest in knowledge production are maximal) the innovation process may not perform well, since agents may have difficulties to cooperate, to achieve coordination. To provide incentives to innovators is often necessary but it is not enough because incentives are worth nothing if firms cannot find the external competences that would enable them to implement their innovations. Hence, one of the most important points underlined by this new approach is that appropriation concerns should maybe not be the central preoccupation of policy makers. Policies oriented to help coordination between knowledge producers and to facilitate the circulation of knowledge are also required.

Among other solutions, this conclusion provides a direct rationale for policies aiming at developing systems of innovation at the regional, national and even international levels. With the purpose to encourage the formation of such innovation systems, policy makers may provide facilities to connect the different actors such as firms, public researchers, other public institutions, financing actors, etc. Governments may promote R&D cooperation, encourage the diffusion of knowledge through conferences or scientific papers, facilitate connections between firms and individuals by organizing conferences, etc. An important role of public policy is therefore to nurture a culture supporting informal relationships and to settle institutions to arrange conferences, seminars, and other social activities that are targeted to allow individual researchers and firms to keep meeting each other's.

Regarding patents, policies aiming at improving the coordination role of patents are essentially required. We strongly believe that patents are not only useful to provide incentives but that they may also ensure the coordination between agents involved in the knowledge production process, as it will be stressed in chapter V. Patents can manage to be a powerful tool to solve coordination failures and to improve knowledge circulation because they provide a signal of where competences are located and they associate this signal with a property right. Paradoxically, property rights may often favour knowledge transfer because they are key features in negotiations between firms.

To summarize, following the vision of knowledge and of its production process that is considered, different innovation policies are needed. On the one hand, the traditional view puts all the weight on the lack of incentives and hence on the need to restore appropriation. On the other hand, the view in terms of collaborations and non-market interactions puts more weight on the necessity to ensure a wide circulation of knowledge and the coordination among agents.

Conclusion of the chapter

Economists traditionally consider knowledge flows as being due to externalities, meaning that, once produced, new knowledge is assumed to spill over from its creative source and to feed a public pool of knowledge from which other firms can draw freely. Following the definition of an externality, firms are viewed as completely exogenous in this process of knowledge transfer. They can control neither the diffusion of their knowledge nor the absorption of external knowledge. Moreover, firms are assumed to be isolated and anonymous agents connected only through market mechanisms.

In this chapter we revisited the three main points on which this traditional approach relies: We stressed that agents are not isolated and anonymous and that they do not interact only under the rigid structures of the market. Innovation is a complex collective and networking process in which firms develop many non market interactions. Moreover, the outcome of this process, new knowledge, does not flow 'in the air' and is not available without costs to other firms. It is a collective or a club good in the sense that it flows only within specific structures, clubs, networks, etc.

Furthermore, we stressed that knowledge flows are not exogenous. They depend, at least to some extent, on the behaviours of the agents, who can control their emission of knowledge as well as the absorption of external knowledge. Firms cannot passively absorb knowledge. They must build an absorption capacity and cooperate with other firms in order to access outside knowledge. Similarly, knowledge does not spill over randomly from its source but is often voluntarily disclosed.

If the theory on the absorption capacity of external knowledge has been extensively developed since the 1980s and the work of Cohen and Levinthal, the interest on firms' emission capacity of knowledge is recent and, for most of it, a theory has still to be built. Our task in the rest of this work will be to contribute to the establishment of the foundations of such a theory.

CHAPTER II:

OPEN KNOWLEDGE DISCLOSURE: AN OVERVIEW OF THE EMPIRICAL EVIDENCE AND THE ECONOMIC MOTIVATIONS

The departure point of this chapter is the ascertainment that, as it was stressed in the first chapter, knowledge does not always generate spillover. Firms have the possibility to keep their new knowledge secret during a very long spell of time. Yet, many firms often choose to voluntarily disclose some of their new knowledge. The fatherhood of the literature on knowledge disclosure as a rational economic behaviour among profit seeking firms is usually granted to Allen (1983).

When exploring the reasons that encourage firms to openly disclose knowledge, it is important to make a distinction between two different types of knowledge disclosure: Closed knowledge disclosure and open knowledge disclosure. Our focus here is on behaviours of open knowledge disclosure, which we define as situations in which a firm decides voluntarily to reveal some of her knowledge to other firms without receiving a direct compensation for this disclosure and without being able to prevent a given firm from accessing the disclosed knowledge. Behaviours of closed knowledge disclosure must be treated separately because we will see that they are closer to knowledge trading than to pure disclosure and, as such, the motivations underlying those behaviours are quite different than those underlying behaviours of open knowledge disclosure.

Since open knowledge disclosure cannot pretend to any direct remuneration, conventional wisdom suggests that such behaviours remain marginal and that firms try usually to keep a tight secrecy over their research. The figures presented here should convince the reader that, contrary to this common belief, behaviours of open knowledge disclosure do occur and are even frequent in many industries.

Furthermore, an important question deals with the reasons that encourage firms to adopt such behaviours. The absence of any direct payment implies that open knowledge disclosure has often been misunderstood by mainstream economics, which uses to refer to the notions of altruism or irrationality to explain them. However, we show here that there is a wide range of extrinsic motivations that encourage firms to openly disclose knowledge. Our overview of these motivations does not pretend to be exhaustive but it nevertheless allows us to question the traditional argument that the best strategy to exploit an innovation is to keep it secret.

This chapter is divided in two parts: In the first part we survey the empirical evidence that tends to confirm the existence of behaviours of open knowledge disclosure. We also review the main channels through which firms may openly disclose knowledge. Then, in the second part, we provide an overview of the economic reasons that may encourage firms to adopt behaviours of open knowledge disclosure.

II.1. Definition and empirical illustration

II.1.1. Definition of open knowledge disclosure

Although this manner of introducing a central concept may be viewed as abrupt and inelegant, in order to avoid ambiguity it seems appropriate to us to start with a definition: Open knowledge disclosure refers to a situation in which a firm decides voluntarily to reveal some of her knowledge to other firms (meaning that she could have kept this knowledge secret), without receiving a direct compensation (monetary or not) for this disclosure and without being able to prevent a given firm from being granted access to the disclosed knowledge. Hence, there are three dimensions that count to characterise open knowledge disclosure: The disclosure must be voluntary, it must be free (in the sense of not remunerated) and it must be open (in the sense of not limited to some well specified recipients).

The disclosure must be voluntary

First, the disclosure must be voluntary, which means that its owner could have appropriated the disclosed knowledge to some extent, i.e. knowledge does not automatically spillover from its creative source. As it was stressed in chapter I, this condition is often fulfilled (see section I.2.1.). Indeed, notwithstanding that a fraction of the knowledge produced by a firm always leaks and profits other firms, who can access this knowledge through reverse engineering for instance, most of the time firms can appropriate their new knowledge, at least in the short run.

Knowledge, even if codified and public, is far from being accessible to everybody. Firms can appropriate important amount of the knowledge they produce. The corollary of this result is that firms have an emission capacity of their knowledge in the sense that they can choose when, how and to whom to diffuse their knowledge, if they decide to reveal it. We see therefore that knowledge flows are not exclusively undesired leakages that cannot be avoided. Firms may sometimes wish to disclose knowledge.

The disclosure must be free

A second requirement is that the disclosure must not involve any specific agreement between the sender and the recipients. This means, among others, that the latter can access the disclosed knowledge without imposition of any direct payment, in other words, that open knowledge disclosure is not directly remunerated. In some sense open knowledge disclosure has the property of a gift. This provision implies that we do not consider the sale of exploitation licenses or the activity of scientific expertise, for instance, as open knowledge disclosure.

Two remarks must be made about this feature of gratuity: First, the fact that the disclosure is free does not mean that it is not profitable to the sender, on the contrary. It is one of the aims of this chapter to show that firms may earn substantial indirect benefits from the free disclosure of knowledge. Second, it does not mean that the acquisition of the disclosed knowledge is free for the recipient. The latter must almost always engage important costs to locate where the knowledge is, to be granted access to this knowledge and to absorb it. For instance, in order to access knowledge disclosed during conferences, a firm must pay conference fees as well as the journey to go to the conference. In order to access knowledge on the Internet, a firm has to pay the connection. Or, in order to use knowledge that has been published in a paper a firm must first buy this paper and then she must build the necessary competences to understand it.

The disclosure must be open

Let us now turn to the explanation of the third point that characterises open knowledge disclosure, namely the openness dimension. There is indeed a sharp difference between behaviours of open knowledge disclosure and behaviours of closed knowledge disclosure. Basically, the difference between these two concepts deals with the means to access the disclosed knowledge. When the sender can decide exactly the population to which he wants to disclose his knowledge (i.e. when he can prevent some agents from accessing the disclosed knowledge) then the disclosure is said to be closed. Conversely, when the sender cannot exclude a given agent from learning the disclosed knowledge then the disclosure is considered as open, i.e. once knowledge is openly disclosed the sender cannot prevent a given agent from accessing this knowledge[21].

Therefore, in the case of closed knowledge disclosure the sender can choose to exclude some agents from learning the disclosed knowledge[22]. In this case, and conversely to open knowledge disclosure, the exchanged knowledge is expected to be sometimes tacit, recipients are most of the time not anonymous and the remuneration of the diffusion is often agreed before the disclosure. The disclosed knowledge may be tacit because the sender and the recipient may have physical contacts, which makes the transfer of tacit knowledge possible. Furthermore, for the sender the gains arising from closed knowledge disclosure are most of the time known because, again, the sender can choose and select the recipients and therefore can establish implicit or explicit agreements that specify a compensation for the disclosure.

Closed knowledge disclosure may occur through common practice, training of employees of other firms, exchange of employees, meetings, visits of factories, exchange of materials (software for instance), etc. These behaviours are quite similar to patterns of informal cooperative R&D, which led von Hippel (1987 and 1988) to assimilate closed knowledge disclosure to know-how trading rather than to pure knowledge disclosure because what happens is not really a disclosure in the sense of the above definition but rather an exchange realized on the basis of a reciprocal agreement.

Many examples of closed knowledge disclosure have been emphasised in the first chapter. For instance, we have seen that consortia, such as Sematech or CEPH, make their research available only to members of the consortia during a certain time. Let us add here one more example, namely the case of the US steel and mini-mill industry. Von Hippel (1987 and 1988) and then Schrader (1991) both enlightened that many informal exchanges occurred between employees of different firms in this industry. Interviews reveal that employees frequently disclose technical information to colleagues in

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[21] In the case of open knowledge disclosure the sender looses control over the diffusion of his knowledge but he can still keep control over its use if he wants to (for instance, if the knowledge is patented or if it is impossible to use it without an asset that is kept secret, etc.). There is a difference between having access to the disclosed knowledge and being allowed to use this knowledge. One can learn something without being allowed to use this knowledge in order to solve certain well-specified problems.

[22] But to do so he must rely on the collaboration of the partners to whom he has disclosed his knowledge.

other firms, including competitors. For instance, Schrader pointed out that numerous exchanges occurred at the frequent meetings at the Association of Iron and Steel Engineers. Furthermore, he also noticed that these exchanges seem to be desirable from the point of view of firms. Lhuillery (2001, p. 8) also observed that disclosure is often embedded in a formal framework, such as official R&D cooperative agreements, from which non members are excluded.

To summarize, in the case of closed knowledge disclosure, employees do not disclose information randomly but rather trade information consciously within well specified networks of agents.

Quite different is open knowledge disclosure, since in this case everybody is given a chance to access the disclosed knowledge. The sender cannot control the population of recipients, he cannot discriminate between firms by disclosing his knowledge only to some of them. This kind of disclosure occurs through scientific publications, lectures at conferences, patents or information released on web sites. Of course, in the case of open knowledge disclosure the population of recipients can also be targeted because the choice of a channel of diffusion determines this population in part. But the important point is that, conversely to closed knowledge disclosure, the sender cannot prevent a given firm from accessing the disclosed knowledge. For instance, once a paper is published in a scientific journal it becomes impossible for the author to control its diffusion. Whereas, if the same paper is presented in a meeting inside the company who hires the author then it is possible to strictly control the population of recipients by thoroughly selecting the people who attend the meeting.

To illustrate the differences between open and closed knowledge disclosure, let us consider two examples: When knowledge is disclosed in a newspaper that can be bought almost everywhere then it is openly disclosed. But if this knowledge is disclosed in a newsletter that is mailed only to a few people then it becomes closely disclosed. Similarly, if knowledge is disclosed in a conference open to everybody it is openly disclosed. Whereas if it is disclosed in a meeting, such as the one of the Association of Iron and Steel Engineers underlined by Schrader above, it is closely disclosed, since access is controlled and may be forbidden to certain agents.

It is important to distinguish between open and closed knowledge disclosure because they refer to quite different situations. For instance, the motivations that induce firms to reveal are different: In the case of closed knowledge disclosure the remuneration of the disclosure is more straightforward than in the case of open knowledge disclosure, since in this latter case knowledge is revealed without any kind of agreement, implicit or explicit, between the sender and the recipients, which would ensure reciprocity. As we already mentioned, closed knowledge disclosure is closer to knowledge trading than to pure knowledge disclosure. Furthermore, the vectors through which the diffusion occurs also differ: In the case of open knowledge disclosure the sender and the recipient do not know each other while in the case of restrained knowledge disclosure they can be more or less in touch. Let us conclude this part by two important remarks.

(i) To openly disclose knowledge may involve important costs. Among others, as it is stressed in the next remark, the disclosed knowledge must be codified and the codification process may sometimes be quite expensive. Furthermore, the vector through which the diffusion is operated may not be free. For instance, in order to present a paper in a conference authors will have to pay conference fees. Similarly, to openly disclose knowledge through a patent implies that firms must pay the application fees. But these costs are likely to remain marginal compared to the cost of providing useful information to potential competitors. Indeed, to openly disclose knowledge means to help other firms (including competitors) to solve specific technical problems, which may therefore sharply affect the sender's profitability through the effect of competition. This sole cost may frequently deter firms from openly disclosing knowledge, even if other costs can be neglected.

(ii) It is important to emphasise the role of codification in the process of open knowledge disclosure. Codification is a prerequisite to open knowledge disclosure because to openly disclose knowledge requires that the sender must be able to explain this knowledge to recipients. And tacit knowledge is by definition non articulated, meaning that one cannot deliberately explain it to others. Before being possibly openly disclosed, knowledge must therefore be framed into a model, expressed

into a language and written down into an artificial support. In one word, knowledge must be codified prior to be openly disclosed[23].

Codification is a necessary condition, a prerequisite to open knowledge disclosure but it is not a sufficient condition to open knowledge disclosure. Indeed, once the knowledge is codified the owner can still choose to keep it secret. This being said, two remarks should be added about tacit and codified knowledge:

First, the fact that codification is a prerequisite to open knowledge disclosure does not prevent the recipient from acquiring tacit knowledge from the disclosure. But this tacit knowledge is assimilated only after personal experiments and learning and nothing can warrant that the recipient will assimilate precisely the tacit knowledge that the sender wanted to transmit. It is sometimes easier to learn from a teacher than from a codified piece of knowledge, a book for instance, but it is always possible to acquire tacit knowledge from both after a good deal of experimentation. Physical contacts, when an apprentice can observe carefully what his master is doing, only reduce the needed amount of experimentation and the time of learning. In other words, it is possible to acquire tacit knowledge by reading a book but this transfer of knowledge is more hazardous than when there are physical contacts between the sender and the recipient.

Second, the highly theoretical question around the feasibility of codification and hence around the feasibility of the transfer of tacit knowledge is voluntarily neglected here. Nevertheless, the reader must be aware that many scholars think that it is not possible to replicate tacit knowledge identically because this knowledge is part of its human support. Thus, when the support changes the knowledge embodied in it must change too. This implies that the knowledge copied or transferred is never quite identical to the original. The codified knowledge is at best a picture of the original tacit knowledge. Hence it is often argued that codification is impossible. However, without disagreeing with the view that tacit knowledge cannot be identically replicated, we prefer the term used by Cowan and Foray

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[23] Only through common practice, through a master-apprentice relationship, is it possible to transmit voluntarily tacit knowledge without necessarily codifying it. In this case, the master and the apprentice can practice together, the apprentice being then able to observe and to imitate his master. However, we see that this way of transferring tacit knowledge requires physical contacts and even more, a stable relation between the sender and the recipient. As such it is typically an example of closed knowledge disclosure and not of open knowledge disclosure.

(1997, p. 600) who explain that: “codification is never complete” (Polanyi, 1958, p. 70, also noticed that: “articulation always remains incomplete”). We prefer this term because if it is true that an individual who wishes to codify tacit knowledge cannot do it completely, he can nevertheless do it to a certain extent.

To summarize, behaviours of open knowledge disclosure have been defined as situations where a firm decides voluntarily to disclose some of her knowledge, without being ensured of any remuneration and without being able to restrain the access to this disclosed knowledge. Let us now use some examples and figures in order to show that such behaviours do occur frequently in some industries. We will also underline the main channels through which this disclosure is operated, which are publications in scientific journals, conferences and other meetings, the patent system and the Internet.

II.1.2. Empirical evidence of open knowledge disclosure

II.1.2.1. Publications in scientific newspapers

The first author, to our knowledge, to stress behaviours of open knowledge disclosure was Allen in 1983, who studied the evolution of the technology in the blast furnace industry at the end of the XIXth century. Allen points out that in this particular industry many knowledge exchanges occurred among firms in the industrial district of Cleveland (UK) between 1850 and 1875. He notices further that these exchanges led to important technological improvements regarding the size of the furnaces (from fifty feet to eighty feet) and their temperature (from 600°F to 1400°F), which in turn led to an important decrease of production costs. This was perceived as a quite puzzling finding then because, against the common belief of the period, this example suggested that behaviours of voluntary knowledge disclosure did contribute to increasing firms’ profitability or at the very least did not undermine this profitability. Furthermore, Allen (1983, p.7) explains that knowledge used to be conveyed both through informal (researchers meeting) and formal (academic publications) channels. He writes that:

> "Formal presentations through papers presented to engineering societies was the second channel through which information was released […] Papers were presented which disclosed considerable detail about the design and efficiency of different plants. The papers and the subsequent discussion were printed in the proceedings of the society. […] Since most of these ironworks contained furnaces of several vintages and the authors of the papers tried to use the resulting data to estimate the impact of increasing height and temperature on fuel consumption, an impressive amount of useful information was made available to potential entrants".

(Allen, 1983, p. 8-9)

Hence, new innovations and their degrees of performance were made available to other firms of the district in scientific publications, which are one of the most privileged channels to openly disclose knowledge. It is well known nowadays that many firms, although they monitor this disclosure, allow their researchers to publish their work in scientific reviews.

This is the case, for instance, in the pharmaceutical industry. Koenig (1983) collected data from the *Science Citation Index* about 24 pharmaceutical companies. Only within the short period 1970-1974, he counted 9803 publications reported in basic biomedical research journals written by researchers working for one of these companies. More recently, Cockburn and Henderson (1998) studied a sample of twenty major pharmaceutical firms and showed that between 1980 and 1994 these twenty firms published 68,186 papers.

The fact that pharmaceutical companies publish may seem puzzling at first sight because it is well known that pharmaceutical companies are among the few who rely extensively on the patent system to protect their innovation (see Chapter V). However, it is often argued that publishing is a way for these companies to gain reputation and hence to accelerate the market authorization delivered by the *Food and Drug Administration* (FDA). In any case, it may be interesting to observe how patenting and publishing strategies may be complements or not. Among others, we will see in the next part that firms often let their researchers publish only once the firm has been granted a patent. There is therefore a strong asymmetry between the policy of strict secrecy that must be respected before and during the patent application and the policy of disclosure that is tolerated after the patent has been granted.

Hicks (1995) attempted to measure the tendency of firms toward scientific publications. The figures suggested in her paper are sometimes impressive and, from a global point of view, they convince the reader of the importance of behaviours of open knowledge disclosure through scientific publications. For instance, we learn from her that in 1989 certain companies published more than 200 papers per year with one or two reaching 500 papers. She concludes that: "Firms such as Philips, Hitachi, ICI, Ciba, Siemens, Sandoz, Roche, Hoechst and Toshiba contribute as much to the public literature as medium sized universities" (Hicks, 1995, p. 403).

This is a remarkable finding since firms publish usually in one domain whereas universities publish in almost all technological fields, suggesting that in their own fields of competence firms publish far more than many universities. This point is confirmed by Lim (2000) who finds out that in the field of copper interconnects, IBM authored forty publications from 1985 to 1997, which is twice as much as the most productive universities, who published twenty or less papers during the same period.

Japanese firms also publish in scientific newspapers as it is showed by Hicks, Ishizuka, Keen and Sweet (1994) who counted the papers of 28 Japanese companies. The results are presented in table II.1. below. According to the authors these papers represent only between 40 and 50% of the total number of papers published by each firm, since Japanese-speaking journals were not included in the count. However, the overall picture is that Japanese companies do publish in international scientific newspapers and that their contribution sharply increased from 1980 to 1989. To avoid repetition, data about publications of European firms are not reproduced here but they show a similar trend (Hicks, Isard and Martin, 1996, for detailed figures).

Table II.1: Publications from Japanese companies in 1980, 1984 and 1989 (reproduced from Hicks, Ishizuka, Keen and Sweet, 1994)

Company name	1980	1984	1989
Ajinomoto	38	24	66
Asahi Chemical	11	30	40
Asahi Glas	12	5	18
Fuji Photo	8	13	2
Fujitsu	85	78	127
Hayashibara Biochemical Labs	2	1	15
Hitachi	280	259	431
Kao Corp	14	19	31
Kirin Brewery	6	7	17
Kobe Steel	16	16	54
Kyowa Hakka Kogyo	41	34	69
Matsushita Electric Industry	59	72	134
Mitsubishi Electric	81	58	153
Mitsubishi Kasai	70	89	137
Mitusi Toastu Chemical	10	14	20
NEC	77	86	179
Nippon Steel	34	40	106
Nissan	10	12	16
NTT	465	489	518
Sagami Chemical	32	38	40
Shinogi & Co.	55	58	169
Sony	38	43	44
Sumitomo Chemical	63	66	66
Sumitomo Electric Industry	17	15	32
Suntory	16	35	64
Takeda Chemical	114	94	119
Toshiba	72	148	205
Toyota	11	30	53
Total	**1737**	**1873**	**2945**

Source: Hicks, Ishizuka, Keen and Sweet (1994). Data are computed from the *Science Citation Index*, the Japan Information Center of Science and Technology and from the original journals.

More recently, an inquiry realized by *ScienceWatch*[24] shows that many firms were among the most active institutions in terms of publications between 1991 and 2001. This is the case in all technological fields, although the ranking is still dominated by the most famous US universities such as Harvard or MIT. For instance, in "Computer Science" IBM comes first (with 2939 papers and 11781 citations) and AT&T second (with 2402 papers and 8451 citations). These two firms published twice as much as Stanford and MIT who are third and fourth. Similarly, in "Physics", AT&T and IBM are among the five biggest publishers (AT&T is first) both with more than 4000 papers and more than 80000 citations. In "Pharmacology and toxicology", we also find two firms among the five, namely GlaxoWellcome and Merck. It appears therefore, as Allen first emphasized, that firms tend to let their scientists publish massively in scientific journals.

Furthermore, at the national level it is generally estimated (Hicks, 1995) that companies contributed to 8% of UK papers in 1991, that they produced on average 6% of Dutch scientific output between 1980 and 1989 (De bruin, Moed and Schoneveld, 1992) and 9% of science and engineering publications in the US in 1991.

It is therefore indisputable that scientists working in private institutions publish, but a central point is whether or not these publications contain valuable information and are helpful to other firms in order to improve their own research. An answer can be made by counting the citations of the papers. Papers published by firms are highly cited on average, not less than papers from universities. Koenig (1983) found, for instance, that the 9803 publications he observed regarding 24 pharmaceutical firms had been quoted 17957 times only in the three years that followed the publication. Hicks (1995, p. 403) explains that: "In the biological sciences nine corporations have citations per paper averages that rank them among the top 25 universities […] In the physical sciences the situation is similar, with six companies ranking alongside the top 5 universities". Hence, if we agree to proxy the quality of the

[24] Sources are "Heavy Hitters, Outsized Influence", *ScienceWatch*, 2001, vol. 12, n°4.

ScienceWatch features a listing of the five institutions that have been most cited in 18 fields during the last decade (1991-2001). To compile these rankings, *ScienceWatch* turned to ISI Essential Science Indicators (ESI), a new web database covering upwards of 7 million articles in 22 broad fields of the sciences and social sciences. The ranking is by number of citations, which may be slightly different from a ranking by number of papers but this does not contradict our point that firms publish massively.

published papers by the number of citations, these figures suggest not only that firms do excellent basic research but also that, through scientific publications, they provide valuable knowledge to other firms, including to their competitors.

II.1.2.2. Presentation in conferences

It is therefore doubtless that, as Allen first emphasized, some firms publish actively in scientific reviews. But Allen's work also stressed another channel through which knowledge can be widely disclosed, namely the attendance of conferences and meetings organized by the engineering association[25]. To encourage scientists to attend conferences may appear quite appealing for a firm, as much useful information can be gathered during such meetings. One may therefore think that firms encourage their researchers to attend conferences but not to reveal information. The objective being to maximize the inflow of information while minimizing the outflow.

However, in practice firms do not behave like this, on the contrary. They not only allow their researchers to attend presentations and gather information but they also encourage them to present their own research and therefore to disclose valuable information without being able to control exactly who benefit from this knowledge (if access to the conference is open to everybody). For instance, we learn from Hicks (1995, p. 178) that in one of her case studies she was astonished to hear that researchers who wanted to attend conferences were: "required [by their direction] to present a paper at any conference attended" in order to obtain financial support from the company. This clearly underlines a willingness, not only to gather information, but also to openly reveal knowledge by attending conferences. This may be so because, in some ways, open knowledge disclosure is a way to facilitate access to information. It allows researchers to present their work, to present the firm who

[25] Presentation in conferences can sometimes be considered as open knowledge disclosure and sometimes as closed disclosure, depending on the accessibility of the conference. If participation is open then the works presented in the conference can be viewed as openly disclosed. But if the participation is controlled, as it is usually the case in professional meetings for which the participation is restrained to a few initiates, then the knowledge disclosure must be considered as closed.

employs them and therefore it increases the trust of other researchers who may be susceptible to provide them with useful information.

This point is raised, for instance, by Gambardella (1992) who noticed that successful pharmaceutical firms are like academic departments in the sense that they implement a policy of open science by allowing their scientists to attend conferences and to publish their works. This openness is viewed as a necessary condition to gain access to valuable sources of external knowledge by entering inner circles of scientific communities (see chapter III). Cockburn and Henderson (1998) also emphasised that researchers working in private firms do not limit themselves to reading journals or to attending conferences. Most of the time, they also play an active role in conferences and colloquia and as such they are active participants in the construction of publicly available knowledge.

II.1.2.3. Patents as devices to openly disclose knowledge

A third channel through which firms may openly disclose some of their knowledge is the patent system (we will come back extensively on the patent system and on its disclosure function in chapter V). When firms apply for a patent they must provide a detailed description of the innovation they want to patent, which must be detailed enough to allow a person aware of the state-of-the-art to reproduce the patented innovation. Once the patent is granted, and in some countries even if the patent is not granted, this description is published, meaning that everybody has free access to it.

Hence it is unquestionable that patents admit a disclosure dimension[26]. Whether the knowledge disclosed in patents is really valuable to other firms is not well established yet and anyway the value of patented knowledge is very heterogeneous across patents, some patents containing incredibly valuable information while others being of absolutely no value. Furthermore, many firms apply for patents with the deliberate intention to misguide their competitors and to communicate wrong information to them. But, however it may be, it does not deny the fact that patents carry some

[26] Furthermore, patents are devices to openly disclose knowledge because when an innovation is patented everybody can read the patent and learn about it without its holder being able to prevent this diffusion. In this sense knowledge disclosed through a patent is openly disclosed.

knowledge. At the very least they signal to other firms the state of the art in a given technological field, they indicate the potentially fruitful domains of research that may be worth exploring and they set aside these domains from those that have already been explored. Put it otherwise, even if patents do not communicate in depth technical results, they do provide useful information to other firms at least by indicating that a given technological field is worth exploring and hence by helping to map the knowledge space. And, as David (1999) puts it, the knowledge that something can be done is itself an important step toward discovering how it may be done.

A major question here is to what extent firms consider patents as a way to disclose knowledge. In other words, do firms sometimes decide to apply for patents because they want to openly disclose their knowledge? Or do they always consider the fact that the knowledge underlying their patented innovation must be revealed as a constraint that they must accept in order to be granted a monopoly right?

It is our conviction that firms may value a patent for its knowledge disclosure function. Actually, to apply for a patent is an expensive way to openly reveal knowledge because there are application and maintenance fees and because the procedure to write the patent is long and costly, but it is also an efficient way to disclose knowledge since the disclosure entails a protection of the innovation. Hence, patents, since they associate the disclosure with an exclusive exploitation right, are likely to be one of the most enjoyable devices for a firm to openly disclose knowledge.

Empirical studies, if they do not clearly confirm this view, provide several insights in this direction. They unanimously stress that, in all but in a handful of industries, patents are not perceived as an efficient way to secure a monopoly rent. Rather, what comes out of most empirical investigations is that patents are viewed mainly as efficient devices to bargain access to other firms' patented innovation by cross-licensing or by forming research joint ventures (see chapter V).

Patents play therefore a key role in the process of R&D cooperation and knowledge exchange. Furthermore, it is interesting to notice that this role does not derive exclusively from the fact that they ensure their holder with a property right. It is also because they disclose knowledge, because they signal where competences are located. Without such a signal, which indicates firms' own competences in a given technological field, firms would have far greater difficulties to find partners that suit them, which in turn would slacken the process of cooperation and knowledge exchange. The knowledge disclosure function of patents is therefore clearly an important feature that helps to explain why patents are valued so much.

The importance of the disclosure function is confirmed empirically by Cohen et al. (2000), who teach us that among the different reasons to apply for a patent, the willingness to enhance the firm's own reputation is quoted by almost half of the respondents (47.9%) to their questionnaire (see chapter V for more details about this questionnaire). As the authors notice, although a fraction of this figure may reflect a vanity component, overall it indicates that patents, through the wide knowledge disclosure they allow, are efficient devices for approaching capital markets or other potential partners.

Furthermore, Patel and Pavitt (1997) emphasised that many firms apply for patents in technological domains that are not related to any of their commercial fields. To reach this conclusion they use a sample of 440 big firms that have been granted US patents within the period 1969-1990. First they identify the technological fields corresponding to all the patents granted to a given firm. Then, they compare this classification with the technological fields that correspond to the principal product group of the firm. The results are interesting: It appears that most of the firms hold patents not related to any of their product groups. For instance, Patel and Pavitt observe that 17 firms in their sample (over 440 firms) are present in commercial sectors directly related to the "computer technology" but 288 firms hold patents in this technological field. Similarly, 18 firms are present in the product group that uses "aircraft technology" but 73 firms hold patents in this technological domain. Or, 21 firms are located in the product group that uses the "instrument technology" but 407 firms hold patents in this field.

These results lead the authors to conclude that firms are more diversified in their technological portfolios than in their product portfolios. They have a much broader range of technologies than products. This finding, which can hardly be explained by assuming that firms use their patent portfolios to exploit commercial monopolies, is consistent with the view that patents are used as a signal of competences in a given technological field and as "bargaining chips" to negotiate R&D cooperation and knowledge exchange.

Clearly, firms do not always view the disclosure function of patents as a constraint that must be fulfilled to be granted a monopoly right. On the contrary, firms may consider positively this open knowledge disclosure dimension of patents, which enables them to use the patent system in order to enhance their reputation or in order to signal their competences to other firms, while keeping a tight control over the use of the disclosed knowledge.

II.1.2.4. Open knowledge disclosure, open source software and the Internet

Open knowledge disclosure is also a central feature of the open source software (OSS) industry. Indeed, OSS are by definition software released with their source code[27]. Within OSS projects, developers choose to disclose their work to other programmers through the revelation of the source code via the Internet, allowing them to use, understand and improve their programs, thus contributing to a fast and steady advance in the resolution of technical problems that are encountered (Lerner and Tirole, 2001; Nuvolari, 2001; Bonaccorsi and Rossi, 2002; Dalle and Jullien, 2003; Lakhani and von Hippel, 2003).

The birth of OSS is linked to the emergence of strategies of appropriation and exclusion within the software industry in the 1980s[28]. Worried about the consequences of the surge of

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[27] The notion of source code is often misunderstood mainly because it is most of the time explained in an ambiguous manner. To avoid such misunderstanding let us quote here the explanation given by Harhoff *et al.*(2003): "Source code is a sequence of instructions to be executed by a computer to accomplish a program's purpose. Programmers write computer software in the form of source code, and also document that source code with brief explanations of the purpose and design of each section of their program. To convert a program into a form that can actually operate a computer, source code is translated into machine code using a software tool called a compiler. The compiling process removes program documentation and creates a binary version of the program – a sequence of computer instructions consisting only of strings of ones and zeros. Binary code is very difficult for programmers to read and interpret. Therefore, programmers or firms that wish to prevent others from understanding and modifying their code will release only binary versions of the software. In contrast, programmers or firms that wish to enable others to understand and update and modify their software will provide them with its source code." (Harhoff *et al.*, 2003, p. 1758).

[28] The 1980s saw the emergence of the first patents on software. Initially software were considered as depending exclusively on the copyright legislation due to their algorithmic content. But following the Diamond vs. Diehr case (1981), patents began to be granted to software designers who could also continue to be granted copyrights (since patents and copyrights protect two different parts of a software). A software can hence be protected by a double layer of protection: A patent for its design and a copyright for the source code and this, without any requirement to disclose the source code.

appropriation in an industry that had proved in the past that it did not need patents or copyrights to ensure a sharp and steady growth, Richard Stallman founded in 1984 the Free Software Foundation (FSF). The purpose of this foundation was to promote the elaboration and the development of free software, an important feature of which is the release of the source code[29]. In order to ensure the freedom of software the FSF developed an exploitation license: The General Public License (GPL) also known as copyleft (by opposition to copyright). The GPL ensures that everybody can use, modify, copy and even distribute a software "protected" by the license at the unique condition that these changes are kept under the copyleft regime, which means that improvements must remain accessible and free for modifications by everybody (i.e. the source code of the improvements must also be released). Hence, access to the source code and freedom become legally inseparable.

This way of developing software, by systematically releasing the source code, has proved to be very efficient. Sendmail, which underlies the routing of e-mails over the Internet, and Apache, which is a free server program that runs more than half of web servers, are prominent examples of successful free software. But doubtless the most famous success of free software is the development of Linux operating system, which was completed in 1991. Linux is the direct descendant of Unix (created by AT&T in 1984). It is often associated with the name of Linus Thorvalds but it represents the work of hundreds of persons before him. Nowadays it is viewed as a major threat for Microsoft in the domain of exploitation systems for networks.

With the development of the Internet the progression of OSS is probably not finished yet. In 1998 an internal Microsoft note stressed that the free software ability to gather the collective knowledge through the Internet was simply fascinating. From our point of view, the OSS movement stresses the increasing importance of the Internet in order to openly disclose information. For instance, more and more firms tend to disclose valuable information on their web sites.

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[29] But this is not the only feature: An OSS may not necessarily be free while free software, by definition, include the disclosure of the source code.

The emergence of OSS has triggered an impressive quantity of economic works that focus on two main points: How does coordination occur between programmers and what are the motivations that encourage programmers to disclose for free thousands and thousands of lines of program? (whereas without the revelation of the source code programs would be very difficult to understand and to copy) Specifically, this second point deserves our attention since it will be the topic of the other half of this chapter.

Empirical and theoretical studies have identified many reasons that encourage programmers to participate in OSS projects. These motivations can be split between those that are intrinsic (the activity is valued for its own sake, it is done for the satisfaction inherent to it) and those that are extrinsic (the activity is carried out for a reward independent of this activity). Intrinsic motivations to participate in OSS projects are the sense of creativity, the willingness to confront one's own capacities by resolving complex problems and the feeling of being a member of a community. Conversely, extrinsic motivations in the case of OSS projects are career concerns (tracks of participation in the development of OSS are easy to establish and firms can easily find qualified programmers by exploring code contributions), the willingness to improve programming skills (by receiving feedbacks from other participants and by being notified of one's own mistakes) or the personal need for a given software[30]. We see therefore that participation in OSS projects may be driven by a complex mix of incentives.

With the purpose to assess the importance of each of these motivations Lakhani and Wolf (2003) gathered data about 684 programmers working on 287 distinct OSS projects. Their most prominent finding is that intrinsic motivations seem to dominate. Programmers report that they participate essentially in order to feel creative and to stimulate their intellect by writing codes. Participation because "project code is intellectually stimulating to write" was reported in 44.9% of the cases. The fact that OSS are useful to improve programming skills is quoted too, but on a more modest scale, suggesting that extrinsic motivations cannot be neglected to explain participation in OSS

[30] A programmer who has developed a specific program that he really needs had better disclose this program to the whole community of programmers in order to test and to debug it. Indeed, it may take him a tremendous amount of time to find all the bugs by himself, whereas by disclosing it widely he multiplies the chances to achieve quickly the same result (as it is often argued by defenders of free software: Given enough eyes (programmers), each problem will be quickly isolated and a solution properly found).

projects. An important finding of this study, on which we will come back later, is that more than one third (38%) of the respondents indicate that their supervisor is aware of their participation in OSS project during work hours and consent to this participation. This finding is of the greatest importance since it tends to suggest that not only programmers but firms as well may profit from openly disclosing knowledge.

To summarize, it has been shown here, and we hope convincingly, that behaviours of open knowledge disclosure do occur frequently through, for instance, scientific publications, patents, the Internet or conferences. However, to moderate slightly our conclusion it must also be acknowledged that most of the time firms are very careful in their activity of knowledge disclosure. Needless to emphasise that secrecy remains an essential strategy for firms. Almost all empirical studies that stressed behaviours of open knowledge disclosure also acknowledged that whenever knowledge is disclosed firms monitor strictly the timing of their disclosure. Lim (2000, p. 41), for instance, in his study on copper interconnect technology, noticed that IBM researchers were allowed: “to publish general ideas but kept valuable process-specific information and recipes proprietary”. As such, disclosure of general or very basic knowledge may not help competitors (at least in the short run) because such knowledge needs time in order to be operational and in order to result in productivity increases. Furthermore, Lim insists on the fact that researchers were allowed to publish only once IBM had established itself as the leader.

However, it remains that behaviours of open knowledge disclosure do occur and therefore it may be important to explain why firms adopt such behaviours. In the next part we provide an overview of the motivations that may induce profit-seeking firms to openly disclose knowledge. For instance, it was underlined above that participants in OSS projects may receive substantial indirect rewards for their participation. Our goal is to extend this conclusion to the whole set of open knowledge disclosure behaviours.

II.2. Why do firms openly disclose knowledge?

"It thus appears that, contrary to common beliefs, firms do not keep tight controls on all information about their new technology and in some cases they seem actively to divulge information. How come?"

(Nelson, 1992, p. 65)

We emphasised earlier that to openly disclose knowledge may involve important costs, the most dissuasive being probably the one that comes from providing useful information to potential rivals, which may sharply affect the firm's profitability through the effect of competition. Furthermore, open knowledge disclosure, as we defined it in introduction, means to offer valuable knowledge to other firms without being ensured of any direct remuneration. Therefore, at first sight it is unclear how these behaviours can be profitable from an economic point of view.

These two features, high costs and uncertain benefits, explain why industrial economists have for long considered such behaviours as a puzzle. According to mainstream economic theory, instead of communicating important knowledge to their rivals, which apparently can only be harmful to them, firms should rather try to protect their knowledge through tight secrecy or patents. However, we have seen that innovators are far from obeying to this law and often decide to disclose their discoveries widely. It is the purpose of this section to highlight the indirect mechanisms at work when knowledge is openly disclosed and to show that open knowledge disclosure may sometimes be very profitable. Most of the time there is no need to refer to altruism, bounded rationality or to intrinsic motivations to explain those behaviours.

II.2.1. Preliminary reasons

First of all, in many situations firms decide to widely disclose some of their knowledge because somehow the revealed knowledge would have been too hard and too costly to keep secret indefinitely[31]. Strict secrecy is hard to preserve in the long run due to researcher mobility, reverse engineering, informal contacts between employees, etc. For instance, knowledge embodied in the artefact produced by the firm and sold on the market is impossible to keep secret for long. The extent to which this knowledge profits other firms depends exclusively on the ability of those firms to reverse engineer the innovation and to learn from this experiment. Similarly, knowledge regarding innovation processes may also spill over because the development of an innovation often necessitates competences that the firm does not possess and as such it usually involves external contractors, consulting engineers among others, who learn from their work and swarm this knowledge in other firms, even unconsciously.

In order to stop or to reduce these knowledge spillovers firms must be willing to engage in important costs but even then it is impossible to pretend to control all the knowledge leakages. It follows that in many cases for which a firm identifies some knowledge that cannot be kept secret for long, she may as well decide to reveal this knowledge voluntarily[32]. This point was already raised by Allen (1983) who found it to be one of the most important causes of free knowledge disclosure. He argued, among others, that in many cases: "so many people would know the relevant information that it would have been costly to keep it secret […] since secrecy would be so hard to maintain, the release of information is not surprising" (Allen, 1983, p. 17).

A second situation for which a firm may decide to reveal some of her knowledge widely is when this disclosure does not harm her. For instance, Nelson (1992) explains that: "letting generic

[31] An economic world without knowledge spillovers is in itself a contradiction, since in such a world there could not exist any economic activity (Callon, 1999). For instance, the only way to prevent firms from doing reverse engineering is to stop the industrial production and all commercial activity. It is because knowledge spills over from a given agent and because this leakage generates profits through industrial and commercial activity, that firms cannot avoid knowledge spillovers. The latter are necessary to firms' survival.

[32] It should be noted that in the definition of open knowledge disclosure that was given above we stressed that the disclosed knowledge must have possibly been kept secret. Therefore the motive underlined here does not concern pure behaviours of open knowledge disclosure. However, to make these two points of view compatible we can argue that this incentive applies to situations for which the disclosed knowledge is appropriable in the short run but not on longer term. Therefore, although they could keep it secret for a while, firms may prefer to openly reveal knowledge because they know that the secrecy cannot be preserved indefinitely.

knowledge go free does not handicap a firm from reaping handsomely from its product innovation if it has a significant head start on production and marketing of the product in question" (Nelson, 1992, p. 65). Indeed, when a firm has an important advantage in the use of a given technology she has often no preference between revealing it or not because imitation takes time and therefore, once the disclosed innovation is imitated, the innovator has often already innovated one step further along the technological frontier.

Similarly, a firm may be indifferent whether she keeps her knowledge secret or she discloses it widely when she occupies a steady monopoly position, due to patents that are not contestable for instance. This may explain, among others, why pharmaceutical firms do publish massively. It is indeed well-known that pharmaceutical patents are strong and hard to invent around. Therefore, when a firm has been granted such a patent she can publish without any fear of being imitated. In such situations in which the disclosure does not directly affect firms' profit it is not surprising that these firms decide to reveal some of their knowledge.

Obviously these cases, for which the disclosure is motivated either by the absence of disincentives or by the difficulties to do something else, are of little interest if we intend, as we do, to explore firms' strategic motivations to widely disclose their knowledge. Let us present now some of the real incentives that, taken separately or together, explain why firms often decide to openly disclose knowledge although this disclosed knowledge could have been kept secret and although the disclosure is, at first sight, harmful.

II.2.2. To trigger reciprocity: The use of infinitely repeated game theory

"A gift always looks for a counter gift"

Marcel Mauss (1923)

A first explanation of such behaviours can be found in the literature of infinitely repeated games (von Hippel, 1987). It is indeed well known in game theory that infinitely repeated games allow the settlement of behaviours that may not be stable if the game is not repeated.

To illustrate our point, let us assume a very simple situation in which two rival firms *A* and *B* have each the choice between keeping their knowledge secret (strategy noted *Se*) or revealing it to the other firm (the *OKD* strategy, like open knowledge disclosure). Let us assume further that the payments for each firm are as described in Table II.2. below:

Table II.2: Payments of firms A and B

		B	
		Se	*OKD*
A	*Se*	(a,a)	(c,d)
	OKD	(d,c)	(b,b)

With parameters a, b, c and d fixed such as $c>b>a>d$. Each firm prefers the situation in which they both disclose their knowledge than the one in which none of them discloses it. But each firm also prefers not to disclose knowing that the other firm discloses her knowledge. This is due to the rivalry effect, which implies that an increase in the knowledge of a rival has an automatic negative effect on the profits of the other firm.

In this simple game played only once there is one single Nash equilibrium (Se,Se), which is Pareto dominated by (OKD,OKD), the situation in which each firm reveals her knowledge. This situation is analogous to the famous prisoner's dilemma. Firms would prefer a situation in which they both disclose their knowledge but the difficulty to make a commitment that would ensure each firm that the other will indeed reveal implies that both firms decide to keep their knowledge secret.

Now, let us assume that the same game is repeated infinitely, both firms having to choose at each period between strategies *Se* and *OKD* and the total profit for each firm being the sum of the profits at each period weighted by a time discount factor. It is possible now that both firms may be induced to reveal their knowledge at each period of the game.

Indeed, let us consider the following strategy, which for simplicity's sake we call strategy *T* (see Table II.3. below): At the first period of the game both firms play *OKD*. Then, at each period *t*, firm i ($i=A,B$) plays *OKD* provided that none of the two firms has ever played *Se* in all the periods before period *t*. Furthermore, if either firm *A* or firm *B* plays *Se* at a moment *t* of the game then both firms never disclose again for the remaining of the game. This punishment is a threat that is meant to deter the other firm from betraying and playing *Se* at a given period of the game. This strategy is an example of a *trigger strategy*, so called because players cooperate until someone deviates, which triggers a switch to non-cooperation forever after.

Table II.3: Definition of strategy *T* (similar for firms *A* and *B*)
1) At the initial stage both firms play *OKD*. 2) If both firms *A* and *B* never played *Se* in all the periods *t-k* $(k=1,...,t-1)$ then firm $i=A,B$ plays *OKD* in period *t*. 3) If either firm *A* or firm *B* plays *Se* in period *t* then firm $i=A,B$ plays *Se* for all the periods $t+k$ $(k=1,...,n,(n\rightarrow\infty))$.

If both firms *A* and *B* adopt strategy *T* then it is clear that the two firms will choose to disclose their knowledge at each period of the game. Furthermore, it is well known in game theory that a situation in which both firms play strategy *T* is a subgame perfect Nash equilibrium, if only the preference for the present of both firms is not too high (Gibbons, 1992, for instance). Hence, in a game that is repeated infinitely, a strategy for which firms decide to always disclose their knowledge and for which there is a threat of punishment in case of deviation (which means in case one firm decides not to reveal her knowledge in a given period) can be an equilibrium.

To summarize, it may be rational for firms to always reveal their knowledge when an important number of periods is considered. This difference with a situation in which the game is not repeated is due to the fact that in our infinitely repeated game firms can make an efficient commitment that ensures the other firm that they will reveal their knowledge in the future. This commitment is enforced by the fear that the other firm will stop revealing in the remaining of the game if only the firm decides not to disclose her knowledge in one period. The repetition of events allows us therefore to interpret behaviours of open knowledge disclosure as a tacit agreement between firms, each of them agreeing to disclose as long as the other firm also does it. This expectation of reciprocity appears to be one of the major rules that guide open knowledge disclosure. This finding calls for two short remarks:

(i) Eaton and Eswaran (2001) explored in more depth the problem of knowledge disclosure in an infinitely repeated game, which enabled them to modify slightly the optimistic conclusions we reached here regarding the emergence of behaviours of open knowledge disclosure. They show that when there is indivisibility or stochasticity in the innovation process, a trigger strategy such as the one described above may not lead to subgame perfect Nash equilibrium, meaning that these two features, uncertainty and indivisibility, may undermine the emergence of disclosure behaviours. For instance, the presence of stochastic innovations may prevent firms from disclosing because when a firm gets a rare and valuable draw she anticipates that it may be impossible for other firms to reciprocate before a long time, i.e. she will rather choose to keep this rare innovation secret as long as possible.

(ii) An analogy can be drawn between the economic explanation of open knowledge disclosure given here, which involves a credible threat that allows the enforcement of cooperation, and a more anthropologist explanation, which rests on the theory of gift and counter-gift (Mauss, 1923). Following this latter view, firms expect reciprocity when they reveal and in one sense force this reciprocity not because they threaten other firms to stop revealing in the future but because social pressures commit other firms to reciprocate. The disclosing firm gains, in some sense, an “information credit” (Cassier and Foray, 1999a). The beneficiary is indebted to her and will have to reciprocate in the future because a gift automatically calls for a counter-gift. Hence, it is argued here that open

knowledge disclosure does not result from rational choices but rather rests on a more anthropologist argument, which assumes that firms establish arrangements that are similar to those that occurred between primitive people. However explanation may be true, the main point that has been enlightened here is that behaviours of open knowledge disclosure can be explained by the repetition of events and the expectation of reciprocity.

II.2.3. To trigger pecuniary spillovers

> "By freely revealing information regarding an innovation product or process, a user makes it possible for manufacturers to learn about that innovation, to improve upon it and also possibly to offer it at a lower price"
>
> (Harhoff, Henkel and von Hippel, 2003, p. 1756)

Harhoff, Henkel and von Hippel (2003) showed recently that behaviours of open knowledge disclosure can be encouraged by the existence of pecuniary positive spillovers. In other words, they argue that an innovator may be induced to disclose widely some of the knowledge underlying his innovation in order that his suppliers in upstream sectors use this knowledge to improve their products, to adapt their supply to the innovation or to provide services related to the innovation (such as repairing or maintenance). Then, to close the loop, if the suppliers make these improvements available to users (including the innovator) via commercial sales, the innovator may benefit from his knowledge disclosure under the form of pecuniary spillovers, meaning under the form of better quality and/or better adapted inputs at a lower price. In this case, open knowledge disclosure triggers important cost reduction or productivity increase due to new equipments. To illustrate their idea, Harhoff *et al.* give the following example (see also Lim, 2000):

> "IBM was first to develop a process to manufacture semiconductors that incorporated copper interconnections among circuits elements instead of the traditionally-used aluminium ones. This innovation provided a major improvement to semiconductor performance, and on the face of it, it would

have paid IBM to not reveal its process to others. After a delay IBM did, however freely reveal increasing amounts of proprietary process information to rival users and to equipment suppliers. IBM freely revealed information about its innovation because it needed equipment to implement the process on a production scale […] Thus, IBM was motivated to 'openly reveal' its innovation by the incentive of inducing manufacturer improvements."

(Harhoff *et al.*, 2003, p. 1757)

Harhoff *et al.* explored the conditions that determine the choice to openly disclose knowledge by considering a three agents model with one manufacturer firm and two user firms. User firms can choose among two strategies to exploit their innovation: *(i)* They can keep it secret, which gives the firm a competitive advantage over the other user firm, which in turn increases the profit of the firm who innovates and decreases, through a rivalry effect, the profit of the other user firm; *(ii)* They can openly reveal it in order that the manufacturer firm learns about it and improves the goods that are supplied to both user firms. The decision to reveal or not is modelled by using a sequential-move game (see Figure II.1. below):

(1) In the first stage innovative users decide to openly reveal or not their innovation

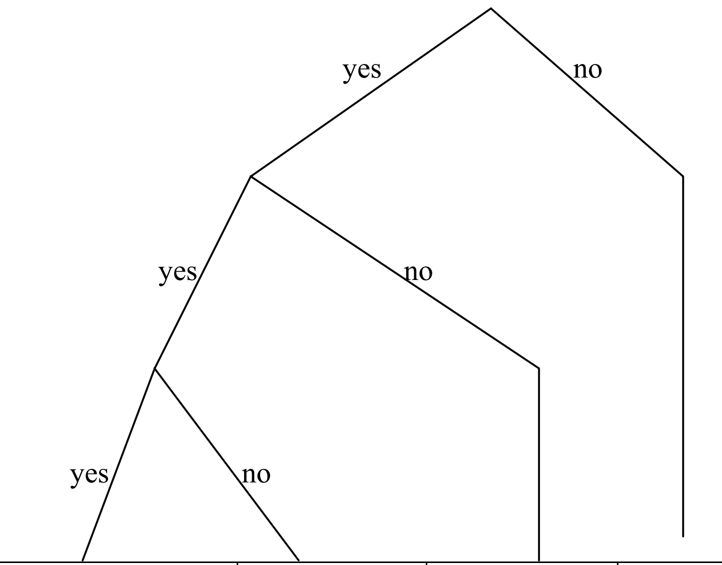
(2) Then the manufacturer firm decides whether or not to improve her products and to adapt them to the disclosed innovation.

(3) Finally, both user firms decide whether or not to adopt the improved inputs.

Conclusions of the model are unambiguous: As claimed by the authors, under realistic values for the parameters (the degree of competition, the degree of generality of the technology, the cost to adopt the improvements done by the manufacturer firm and the level of these improvements; see Appendix II.1) open knowledge disclosure in order to trigger pecuniary spillovers pays, meaning that there exists a subgame perfect Nash equilibrium for which innovative users choose to disclose their innovation, the manufacturer chooses to improve his products and both users choose to buy the improvements.

Figure II.1: Decision tree when only one user innovates (reproduced from Harhoff *et al.*, 2003, p. 1761)

Stage	Player	Decision
1	User 1	Reveal
2	Manufacturer	Improve
3	User 2	Adopt



Payoffs user 1	$(1+\mu)\delta-\alpha\gamma(1+\mu)\delta-c$	$(1+\mu)\delta-\alpha\gamma\delta-c$	$\delta-\alpha\gamma\delta$	δ
Payoffs user 2	$\gamma(1+\mu)\delta-\alpha(1+\mu)\delta-c$	$\gamma\delta-\alpha(1+\mu)\delta$	$\gamma\delta-\alpha\delta$	$-\alpha\delta$
Payoffs manufacturer	1	-1	0	0

Note: An explanation of the variables used by Harhoff *et al.* is provided in Appendix II.1

The decision to reveal or not depends on several parameters: The degree of competition between user firms and the cost to adopt the improved input play negatively while, conversely, the extent to which the manufacturer firm improves her product affects positively the decision to reveal, all other things being held constant. Also, the degree of generality of the new technology has an undetermined effect on the decision to reveal. On the one hand, it affects negatively the revealing decision because the more general (i.e. the less specific) the disclosed knowledge the more easily it profits competitors and hence the more expensive the disclosure. But on the other hand, it also affects positively the revealing decision because the more general the knowledge, the more the other firm will be willing to adopt the manufacturer's improvements and hence the higher the probability that the manufacturer decides to implement these improvements.

II.2.4. To enhance the production in downstream sectors

It was argued above that it may be rational for a firm to disclose knowledge in order that suppliers in upstream sectors use it, the firm who disclosed being then rewarded under the form of pecuniary knowledge spillovers. Here, the focus is also on vertical relations between users and suppliers, the only difference being that it is now suppliers who disclose knowledge and users in downstream sectors who are targeted by this disclosure.

Indeed, Harhoff (1996) underlined that firms in upstream sectors may be induced to openly disclose valuable information in order to expand the production in downstream sectors (to increase the size of the downstream market), thus enhancing the demand of production factors that is addressed to them. To illustrate this idea, Harhoff considers a model with two vertically related industries. A monopolist supplier faces an oligopolistic buyer industry in which firms use a factor of production delivered by the monopolist supplier. In this framework Harhoff (p. 907) shows that: "the monopolist supplier can contribute to downstream production improvements by creating knowledge spillovers which downstream firms use as a substitute for their own R&D effort".

Suppliers in upstream sectors may find it profitable to disclose knowledge to downstream sectors for two reasons: *(i)* This disclosure may facilitate entry in downstream sectors by diminishing sunk costs and by lowering entry barriers, which leads to enhancing the number of firms in this sector and hence to increasing the demand addressed to supplier firms; *(ii)* Even when the structure of the downstream sector is not endogenous, meaning that entry is not allowed, the monopolist supplier may have incentives to disclose knowledge to downstream sectors in order to improve the quality of the research in these sectors, which in turn decreases production costs and increases the global production. Overall, the knowledge disclosure may hence enhance the demand for intermediate goods addressed to the firm who disclosed.

Of course the extent to which open knowledge disclosure may benefit firms in upstream sectors depends not only on the global increase of the demand addressed to them but also on the degree of competition between firms in the upstream sector. However, Harhoff considers a single monopolist supplier and therefore does not include this second factor in his model.

An example of such behaviours of knowledge disclosure from upstream to downstream sectors was provided by VanderWerf (1992), who studied the development of the two following technologies: The thermoplastics forming and moulding technical process and the application of industrial gases. The author points out that in one third of the cases it is the suppliers of materials related to these technologies who were identified as the innovators. However, according to VanderWerf, suppliers did not charge licensing fees for their innovation but rather disclosed them freely in order to enable users to incorporate them and hence in order to enhance the demand for their commodity.

II.2.5. To trigger feedbacks from users in downstream sectors

Furthermore, firms in upstream sectors may also decide to openly reveal some part of their knowledge in order to get important comments from users in downstream sectors. Indeed, the role of users within the knowledge creation process is more and more often acknowledged. Users have an irreplaceable situation to produce new knowledge, since they are offered the opportunity to do so simply through their main activity, which is to use things (they learn by using). Hence, ensuring knowledge interactions between users and suppliers is an important feature of a new style of user-guided, if not of user-driven R&D (David and Foray, 1994, p. 39). It follows that producers can gain a lot simply by sharing some knowledge with users, the latter having probably many things to teach them. In other words, firms may sometimes decide to openly reveal some part of their knowledge in order to get important comments from users, which in turn may allow disclosing firms to improve their own performances.

Examples of such behaviours are to be found in many sectors. Users play a key role in the innovation process in fields as diverse as medical surgery instruments, sports equipment, library information systems, pipe hanger hardware and printed circuit CAD software (Henkel and von Hippel, 2003, table 1, p. 4). For instance, Morrison, Roberts and von Hippel (2000) studied the case of OPAC, a computerised information search system used by libraries. They point out that 26% of users modified their OPAC version in some way and furthermore, OPAC manufacturers and suppliers judged a significant fraction of this knowledge generated by users to be of potential commercial value for them.

This example illustrates therefore the potential benefits that manufacturers may experience by merely improving their relations with users.

The software industry and the game industry are probably the most prominent sectors in which consumers have proved to play an important role in the process of knowledge creation. For instance, several months before the launch of its operating system Mac OS X, Macintosh diffused experimental versions on the Internet. Comments from users were encouraged by a promise of reduction on the final version. This example stresses the role of the Internet to facilitate the exchange between users and producers.

Similarly, Jeppesen (2001) considered a case study in the computer game industry and showed how the establishment of a close relationship with her consumers enabled the studied firm to improve her product design. Jeppesen also stressed the importance of the Internet in this process. Specifically, he explains that the results that firms can obtain from consumers' knowledge are favoured by two things: Firms' ability to exploit new opportunities of ICT (information and communication technology) to establish interfaces connecting them with consumers and, second, firms' ability to initiate a mode of organization by which the consumers are guided and motivated to reveal merely relevant knowledge. To conclude, Jeppesen claims that a new approach to innovation, relying on consumers' knowledge, is emerging and will hence favour those firms who are best able to exploit this new source of knowledge. Within this perspective, it is likely that to release knowledge may be a necessary step to exploit the link with consumers which, according to Jeppesen, may be so fruitful for firms.

II.2.6. To trigger network effects

Behaviours of open knowledge disclosure may also be explained by the willingness to trigger network effects either by increasing the use of a given technology (if the value of this technology increases with the number of firms using it) or by allowing compatibility for a given product (if the value of this product increases with the number of consumers).

(i) First, a firm may disclose her knowledge underlying a given technology widely in order to decrease the cost of adoption of this technology for other firms (including rival firms) and hence in order to facilitate the implementation of this technology as a standard in the industry. This being the case, for instance, because there are network effects that make that the value of this technology depends positively on how many agents are using it.

To increase the number of users of a technology may increase the value of this technology through several mechanisms: The firm who discloses may then be able to benefit from technological improvements realised by other firms (which is not possible if technologies are not compatible), she may benefit from costs reduction due to economies of scale realised by suppliers and third, the risk of moral hazard regarding inputs' quality may also be reduced since, if the technology is used by a high number of firms many suppliers may find it profitable to offer inputs.

For instance, cost reductions that stem from the use of a technology that is commonly used take the form of an experienced labour force, of components and maintenance services that can be obtained more easily and at a lower price, etc. Conversely, for a firm who uses a rare or even unique technology it may be more difficult and expensive to obtain services and inputs from suppliers because the size of the market is not sufficient to ensure their profitability. An illustration of behaviours of open knowledge disclosure aiming at reducing production costs is given by Lim (2000), who teaches us that:

> "Several IBM employees realized in the mid 1990s that the company would benefit from lower equipment costs if the rest of the industry also adopted copper technology […] In line with this, IBM relied on an external supplier for the equipment (Novellus) and later relaxed its secrecy to a degree. Although it continues to guard sensitive process information, IBM has also begun to share its copper technology with other companies, including Siemens (Infineon), Sanyo, and a start-up foundry in Taiwan"

(Lim, 2000, p. 41).

Furthermore, a firm may have an interest to see her own technology used widely by competitors because she has important advantages over rival firms in the use of this technology. Until now we explained how a firm may benefit from the implementation of a standard technology in the industry. But now we insist on the fact that it may be far more advantageous for a given firm to implement her own technology as the standard rather than another unknown technology. Indeed, firms have often important advantages over their rival firms in the use of their own technology. For instance, they may have a better or cheaper access to complementary services or/and to inputs that are related to the use of the technology. The revealed technology may also be to some degree specific to the assets owned by the disclosing firm, which gives her an important head start (this point was already stressed by Hirschleifer, 1971). Also, the willingness for a firm to see her own technology adopted as a standard may be justified by the opportunities to make profits out of the sale of products complementary to this technology.

However, a key point with network effects in the adoption of a new technology is the role of the pioneers, the first adopters. Arthur (1989) showed that in presence of increasing returns in the adoption process, it may not be the best technology that is widely adopted and that dominates the others. But rather, it is the technology that was first made available. In other words, competition may often drive the industry into standardisation on the wrong system. The reason being that once a technology has been adopted by pioneers, it gains a first mover advantage that is most of the time hard to catch up for a technology that comes later, even if this technology is better. This point was illustrated, among others, by David (1985) in his study of the history of Qwerty. David concludes that such a lock-in on under optimal technology may occur frequently in the presence of strong technical interrelatedness, scale economies and irreversibility due to learning and habituation[33].

Now it is easy to understand why a firm who develops a new technology may wish to widely disclose the knowledge underlying this technology. This may be so because being first to reveal increases a firm's chances of having her own technology adopted as the standard of the industry.

[33] However, Dalle (1995) showed that the adoption process in the presence of increasing returns in use does not always lead to the elimination of all the technologies but the winner's. Several technologies can cohabit in niches. This result is illustrated by the survival of the Betamax technology (the rival of VHS) in Colombia and for professional users.

Conversely, not revealing a given technology may lead to the emergence of another technology that imposes itself as a standard and for which the other firms, who did not want to release their technology, may have some difficulties to adapt.

Of course, such a strategy of knowledge disclosure aiming at benefiting from network effects in the use of a new technology may be profitable only provided that the gains stemming from the increased use of the new technology are more important than the loss due to sharper competition. Using the words of Boivin (2000), the market size effect must dominate the market share effect.

(ii) Firms may also be induced to openly disclose some knowledge in order to facilitate the emergence of compatibility between their own product and competitors' products, since there may exist some pure consumption network effects that make the product more profitable if more consumers use it (Farrell and Saloner, 1985 and 1986; Katz and Shapiro, 1985).

Consumption network effects occur when the value of a given good increases with the number of consumers of this good. The classical example of a good that is subject to such consumption network effects is the telephone. The more people are connected the more it is interesting for other people to be connected. Conversely, when few people are connected it is not worthwhile for other consumers to be connected. Such network effects do not emerge only when dealing with pure network goods such as the telephone or the Internet. They can also affect classical goods, which are sometimes more highly valued by consumers when they are widely consumed. Katz and Shapiro (1985) give several reasons that may explain such consumption network effects (see also Boivin, 2000). This may occur because an important consumption of a given good induces more and better complementary products, a better quality of services such as repairing and maintenance, or provides a signal of quality to consumers (psychological, band-wagon effects).

Therefore, due to consumption network effects, an innovator may find it profitable to disclose the knowledge underlying a product innovation in order to make it easier for other firms to render their own product compatible with the product of the disclosing firm. Here, the disclosure makes it possible to settle compatibility between different commercial products, which triggers an increase of the value of these products for the consumers, which in turn may affect positively the demand addressed to the firm who disclosed. Again, the extent to which such a strategy is profitable depends on the extent of the market size effect as compared with the market share effect.

To conclude with network effects, it is to be noted that the willingness to see a given technology or a given product adopted as a standard may also be justified by the opportunities to make profits with the sale of complement products. Indeed, when a firm also sells products that are complements to a given technology (or a given product) she may be willing to disclose knowledge related to this technology (or product) in order to increase the use of this technology (or product) and hence in order to increase profits coming from these complement sales. This may be so even if the disclosure decreases the profits earned from the direct exploitation of the revealed technology (or product).

This behaviour has been observed, among others, in the open source software industry in which firms usually do not charge for the installation of the exploitation system or other open source programs. But, as Lerner and Tirole (2001, p. 820) state it: "The corporate response to the open source movement is equally interesting; new companies such as Red Hat and VA Linux have undergone well-publicized initial public offerings. Such companies do not directly make money from the open source programs (which, after all, are freely available), but rather charge for complementary services (documentation, installation software, utilities, etc.)". Similarly, Lim (200, p. 41) explains that Intel shares its research results willingly with other firms: "in the hope that those firms develop complementary products, thereby increasing the demand for Intel's product".

II.2.7. To improve higher order knowledge

Another incentive to disclose knowledge deals with what is called higher order knowledge, which is knowledge about what others know and about what others know that we know, etc. (Koessler, 2000). This kind of knowledge plays a crucial role in interactive situations and often influences the decisions made by players. Clearly, if a firm believes that other firms know or do not know given information then her strategy may not be the same.

In this line of reasoning, a given firm may be tempted to disclose some knowledge widely in order to improve her higher order knowledge, meaning in order to be certain that others know. Merely by disclosing knowledge the firm improves her own knowledge since the disclosure enables this firm to know that others know. In other words, the act of teaching is inseparable from the one of learning because at the very least teaching permits to improve higher order knowledge.

We identify at least two situations for which higher order knowledge may matter for a given firm and hence for which this firm may decide to disclose some of her knowledge. First, she may do so in order to facilitate communication with other entities. Indeed, higher order knowledge is very important in the communication process. In order to implement a communication between firms, it is absolutely necessary that these firms share a certain common base of knowledge. Hence firms may have to reveal some of the knowledge they hold prior to be able to communicate.

Also, a firm may decide to reveal knowledge in order to decrease the uncertainty about what others know. As it was mentioned above, firms' behaviours depend on their knowledge about others' knowledge. And sometimes firms may prefer to be certain that other firms know rather than to be uncertain whether or not they know (even if under complete information the firm is better than if other firms do not know). In this case, open knowledge disclosure may only be aimed at reducing the uncertainty about what others know.

II.2.8. To trigger reputation effects

Behaviours of open knowledge disclosure are also often encouraged by reputation concerns. Dasgupta and David (1994) already pointed out the important role of reputation to provide incentives in the academic community. But most of the time reputation plays also an important role in the industrial community.

For instance, reputation is an important feature to provide motivations to researchers who work for private firms. Indeed, researchers are human beings and as such they value not only their salary but also their reputation as scientists. Most of them appreciate being praised for their research and want to be admired. Moreover, researchers own reputations are an important asset for their career.

It may be crucial in order to find better jobs in the future[34]. Hence, either for career concern or for ego gratification, researchers are greatly concerned with their own reputations, which may thus encourage them to publish the outcome of their research widely. This tendency is still reinforced by the fact that most researchers who work for private firms come from universities and have been nurtured under the 'publish or perish' regime. Once in the industrial world these researchers tend to keep the habits they developed in the academic sector. They continue to attend conferences, to exchange information with ex-colleagues, etc.

Firms may try to slow down, to control this natural tendency of their researchers toward publication, but they cannot prevent it completely. Salary increase may convince researchers to keep their work secret only until a certain point. A policy of total secrecy can never be completely adopted by firms, unless they take the risk to see most of their best researchers quit and be hired by rival firms, who would agree to let them publish and participate in conferences. This point is emphasized by Hicks (1995), among others, who teaches us that, when questioned, firms usually confess that: "Apparently good salaries, excellent equipment and freedom from teaching administrative duties and all the hassle of university research are not enough to entice top scientists into corporate work" (Hicks, 1995, p. 413). Lim (200, p. 41) also notices that: "If IBM had not allowed anything to be published at all, it would have had difficulty getting talented individuals to work on the project".

This high value that researchers usually grant to their own reputations is often perceived as the most powerful argument to explain behaviours of open knowledge disclosure. In this case, open knowledge disclosure is initiated entirely by individual research staff independently of firms' top management, who is forced to accept these behaviours to keep their best researchers in the firm. But it is nevertheless indisputable that open knowledge disclosure also directly profits to firms through several different mechanisms, as it has been shown in this chapter. In line with this feeling, Allen (1983, p. 17), after having acknowledged that the main motivation to open knowledge disclosure

[34] This reputation effect can help to explain, among others, behaviours of open knowledge disclosure in the software industry, in which it is particularly important for programmers who participate in open source software projects to ensure their own reputation in order to improve their position on the job market. Lhakani and Wolf (2003) explain, for instance, that archiving of OSS makes it possible to track and to assess in details the participation of each individual to the elaboration of a given program. Hence, firms looking for particular skills can easily recruit merely by observing the contributions to OSS.

behaviours is the willingness of researchers to advance their careers and therefore that the disclosure may occur independently of the firm, expresses nevertheless his conviction that firms, all things being accounted for, do benefit from this disclosure (this point is also reinforced by the fact that in many cases, top managers are aware of knowledge disclosure behaviours and approve them (Lakhani and Wolf, 2003)).

To put it plainly, reputation is also an important source of profits for firms. For instance, it was argued above that open knowledge disclosure provides researchers with a higher motivation, that it stimulates their creativity. This clearly directly profits their employer too. Moreover, to allow researchers to publish is also a way to measure their performances (which is important for firms since the output of a research activity is something quite intangible), to monitor and to reward them relatively cheaply. Barros and Stoneman (2002, p. 23) noticed, for instance, that there is a broad range of things people can be measured on and that publication in academic journals may be a manner to assess the performances of the R&D. As such, it may often pay for a firm to implement a system of internal promotion of researchers based on their publishing activities. In line with this argument, Henderson and Cockburn (1994) showed that firms who promote researchers on the basis of their standing in the scientific community are significantly more productive than their rivals.

Furthermore, open knowledge disclosure may also be explained by the firms' willingness to enhance their own reputation. Indeed, if a strategy of secrecy may well be profitable in the short run, to reveal her knowledge widely may enable a firm to be endowed with a strong reputation as innovator, to raise her image or goodwill, which in turn may be a source of substantial benefits.

(i) A reputation as innovator may allow a firm to increase her sales because consumers usually highly value such signals. This may explain for instance why many firms refer explicitly to their innovativeness in their advertising. Consumers are often sensitive to such signals because they interpret the fact that the firm is at the forefront of the technology as an indicator of quality. Therefore open knowledge revealing may pay if only the increase of the demand that is triggered by this disclosure surpasses the negative effect of providing useful information to competitors.

(ii) The reputation that may be acquired by openly disclosing knowledge may also help the firm to protect niches by deterring potential competitors to enter the sector. The disclosure may hence warrant the firm a favourable competitive position. However, such a strategy is always risky since if it fails, it may have the opposite effect of what was initially desired by accelerating the entry of other firms because it provides them with useful knowledge. Such dissuasive effects may also occur in patent races.

(iii) Being credited of a reputation as innovator may also be profitable to a firm because it may improve her position on the credit market. It may facilitate access to credit and financing from banks, venture capitalists and stock markets. Indeed, innovativeness is often associated to long run profitability. As such, to disclose some knowledge widely may be a way to send a signal of profitability or at least of dynamism to potential financers, which in turn will increase the chance of being granted funding. The reason being that financers, when they decide the allocation of their funds, do not know perfectly the future profitability of each possible project to be supported. Therefore, the fact that one of the candidates employs researchers who publish in scientific reviews, who are famous scientists or who have been granted several patents, is often a positive indicator and may help this candidate to be granted the financing.

Specifically, patents are highly valued by financiers since they reflect both the competence of the holder and the fact that this holder benefits from a monopoly position, which is a tangible asset. It is often argued that without first being granted a patent, small start-up companies cannot obtain money from venture capitalists. In this case patents are a prerequisite to financing. This statement is confirmed by Hall and Ziedonis (2001, p. 104) who studied the semiconductor industry and conclude that: “Our interviews suggest that stronger patent rights are especially critical to these firms in attracting venture capital funds”. Furthermore, econometric studies have for long stressed a tight correlation between the numbers of patents held by a given firm and its financial valuation by the stock market (Griliches, 1984). Patents, since they are often a sign of long run benefits for a firm, are quickly valued by the market, far before they result in tangible benefits. This rapid impact of patents on market value may suggest that patents are an important device to attract investors.

A similar mechanism is at work in situations for which firms aim at attracting public grants, subsidies or contracts. Indeed, the central authority that is in charge of the allocation of public contract is often not able to decide exactly who is the most competent firm, the one who may best use the public purse. As such, firms who openly reveal their knowledge may be well positioned in order to be attributed such public contracts.

(iv) Similarly, open knowledge disclosure may help a firm to hire the brightest students who have just finished university training. Indeed, young researchers value the intellectual challenge highly. They want to work within a stimulating environment. But these young graduate students do not know which firm offers the best challenge and the best environment. Firms may therefore be induced to disclose knowledge, to allow their researchers to publish and to attend conferences in order to signal their competences to young graduate students and to attract them more easily. Publications may hence act as a powerful recruiting tool. In addition, most of the time, to allow researchers to publish is the only way to keep them in the company.

This situation is the exact opposite of the one studied by Spence (1973) in his seminal work on adverse selection. Spence argued that firms, when they consider hiring people, face adverse selection problems because they cannot differentiate between competent employees and others. Hence he showed that competent workers who were looking for jobs may be induced to do graduate studies mainly in order to prove to potential employers that they are competent. According to this vision, graduate studies would be mainly a signal of competence sent to employers in order to help them to break adverse selection problems. Here we point out that bright graduate students, who have to choose an employer, face also adverse selection problems since they do not know the competences of their future firm. Therefore firms too may be induced to implement strategies, such as open knowledge disclosure, in order to solve these problems of adverse selection and to hire the brightest students.

(v) Another motive that may induce firms to openly disclose knowledge and that we decided, by default, to store with the reputation effects, is firms' willingness to misguide competitors. Within a competitive environment in which firms observe each others, use technological intelligence in order to

forecast what competitors are doing and to anticipate their next innovation, firms may sometimes choose to openly disclose knowledge in order to jam the signal and therefore to misguide their competitors. For instance, it is well-known in intellectual property management that many firms often decide to over-patent in order to bury their patents that really matter in the bulk of other patents of lesser interest for competitors.

(vi) Finally, open knowledge disclosure may be a manner to signal firms' own competences to potential partners in order to begin a profitable cooperation with these partners. Indeed, it was argued in the previous chapter that knowledge production is a collective process that requires the cooperation of numerous firms. And clearly, a firm is more interested to establish a relationship with another firm who is at the forefront of technological development. But an important question is how can firms select their partners? How can firms infer the competences of their potential partners? How can they be sure to work with competent suppliers? These questions are especially relevant for short run, not repeated relationships. We will see in the next chapter that behaviours of open knowledge disclosure can help to some extent to solve these problems of incomplete information that impede the collective process of innovation. Open knowledge disclosure, by signalling the competences of the disclosing firm to the academic and industrial communities, can help firms to find partners with whom to cooperate in R&D more easily.

This focus on the indirect benefits arising from the reputation that stem from open knowledge disclosure helps to understand why firms sometimes pay huge amounts of money to hire famous academic researchers, whose function in the firm is often not to work to the resolution of technical problems. Rather, these star scientists ensure the reputation of the firm. As such, they facilitate cooperation with academic partners, with financial markets, with other firms, etc. In other words, they provide access to their networks, which in turn opens the door to valuable stock of external knowledge.

II.2.9. The case of patent races

To conclude this part about the motivations that firms may find to openly disclose knowledge, let us introduce the case of patent races, which is interesting since it cumulates several of the incentives that have been reviewed so far.

For instance, during a patent race a firm may choose to openly disclose knowledge to misguide her rivals. Or a firm who believes that she is far ahead of other firms may find it profitable to disclose knowledge in order to dissuade her rivals from continuing the race. Conversely, patent races can also induce laggards to openly disclose knowledge with the purpose to prevent the firm who leads the race from being granted a patent. This may happen if a firm realises that she will not be able to be granted a patent but that she knows enough about the technology in order to publish and thus to prevent firms who may be ahead in the race from being granted a patent. Here open knowledge disclosure may be viewed as an attempt to cut the grass under the feet of the leader. By publishing part of an invention a firm can keep its freedom to commercialise an innovation while avoiding the risk of another firm patenting it. As Cohen *et al.* (2000) emphasised, failure to disclose knowledge may increase the risk of being excluded from the industry by a rival patent.

Moreover, De Fraja (1993) suggests that patent races may provide incentives to firms to disclose some part of their knowledge to the general public because, given the uncertainty and the costs of the race, they may prefer to be second quickly and with certainty rather than to be eventually first in the future. Within a patent race framework it is indeed possible that a rival's success increases a firm's own expected profit by decreasing both the expected benefits and costs of the race (if only the expected costs decrease more than the expected benefits).

Mainstream economic literature generally regards patent races as competitions where the "winner takes all" and hence where all the investments are sunk costs in case the firm is not first. But this view is usually not relevant since, even if a laggard is not granted a patent, participation in the patent race may nevertheless yields substantial benefits. For instance, imitation of the patented innovation is always possible (patent laws can be infringed), a patent does not last forever and, anyway, the knowledge that has been acquired during the race is never lost and can be used to develop other innovations.

Within such patent races in which ‘the winner does not take all’, De Fraja shows that it exists a non-cooperative Nash equilibrium for which one or more firms may decide to disclose some knowledge in order to reduce both the overall expected costs and benefits of the race. De Fraja compares this situation with the choice of a lottery ticket. He argues that sometimes one may prefer a ticket with a smaller prize but a higher probability of success.

Conclusion of the chapter

Open knowledge disclosure has been defined as a situation in which a firm decides voluntarily to disclose some of her knowledge, without any explicit contractual agreements (meaning without any direct remuneration) and without being able to control the population of recipients of this disclosed knowledge.

This chapter aimed first at showing with the help of empirical illustrations that, conversely to conventional wisdom, firms in diverse industries do often openly disclose part of their knowledge. This disclosure occurs through conferences, publications in newspapers and books, patents and through the Internet. Our purpose was to provide evidence that open knowledge disclosure is a frequent phenomenon in some industries and as such that it is necessary to improve our understanding of these behaviours.

Second, this chapter aimed at presenting some of the reasons that encourage profit-seeking firms to adopt behaviours of open knowledge disclosure. We thus reviewed many indirect mechanisms that can make open knowledge disclosure very profitable for a firm, although there is no direct remuneration. For instance, open knowledge disclosure may trigger reciprocity, pecuniary spillovers, feedbacks from consumers, network effects or may enhance the reputation of the firm who disclosed. Among others, our goal was to prove that there is no need to refer to concepts such as irrationality, altruism or intrinsic motivations to explain behaviours of open knowledge disclosure.

The next chapter aims at deepening one of the incentives put forward here, namely the decision to openly disclose knowledge in order to increase the firm own reputation and to solve problems of incomplete information that may arise within the innovation process.

CHAPTER III:

OPEN KNOWLEDGE DISCLOSURE, INCOMPLETE INFORMATION AND THE FORMATION OF R&D COLLABORATIONS

Behaviours of open knowledge disclosure are frequent in many industries and can sometimes be highly profitable. They are not rare behaviours resulting mainly from a lack of rationality or a kind of altruism from the sender. In the previous chapter we discussed several reasons that may encourage firms to openly disclose knowledge and now we would like to develop one of them in more depth, namely open knowledge disclosure as a signal of competences aiming at facilitating informal or formal R&D cooperation with other firms. In other words, in this chapter we attempt to explain why firms openly disclose knowledge by combining two different domains of the economic literature: Economics of innovation and economics of information or, more specifically, of incomplete information.

In recent years scholars considerably improved their understanding of the innovation process. Far from the individual and linear model of knowledge production Gibbons (1994, p. vii) suggests that: "knowledge production involves the close interactions of many actors and this means that knowledge production is becoming more socially accountable". Put it otherwise, production of new knowledge is a collective process. Firms who intend to be innovative must develop collaborations with other firms or with public institutions. This point was clearly emphasised in the first chapter.

Yet, this collective process of innovation occurs in an environment of incomplete information. For instance, it is not straightforward for firms willing to develop R&D partnerships to identify potential partners and to distinguish between competent and less competent ones. Agents involved in collective forms of knowledge production must therefore address adverse selection problems (Akerlof, 1970; Spence, 1973) because they do not know exactly the competences of their potential partners.

These problems of incomplete information that are inherent to the knowledge production process can provide an explanation for behaviours of open knowledge disclosure. Indeed, competent firms who are looking for partners with whom to cooperate in R&D can sometimes think it a profitable strategy to disclose some of their knowledge, even the most valuable, in order to signal their know-how to the industrial and academic communities, thus breaking the uncertainty about their competences. Due to problems of incomplete information open knowledge disclosure may hence be an efficient strategy to facilitate R&D collaborations with other firms.

This chapter is structured as follows: In the first part we remind why it is so important for firms who intend to remain innovative to develop R&D collaborations. Specific emphasis is put on the importance of R&D collaborations in order to access knowledge held by other organizations. Then we summarize shortly the economic literature on adverse selection problems and we clarify the link between problems of incomplete information that occur in the innovation process and open knowledge disclosure. In the second part we develop two models aiming at illustrating that strategies of open knowledge disclosure, since they enable firms to facilitate R&D cooperation, can be profitable. One is inspired by the analytical framework used by Cohen and Levinthal (1989) and the second is a signalling game under incomplete information.

III.1. Open knowledge disclosure and the formation of R&D collaborations

III.1.1. The benefits of formal and informal R&D collaborations

> "In mode 2, knowledge production and knowledge appropriation converge. The outcomes are likely to be commensurate with the degree of involvement. Only those who take part in knowledge production are likely to share its appropriation".
>
> Gibbons (1994, p. 165)

Nowadays, knowledge production is widely considered by scholars as a collective process. One single person or one single firm hardly has the ability to innovate alone. Economic agents must cooperate, must set up formal research joint ventures (RSV) or more informal collaborations in which they have the possibility to exchange some of their knowledge and to share specific competences. R&D collaborations with other firms or with universities are important for firms for two main reasons:

(1) They increase research efficiency. First, because firms cannot do everything by themselves and hence they need to develop synergies with partners who can bring complementary competences. Second, because R&D collaborations with other firms allow sharing the tasks, the costs and the risks of doing research. In other words, they allow a more efficient division of labour.

(2) They open access to technical opportunities and to external sources of knowledge. First, because they help recruiting young researchers and hiring individuals with relevant skills and valuable tacit knowledge. Second, because they allow accessing new technologies and sticky knowledge held by partners (which would not be available otherwise since knowledge is usually not a public good that once produced becomes available to everybody but is rather a sticky good that remains within the organization or network that has produced it). Third, because they enable firms to gain early warning of where things are starting to happen. In clear, companies who develop many collaborations keep intellectual alert and are able to move quickly into new areas.

Specifically, being part of R&D collaborations is important to absorb external knowledge because such collaborations *exclude* as well as they *include*. If firms who are part of R&D collaborations have a privileged position to acquire knowledge held by their partners, firms who are outside can often not access knowledge produced within the collaboration. This is the meaning of Gibbons' quotation in introduction of this section, which clearly emphasises the importance of developing R&D collaborations with other firms in order to be able to access knowledge produced by these firms. Since knowledge remains within the group of firms who produced it, firms who want to absorb this knowledge must first enter the club in which it is enclosed.

R&D collaborations are therefore essential to access valuable external sources of knowledge. For a given firm, to neglect her connectedness with other firms or with public institutions may have huge negative repercussions on her innovativeness and hence on her overall profitability. To illustrate the importance of R&D collaborations in order to acquire external knowledge, let us present a story drawn from Lim (2000), who studied the case of copper interconnect technology for semiconductors.

Lim observes that it was IBM who originally developed this technology. Among the other firms who invested in this technology some were able to catch up and to adopt the technology while others were not. The salient point here is that some firms performed little R&D but were able to catch up faster than other firms who performed far more R&D. Lim attributes this struggling pattern to what he refers as firms' connectedness. Firms who were able to catch up were better connected, had developed more collaborations than those who failed. For instance, Lim explains that better connected firms were able to access the technology by leveraging their connectedness to Sematech, universities and other firms that had access to copper technology, rather than by relying on their own R&D. Lim formulates the following conclusion:

> "A firm that does not perform R&D is not excluded from building absorptive capacity if alternatives are feasible. Such alternatives include funding research at universities, co-authoring with academics, joining R&D consortia, and forming alliances with other companies with access to technology. These activities permit a firm to remain in close connection with important external sources of technical knowledge."
>
> (Lim, 2000, p. 7)

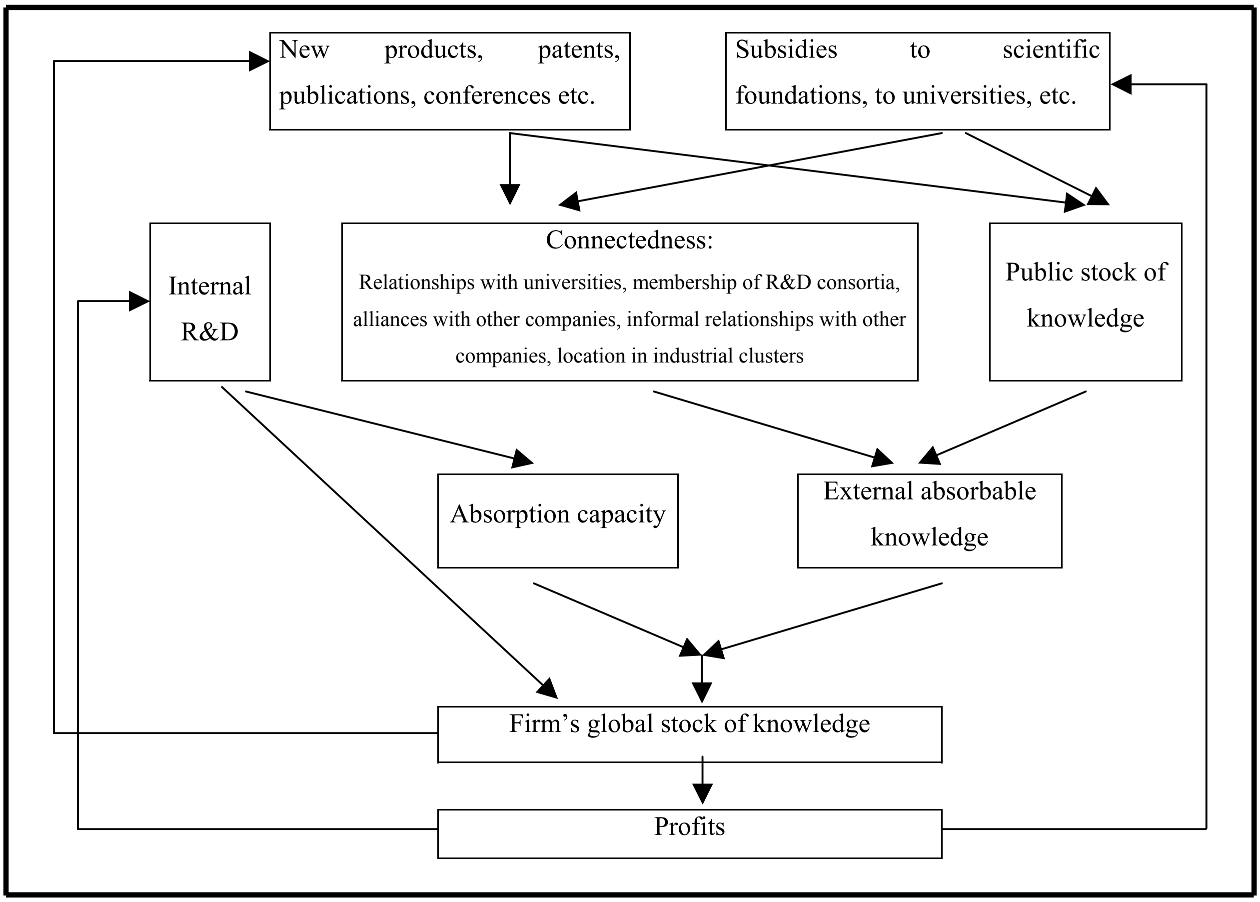
This example fits perfectly to the point we want to make here: In order to be able to absorb external knowledge it is not enough for a given firm to develop a strong absorption capacity, which is of no use if this firm cannot access external knowledge. It is also necessary to develop her connectedness with potential sources of knowledge, to be part of networks in which knowledge is flowing. Developing her absorption capacity instead of her connectedness leads to a situation in which a firm is able to absorb knowledge but does not have any external knowledge to absorb. Conversely, developing her connectedness and not her absorption capacity is equivalent to having a lot of potential knowledge to absorb but not the ability to absorb it. In clear, as it is illustrated in figure III.1. below, the degree of connectedness of firms is a key element to determine their ability to absorb knowledge. A firm's absorptive capacity depends both on her internal R&D activity and on her connectedness to external sources of relevant technical knowledge (Cockburn and Henderson, 1998).

The traditional view of innovation, which assumes that knowledge flows in the air and is available to everybody, was doomed to neglect the importance of connectedness. If knowledge is a public good there is no need to be connected to its source in order to access it since, by definition of a public good, once knowledge is produced everybody can access it. The central point to absorb external knowledge is therefore to invest in the development of an important absorption capacity.

However, departing from this classical view we adopt here a more evolutionist perspective in which, as it was explained in chapter I, the innovation process is considered as a collective process and knowledge as a collective good in the sense that it flows only within a precise set of well defined agents. This break-though leads to emphasise not only the role of internal R&D investments to absorb external knowledge but also the importance of firms' address-book, set of collaborations, connectedness, etc. Within this framework relationships developed with external sources of knowledge become at least as relevant, if not more relevant, than own R&D investments in order to absorb external knowledge.

Among others, informal contacts between employees are important. For instance, when a firm needs to solve a technical problem, researchers, especially those with PhDs, are able to gather information from personal contacts in academe. This emphasises the importance of hiring bright scientists from universities. Furthermore, to develop collaborations with universities may be a way to maintain working relationships with teams of recognised excellence or particular expertise in order to keep in touch with developments in particular fields or to hire promising graduate students.

Figure III.1: Absorption of external knowledge as a function of connectedness



To summarize, R&D partnerships are key assets for firms because they allow improving their research but also because they enable firms to access knowledge held by other organizations. Connectedness is among firms' most important assets, maybe as important as other more classical assets such as physical and intellectual capital or labour force[35,36].

[35] Let us illustrate the importance of firms' connectedness by using a simple anecdote: Recently several well-known French politicians faced in court the accusation for having used their influence over local firms to force these firms to employ persons of their neighbourhood fictively, meaning that firms were paying friends of politicians for a work that was not effective. For instance, a firm paid 200,000 euros to a woman supposed to work for her, whereas this woman never came in

Furthermore, R&D collaborations can do more than only facilitating the absorption of external knowledge. Indeed, following Kogut (2000), we can identify two approaches of collaborations as a source of knowledge.

The first one was explained above and merely considers that being part of a club enables members to have access to knowledge held by other members. In this approach knowledge is not specific to the club, which is in some sense only a channel through which firms exchange knowledge. In this respect, knowledge at the level of the collaboration can never equal more than the sum of the knowledge held by each member.

The second approach considers that the club is itself knowledge in the sense that participation to collaboration gives access to knowledge that has been collectively produced and that resides and makes sense only at the collaboration level. In other words, knowledge at the level of the club may equal more than the sum of the knowledge held by each member. As Kogut (2000, p. 407) puts it: "The network is itself knowledge. Not in the sense of providing access to distributed information and capabilities, but in representing a form of coordination guided by enduring principles of organisation […] The structure of a network implies principles of coordination that not only enhance the individual capabilities of member firms, but themselves lead to capabilities that are not isolated to any one firm".

This knowledge specific to the collaboration, which is valuable only in the context of this collaboration, can hardly be available to non-members. To access it, outsiders will not only have to enter the collaboration but also to adopt an active role within this collaboration. They cannot only observe what others are doing and imitate them. Hence, most of the time, R&D collaborations are not only places where a firm can passively absorb knowledge created by others. Firms who develop R&D collaborations actively participate to the creation of new knowledge.

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the company, had no office, no professional car, etc. The firm CEO defended this situation by arguing that his firm benefited from the address-book of the person employed and that this address-book was easily worth 200,000 euros.

[36] Popular old tags often hide remarkable pieces of wisdom behind their relative looseness. For instance, it is commonly argued that 'It does not matter if one does not know how to do a given task. What is important is to know someone who knows how to accomplish it'. This clearly refers to the importance of connectedness. Using the words of Lundvall and Johnson (1994), this may suggest that for a firm the know-who is more precious than (or at least as precious as) the know-why or the know-how.

II.1.2. How can firms identify potential fruitful R&D partnerships?

> "The abundance of knowledge leads to a problem of localisation of relevant knowledge for firms. If the probability that this knowledge exists and is stocked somewhere is high, the probability that firms do not find where it is stocked is also very high"
>
> Foray (2000, p. 99)[37]

An important question that firms involved in the collective process of innovation have to address is dealing with the problem of finding the most appropriate partners. Indeed, R&D collaborations are costly and risky strategies. For a firm they often mean to give access to her most precious knowledge to her collaborators, who may often be rivals too. R&D collaborations also require sometimes investing in the construction of common, specific assets (Williamson, 1975), exposing therefore firms to risks of hold-up. Furthermore, firms have the capacity to manage only a finite number of collaborations. They cannot collaborate with everybody. Finally, even in cases these considerations about costs of the collaboration can be neglected, it remains that firms are clearly more interested in collaborating with other firms or public institutions who are at the forefront of the technological frontier. All these elements tend to support the view that firms must thoroughly select their partners.

However, the innovation process takes place in an environment of incomplete information and this feature may constitute an insurmountable obstacle for firms willing to cooperate. Indeed, it is not so straightforward to develop R&D collaborations with other firms or public institutions. The setting up of Research Joint Ventures or of more informal R&D collaborations requires first a stage of localization and identification of the potential profitable partnerships. Once this has been done firms must still convince partners that have been chosen to accept cooperating with them. Yet, this must be

[37] This quotation was originally in French. The translation is mine.

done whereas firms usually do not know the exact characteristics and, more specifically, the competences of other firms.

But if firms do not know the competences of their potential partners, how can they identify potential fruitful partnerships? How (on which criteria) can they distinguish between profitable collaborations and less profitable ones? Which variables determine the choice of partners? What happens in the initial stage of the collaboration? Clearly, the formation of R&D collaborations can sometimes be quite complex when information about the characteristics of other firms is not available.

This problem of how to find appropriate partners is at the core of the collaboration process and, as such, at the core of the innovation process itself. But curiously, little economic literature has focused on it. A notable exception is the work of Grossetti and Bès (2002), which we will have the occasion to introduce later in this chapter.

To summarize, the formation of collaborations in R&D occurs in an environment in which information is not complete. Firms willing to develop collaborations with other firms or with public institutions usually do not have all the information about the characteristics of their potential partners, i.e. they are not able to distinguish among all potential partners the ones that fit them best. It may hence be worth making a short detour by the economic literature of incomplete information in order to improve our understanding of what happens in the first stages of R&D collaborations. In particular, such a detour may enable us to provide an explanation for behaviours of open knowledge disclosure.

III.1.3. Introduction to the economics of incomplete information

The economics of incomplete information was developed mainly in the 1970s. It focuses on the interactions between agents who do not share the same information. Fathers of this literature are year 2000 economic Nobel laureates Joseph Stiglitz, Michael Spence and Georges Akerlof, who have been rewarded particularly for their works dealing with economics of information and of incomplete information[38].

Problems of asymmetry of information may occur at two different levels: On the one hand, there may be an asymmetry of information about what an agent is doing. For instance, when an agent cannot observe exactly whether the agent with whom he has made an agreement respects this agreement, although his payoff is function of the other agent respecting the agreement or not. Such situations, in which uncertainty is *ex-post*, after a contract has been set up, are called moral hazard problems. The essential point for agents who have to deal with such moral hazard problems is to implement incentive mechanisms that force other agents to respect the agreement they have contracted.

On the other hand, the asymmetry of information may be about who is the agent, what are his characteristics. For instance, when a given agent – hereafter the principal- does not know the type of the agent with whom he has to deal, although his payoff is function of the characteristics of this agent. For sake of simplicity, in the following we assume the existence of good agents, with whom the principal has an interest to deal, and bad agents, with whom there is less interest or even no interest to complete a transaction. Such situations, in which uncertainty is *ex-ante*, prior a contract is set up, are called adverse selection problems.

Therefore, adverse selection problems arise when a given agent has to select among several other agents in order to get involved in a transaction but is not aware of all the characteristics of these agents[39]. In other words, he does not know the type of the agent(s) he is facing. The central problem for the principal is hence to find out the best agent, the one with whom he would have the highest interest to deal.

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[38] The short overview we make here on incomplete information and signalling is largely drawn from Tirole (1988), Fudenberg and Tirole (1991), Gibbons (1992) and Salanié (1994).

[39] This uncertainty regarding the type of the agents the principal is facing is reinforced in the short run by the fact that usually bad agents have an interest to hide their characteristics to the principal. Conversely, under a dynamic, inter-temporal, framework, bad agents do not always have an interest to lie to the principal. For instance, they may prefer to preserve their reputation, their credibility, rather than to make short run benefits. Thus, adverse selection problems occur mainly during short-term relationships.

Adverse selection problems have been proved to be damaging for the global efficiency of the economy compared to situations in which information is complete (Akerlof, 1970). At the individual level, adverse selection problems penalize the principal, who cannot determine with certainty the agents with whom he should deal and hence who must support the risk of completing a transaction with an agent of the bad type. Similarly it is not favourable for good agents, who can be excluded of a transaction, although the principal would have an interest to deal with them. On the other side, it favours bad agents because it may either prevent their competent rivals from dealing with the principal or give them an opportunity to complete the transaction. At the global level, the market equilibrium, if it exists, is under optimal because all the potential gains of the exchange are not realized. Some transactions that would be profitable for both parts are not completed.

Situations of incomplete information are omnipresent in the facts. For instance, Akerlof (1970) explained that consumers, whatever the type of goods they are buying, are usually in a situation of incomplete information because they cannot identify with certainty the quality of the goods. To illustrate the consequences of adverse selection problems, Akerlof took the example of the market of old cars in the US (the "lemons"). Similarly, Spence (1973) showed that firms who want to hire workers must address adverse selection problems because they cannot infer with certainty the ability of the potential workers. Another example of adverse selection problems was provided by Majluf and Myers (1984) who studied the relationships among firms and potential investors like financial markets or banks. This kind of relationship involves strong asymmetries of information ex-ante of the contract because investors cannot infer exactly the potential value of the different projects.

To summarize, in a wide range of situations adverse selection problems may advantage certain types of agents on the back of the principal and of other types of agents. Victims of adverse selection problems are therefore expected to react and to implement mechanisms that would restore a situation close to complete information. For instance, the principal may ask for a proof of the type of agents he is facing prior to complete a transaction. This may induce some agents to send the principal a signal, which would convey information about their type and hence, which may allow the principal to distinguish between bad and good agents. Such a signal must consist of an action undertaken by good agents and that could not have been done, or with difficulties, by bad agents. Thus, by observing the signal, the principal would be able to infer which kind of agent he is facing. This strategy is well known in the economic literature under the term "signalling" and such behaviours of signalling are indeed widely adopted in many situations that deal with adverse selection problems.

For instance, a guaranty for a product is nothing else than a signal of quality sent to potential buyers in order to break adverse selection problems. Only good sellers, who know that their products are of good quality and that buyers will not have to use the guaranty, can afford such practices. Sellers of low quality products have little interest to propose a guarantee on their product. Similarly, studies at university can be viewed as a signal sent to employers by potential employees. Assuming that less skilled workers have more difficulties to graduate, a firm can increase her probability to hire high skilled workers if she makes her choice only within graduate candidates. Finally, firms in need of investments may have an interest to signal their future profitability and the value of their project, by applying for patents for instance (Hall and Ziedonis, 2001), in order to attract potential investors.

Game theory has proved to provide an efficient framework to study situations of incomplete information in which agents have to choose whether or not to signal their type. Basically, signalling games under incomplete information can be defined as follows: They are dynamic games involving two periods and two players: A sender (the agent) and a receiver (the principal). In a first period the 'nature' draws the type of the agent according to a probability distribution that is common knowledge (but the principal does not observe the choice of the 'nature'). Then, the agent, given his type, chooses to send a message to the principal from a set of feasible messages. This message can take various forms. It may not necessarily involve a deliberate will to inform. Finally, in the second period the principal observes the message (the action chosen by the sender), infers the type of player he is facing and chooses an action from a set of feasible actions. Payoffs are function of the type of the agent and of the actions undertaken by both the agent and the principal.

Technically, signalling games under incomplete information can be solved by using the concept of perfect Bayesian equilibrium (PBE) introduced by Selten (1975) and by Kreps and Wilson (1982). This concept is a mix of Bayesian Nash equilibrium, which is used in static games under incomplete information, and of subgame perfect Nash equilibrium, which is used in dynamic games under complete information. It is hence straightforward to combine these two kinds of equilibrium to solve signalling games under incomplete information, which are dynamic games (with at least two periods) with incomplete information.

A PBE of a signalling game under incomplete information is given by a strategy profile for each player and a set of posterior beliefs (knowing the action in the previous periods) such as: *(i)* Players have some beliefs, meaning that for each non-singleton information set they have a probability distribution over the nodes in their information set; *(ii)* Their strategy is sequentially rational, meaning that given their beliefs and the other players' strategies, the strategy they choose maximizes their expected profit; *(iii)* The beliefs are exact, meaning that they correspond to the optimal decision they generated[40].

Usually a difference is made between different kinds of PBE: Separating, pooling and hybrid PBE. A separating PBE is such that all different types of agents choose different actions in the first period of the game, thus enabling the principal to infer in the second period which type of agents he is facing only by observing actions in the first period. A separating PBE is the ideal situation for the principal, since by observing what has been played by other players he can guess the type of each player, just as in a situation of complete information. Conversely, a pooling PBE is an equilibrium for which all players, whatever their type, choose the same action in the first period. It is hence absolutely not informative for the principal who is not able to distinguish between the different types of agents by observing their action in the first period[41]. Finally, hybrid PBE are such that agents randomise between the different strategies in the first period.

[40] To illustrate this concept of PBE, let us refer to the work of Spence (1973), who is at the origin of the enormous literature on signalling games. Spence used the concept of PBE in a study about informational problems on the job market. He considers a firm who wishes to hire workers but who does not know the skills of potential employees. He defines an equilibrium in the following manner: "The system will be stationary if the employer starts out with conditional probabilistic beliefs about the productivity of workers that after one round are not disconfirmed by the incoming data they generated. We shall refer to such beliefs as self-confirming" (Spence, 1973, p. 360).

[41] On the job market a separating PBE would be such that high productivity workers decide to go to university whereas low productivity workers decide not to. Hence, by observing the level of studies employers can guess with certainty whether a worker is competent or not. Conversely, a pooling PBE is such that all the workers choose the same level of studies.

This part aimed at introducing the basic economics of incomplete information and signalling. Let us now explain shortly, although it is likely that the reader already understood it by himself, the link between adverse selection problems, signalling, the formation of collaborations in R&D and the role we attribute to open knowledge disclosure.

II.1.4. Open knowledge disclosure as a solution to problems of incomplete information that impede R&D collaborations

> "publications aid networking and facilitate collaboration […] they help to raise the image in the academic and scientific community […] they are a ticket to an information network"
>
> (Hicks, 1995, p. 411 and 415).

The innovation process is worth being examined under the light of economics of incomplete information because it is a collective process and as such it is likely to be impeded by adverse selection problems. In particular, it is during the early stage of R&D cooperation, when firms try to infer the competences of potential partners, that problems of adverse selection may arise. Indeed, firms usually do not know the competences of potential partners, which means that they may have problems to distinguish between firms with whom it would be profitable to cooperate and those with whom it would not. We believe that these problems of adverse selection that impede the collective process of innovation can provide an explanation for behaviours of open knowledge disclosure.

We already stressed in the former part that signalling can be an efficient strategy to solve problems of adverse selection. Therefore, in the context of the formation of R&D collaborations, some firms may be induced to send a signal of their competences in order to break the uncertainty about these competences, i.e. in order to signal to other firms that it may be worth accepting cooperating with them. Furthermore, it is clear that open knowledge disclosure may constitute such a signal of competences. In other words, competent firms who want to cooperate with other firms may find it a profitable strategy to disclose some of their knowledge in order to signal their competences to other actors of the innovation process and therefore, in order to find more easily partners with whom to collaborate in R&D. Firms who reveal knowledge may be able to find partners more easily because the disclosure reduces the uncertainty regarding their competences. Open knowledge disclosure can therefore be interpreted as a signal of competences sent to the industrial and academic communities and which aims at breaking adverse selection problems that impede the process of R&D collaborations.

The following metaphor may help the understanding of the point we make here. Mansfield and Mansfield (1993) argued that building an absorption capacity is equivalent, for firms, to open a window on the outside world in order to see what other firms are doing. In this respect, firms may disclose knowledge in order to be seen, to be identified by the people who watch through the window.

This view is in line with the one expressed by Hicks (1995), who argued that publishing signals the existence of un-publishable resources, meaning that open knowledge disclosure may indicate to potential partners that the sender possesses competences that have not been disclosed. Hicks (1995, p. 401) writes that: "Publishing mediates links with other organizations, serving to signal the presence of tacit knowledge and to build the technical reputation necessary to engage in the barter-governed exchange of scientific and technical knowledge".

However, before we go any further it is worth noticing that to openly disclose knowledge may not be the unique strategy that enables firms to break problems of incomplete information. Other strategies, which are displayed in figure III.1. above, are also likely to solve at least partly adverse selection problems. For instance, firms may perform their own R&D without necessarily disclosing their research. In such a case, the reputation of innovator, which is mostly built on the introduction of new products on the market, may allow developing links with other firms. Also, firms may fund research in universities or in science foundations and/or they may hire graduate students who will in the future keep in touch with their academic colleagues. Specifically, performing basic research or at least funding basic research may facilitate the creation of external links with the scientific community.

The problem of the initiation of R&D partnerships has been investigated, among others, by Grossetti and Bès (2002), who explored the ways through which 110 R&D collaborations were initiated in France between firms and public labs. They consider basically that there are three main ways through which R&D collaborations may start[42]: The first is called the "logic of market". It is when collaboration results from a link established through scientific publications or public conferences, meaning that partners met each other's following a publication or a conference. The second is called "the logic of personal network". It is when collaboration results from former existing personal relationships between the two parties (see for instance, the work of Granovetter, 1973 and 1974, dealing with the importance of weak ties in connecting people)[43]. In this case, collaboration is initiated by a person who knows a friend who has a friend working for a company involved in such an activity, etc. The third way to initiate collaboration is the "logic of institutions". In this case collaboration is organized and structured by a public institution that puts the different actors in touch. It is possible to add to this list a fourth way to initiate R&D collaborations, which we may call the logic of chance. Indeed, it must not be neglected that in every process of search there is an important part of chance that plays in order to match partners.

Here, our interest lies precisely in what Grossetti and Bès called "the logic of market", which clearly refers to what we call open knowledge disclosure. Overall, the empirical inquiry done by Grossetti and Bès indicates that for 42 collaborations out of 110 the contact resulted from a "logic of market", for 48 collaborations it stemmed from a "logic of network" and for the 20 remaining collaborations from a "logic of institutions". The "logic of market" to initiate collaborations is specifically important when firms and labs are not located in the same region. Indeed, when the partners are located in the same region "the logic of network" works in 60% of collaborations and "the

[42] It is possible to draw an analogy between the different ways to initiate R&D partnerships and those to match employers and workers on the job market. In the latter case, it is also usually considered that there are three main ways to match employers and workers: *(i)* The signalling way, which was formalized by Spence (1973) in its seminal paper and in which employers hire employees on the basis of a signal, such as higher studies for instance; *(ii)* The network way in which workers and employers are matched through network relationships (a common friend, a family member, etc.) (Sylos Labini, 2004); *(iii)* The institutional way, in which public institutions (like ANPE in France) match employers and workers.

[43] Notice that in this case the personal network is already structured and nothing is said about how it was formed. It is however quite likely that open knowledge disclosure, i.e. the logic of market, played an important role in developing the personal network of the firm.

logic of market” occurs in only 20%. Conversely, when partners are not located in the same region the logic of market works in 59% of cases and the logic of network occurs in only 24%. Hence, this study tends to give some strength to the hypothesis we defend here, since it suggests that participation to conferences or publications can be efficient devices to initiate R&D collaborations.

It is therefore possible to establish a link between open knowledge disclosure and the concept of closed knowledge disclosure that was introduced in chapter II. It appears clearly in the above discussion that strategies of open knowledge disclosure may be essential to enter R&D collaborations and thus to trade knowledge with partners who are parts of these collaborations. Due to the presence of adverse selection problems, open knowledge disclosure is a prerequisite to knowledge trading because it eases the entrance within clubs in which firms trade knowledge. Said otherwise, open knowledge disclosure would therefore be the first step that leads to closed knowledge disclosure.

To summarize, let us insist once again on the relationship between open knowledge disclosure, the formation of collaborations in R&D and problems of incomplete information. As soon as we take for granted that innovation requires the collaboration of several actors and that this process of collaboration takes place within an environment of incomplete information (agents do not know with which partners it would be preferable to cooperate), one may suggest the following proposition: Open knowledge disclosure helps firms to trigger R&D partnerships. Indeed, to openly disclose knowledge constitutes unquestionably a way to enhance firms’ reputation. Therefore it may be a powerful device to improve firms’ position on the ‘market to find R&D collaborations’. Since open knowledge disclosure is a signal of competences, firms who openly disclose knowledge may increase their probability of developing R&D collaborations with other firms. Let us now present two models that aim at illustrating this point.

III.2. Open knowledge disclosure and R&D collaborations: Two attempts of modelling

III.2.1. A simple model *à la* Cohen and Levinthal (1989)

Our purpose here is to show with the help of a very simple model that, as soon as we agree that open knowledge disclosure may trigger R&D collaborations, then there may exist an equilibrium for which such behaviours do occur. For this purpose we use a very simple framework drawn from Cohen and Levinthal (1989). This model, although far too simple to pretend describing the complex reality of things, may provide useful insights about the basic forces at work when knowledge is openly disclosed.

Let us consider an industry composed of n rival firms that produce a homogenous good and whose unique action is to decide the quantity d_i of their knowledge that they openly disclose to other firms. We assume that each firm can decide of the exact amount of knowledge she wants to disclose. This implies among others that knowledge is considered as a perfectly divisible good, that it can be codified and that there exists a scale on which it can be measured and ordered. Furthermore, the rivalry effect excepted (see below), the action of open knowledge disclosure is assumed to be free, meaning that we neglect the cost of codification and publication of knowledge.

Knowledge held by each firm comes both from her own production of knowledge and from the external knowledge that she is able to absorb. This external absorbable knowledge is composed of public knowledge that is accessible to every firm (knowledge that was openly disclosed) and of the knowledge included in the club in which the firm is embodied (see figure III.1. above). Notice that for sake of simplicity we do not assume R&D spillovers, meaning that all knowledge transfers are supposed to be voluntary. It follows that the global stock of knowledge of each firm can be expressed as:

$$z_i = C_i + \gamma_i \left(\left(\sum_{j \neq i} d_j \right) + N(d_i) \right) \qquad (III.1)$$

in which z_i is firm i's global stock of knowledge, C_i the knowledge produced internally by firm i, γ_i $(\leq 0\gamma_i\leq 1)$ firm i's absorption capacity of external knowledge (which is assumed to be exogenous), d_i the amount of knowledge that firm i chooses to openly disclose (and hence that becomes available to all the other firms) and $N(d_i)$ the amount of knowledge that flows within the network in which firm i is embodied. Hence, $\left(\sum_{j\neq i} d_j\right) + N(d_i)$ is the amount of external knowledge available to firm i (that she can absorb if only she has the capacity to do so).

Furthermore, it is assumed that the size of the network in which a given firm is embodied is an increasing function of the knowledge openly disclosed by this firm. We have therefore $N_{d_i} = \frac{\partial N(d_i)}{\partial d_i} > 0$. This hypothesis, which is the central assumption of the model, will be discussed in depth in the following. It rests on the assumption that open knowledge disclosure is a signal of competences aiming at easing the formation of R&D partnerships with other firms and therefore that open knowledge disclosure enables firms to develop more R&D collaborations. The external stock of available knowledge for a given firm i is hence an increasing function of both the amount of knowledge openly disclosed by all the other firms and the amount of knowledge openly disclosed by firm i.

Finally, we assume that profits π^i are an increasing function of the firm's own level of knowledge and a negative function of rival firms' levels of knowledge, which reflects the effect of competition between firms. We also assume that an increase in the stock of knowledge of a rival firm decreases both firm i's profit and firm i's marginal benefit from increasing its level of knowledge. Hence, we have: $\pi^i_{z_i} > 0$, $\pi^i_{z_i z_i} < 0$, $\pi^i_{z_j} < 0$ and $\pi^i_{z_i z_j} < 0$.

Let us now turn to the computation of firms' optimal levels of open knowledge disclosure. In order to do so we assume a competition *à la* Nash in which firms decide the amount of knowledge they disclose, given the disclosure decisions of other firms. Differentiating the profit function of firm i

with respect to d_i we obtain a function, noted R, that expresses firm i's marginal return of open knowledge disclosure:

$$R=\frac{\partial\pi^i(z_i,z_{-i})}{\partial d_i}=\frac{\partial\pi^i}{\partial z_i}\frac{\partial z_i}{\partial d_i}+\sum_{j\neq i}\left(\frac{\partial\pi^i}{\partial z_j}\frac{\partial z_j}{\partial d_i}\right)$$

and, $$R=\underbrace{\pi^i_{z_i}\left(\gamma_i N_{d_i}\right)}_{>0}+\underbrace{\sum_{j\neq i}\pi^i_{z_j}\gamma_j}_{<0} \qquad \textit{(III.2)}$$

Open knowledge disclosure triggers two opposite effects on firms' profits: On the one hand, it increases the number of collaborations firms are involved in, thus contributing to increase their profits, but, on the other hand, it also increases other firms' stock of external absorbable knowledge, which decreases the disclosing firm's profit via the rivalry effect.

Computing the marginal return of open knowledge disclosure for each firm of the industry and setting it equal to the marginal cost (which is assumed to be zero here), we obtain a system of n equations that characterise each firm's optimal open knowledge disclosure decision, given the decisions of the $n-1$ other firms. Solving simultaneously these n equations yields the symmetric equilibrium level of open knowledge disclosure d^* for each firm. But we do not need to compute these equilibrium values in order to obtain interesting results.

Indeed, an important and very helpful feature of this model is that even without computing d^* for each firm, it is possible to study the effect of different variables of the model on d^*. Following Cohen and Levinthal we know that in the context of our n-firms symmetric equilibrium, for any arbitrary parameter k that influences d^*, the sign of $\partial d^* / \partial k$ is the same than the one of $\partial R / \partial k$ (Cohen and Levinthal, 1989, p. 574, for conditions under which this principle works).

Using this result, it is possible to compute the influence of several variables of the model on the equilibrium level of open knowledge disclosure. As a first approximation, let us assume that $\pi^i_{z_i z_j}=0$. Given this simplification, it is straightforward that N_{d_i}, γ_i and $\pi^i_{z_i}$ have a positive effect on d^* while γ_j and $\pi^i_{z_j}$ have a negative effect. In particular, it is useful to notice that the sharper the competition the less the firm is induced to disclose knowledge. Results are not so clear when the second order effect is included. In this case, γ_j has still always a negative effect on d^* but now there may exist situations in which γ_i has a negative effect on d^*[44].

To summarize, this basic model was useful to introduce several important features: First, it considers an endogenous emission capacity of knowledge, since it is assumed that firms can choose the amount of knowledge they make available to other firms. Second, it shows that there exist situations for which firms may find it profitable to openly disclose knowledge[45]. And third, it explores in more depth the concept of stock of external absorbable knowledge.

In this latter respect, the model proposed here is path breaking with the rest of the literature in which it is usually assumed that there exists a global stock of public knowledge, common to all firms, alimented by the spillovers emitted by those firms and in which they can all draw according to their absorption capacity. Departing from this view, the model presented here assumes that the stock of external absorbable knowledge is proper to each firm. It is composed of two parts: A public part, which is composed of knowledge openly disclosed by each firm and which is accessible to all firms in the economy. This public part is completed by a part composed of collective knowledge, which is knowledge embodied within the networks in which firms are located and that is available only to firms who are members of these networks. This assumption that the amount of external absorbable knowledge is a function of the network in which the firm is embodied reflects the fact that usually knowledge does not spill over randomly but rather flows within clubs and is available only to partners of its owner(s).

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[44] We have indeed:

$$\frac{\partial R}{\partial \gamma_i} = \underbrace{\pi^i_{z_i z_i}\left(\sum_{j\neq i} d_j + N(d_i)\right)\gamma_i N_{d_i}}_{<0} + \underbrace{\pi^i_{z_i} N_{d_i}}_{>0} \quad \text{and} \quad \frac{\partial R}{\partial \gamma_j} = \underbrace{\pi^i_{z_i z_j}\left(\sum_{k\neq j} d_k + N(d_j)\right)\gamma_i N_{d_i}}_{<0} + \underbrace{\pi^i_{z_j}}_{<0}$$

[45] If no positive link between open knowledge disclosure and the external absorbable knowledge is assumed then the marginal return of open knowledge disclosure is always negative, meaning that at the equilibrium firms always choose not to disclose any amount of knowledge. But it is straightforward from equation *(III.2)* that, as soon as a positive link is assumed between open knowledge disclosure and the firm's own absorbable stock of external knowledge, it becomes possible that firms choose to openly disclose some of their knowledge at the equilibrium.

The central assumption of this model, which allows to make open knowledge disclosure profitable under specific conditions, is that the network in which the firm is embodied is an increasing function of the amount of knowledge openly disclosed by this firm. However, no attempt to justify this hypothesis was made yet. Let us now present a model in which the positive correlation between open knowledge disclosure and the external stock of absorbable knowledge is due to problems of adverse selection that occur within the collective process of innovation.

III.2.2. A model of signalling with two firms

Let us consider two firms *E* and *A*, respectively drawn from two distinct industries. Assume that these two firms share some technological characteristics but are not rival firms, i.e. they do not compete together[46]. Assume also that these two firms must decide whether or not to collaborate in R&D. Indeed, firms *A* and *E*, although they are not in the same industry, may nevertheless have an interest to cooperate in R&D, since they use common technologies.

Benefits arising from R&D cooperation come essentially from an increase of firms' knowledge stock[47]. As firm *i* cooperates with firm *j* we posit that her knowledge stock becomes $k_i^j \geq k_i$. On the other hand, cooperation between firms *i* and *j* is also likely to involve some costs c_i^j , to acquire compatibility for instance.

[46] The fact that firms *E* and *A* are not rival firms but use similar technologies and thus work on similar research projects can hardly be considered as surprising. It is usual to observe firms from different sectors sharing the same technology: For instance, IBM and Airbus both use electronic technology; Bayer, Aventis and Total-Elf-Fina all use chemical technology, etc.

[47] As stressed in the beginning of this chapter, cooperation in R&D allows increasing firms' stock of knowledge because it opens access to sticky knowledge held by other firms and which requires common practice to be transferred and because it increases research efficiency by allowing a more efficient division of labor and by decreasing both the risks and the costs of doing research.

Furthermore, firm *A* can be of two different types: She can be competent in the technological domain that interests firm *E* (type 1) or not competent or rather less competent in the technological domain that interests firm *E* (type 2)[48]. We assume the following linear profit function for firm *A*:

If she is of the competent type: $\pi_{A1}=\delta_{A1}k_{A1}-\alpha\left(\sum_{j=1,\, j\neq A}^{N}\delta_j k_j\right)$

If she is of the less competent type: $\pi_{A2}=\delta_{A2}k_{A2}-\alpha\left(\sum_{j=1,\, j\neq A}^{N}\delta_j k_j\right)$

in which indexes *A1* and *A2* respectively refer to firm *A* when she is of the competent and less competent type, $\alpha\geq 0$ reflects the intensity of competition between firm *A* and the *N-1* firms who compete with her (firm *E*, since she does not compete with firm *A*, is not included in these *N-1* firms), $\delta_i>0$ reflects firms' ability to transform knowledge into cost reductions and hence into profits and k_i stands for the overall stock of knowledge held by firm *i*[49]. We do not assume any knowledge spillovers, which would imply that k_i has a positive effect on other firms' profits. The only effect of the stock of knowledge on other firms' profits occurs via competition and is hence negative.

Firm *E* does not know the type of firm *A* but only the probability that firm *A* is of a certain type. Indeed, firm *E* only knows that firm *A* is drawn from an industry composed of *n* firms of the competent type and *m* (*N*=*n*+*m*) firms of the less competent type, i.e. firm *E* knows that the probability that firm *A* is of the first type is equal to n/N. Furthermore, we assume that, for both firms, profits after cooperation satisfy the following restrictions:

$$\pi_E^{A1}>\pi_E>\pi_E^{A2}$$

and $\pi_i^E>\pi_i \Leftrightarrow \delta_i\, k_i^E-c_i^E>\delta_i\, k_i$, $i=A1,A2$

in which, π_i^j stands for firm *i*'s profit if she cooperates with firm *j*.

[48] The adjective "competent" does not refer to an absolute level of competence. Rather, it is meaningful only relatively to cooperation with firm *E*, i.e. firms of type 1 are competent in the technological domain that interests firm *E* in the sense that cooperation with this type of firm is better for firm *E* than cooperation with firms of the other type. Hence, it is quite possible that some firms, who are qualified as not competent in our model, are, all technologies accounted for, more competent than firms, who are qualified as competent.

[49] For a maximum of simplicity, we consider the stock of knowledge of each firm as homogeneous and as being the sum of the knowledge regarding all the technologies managed by these firms.

In other words, we consider a situation in which firms *E* and *A* must decide whether or not to cooperate in R&D with each other. Firm *A*, whatever her type, has an interest to cooperate with firm *E* but firm *E* has an interest to cooperate with firm *A* only if the latter is of the competent type[50]. The central problem for firm *E* is that she does not know the type of the firm she is facing. This leads us to focus on the role played by the information that players have when they take their decision whether to cooperate or not. This emphasis put on the role of information immediately allows stressing a basic result of the economics of incomplete information (Akerlof, 1970):

Proposition III.1: Consider a situation in which firm *E* cannot infer exactly the type of firm *A* (does not know whether or not firm *A* is competent but knows the probability that firm *A* is competent) but in which firm *A* knows that cooperation with firm *E* would be profit increasing[51]. Compared to a situation of complete information in which firm *E* knows the type of firm *A*, the existence of incomplete information in the cooperation process tends to:

(1) Penalize firm *E* (the non informed firm), since under incomplete information there is a risk that firm *E* accepts to cooperate with firm *A* although the latter is of the less competent type (i.e. it would have been more profitable to refuse cooperation) or, conversely, there is a risk that she refuses to cooperate with firm *A* although the latter is of the competent type (i.e. it would have been profitable to accept cooperation).

(2) Penalize firm *A* when she is of the most competent type, since under incomplete information firm *A*, although of the competent type and perfectly informed, may be driven out of the cooperation process if she cannot prove to firm *E* that she is of the competent type[52].

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[50] This may be, for instance, because if firm *A* is of the less competent type, costs that firm *E* must support to acquire compatibility are not offset by the benefits that arise from cooperation with a less competent firm.

[51] For sake of simplicity we still assume that, although firm *E* does not know firm *A*'s competences, firm *A* knows firm *E*'s competences. This assumption holds, for instance, if firm *E* has been the leader in her industry for years, if firm *E*'s researchers are famous or if firm *E* has been granted several important patents. Examples of this kind of situation in which there is an asymmetry of information between two firms who are looking to cooperate in R&D are many: As big-pharmaceutical firms try to cooperate with small biotechnology firms, as firms such as Microsoft or IBM try to cooperate with small start ups, etc.

[52] It is also worth noting, but this cannot be proved with our two agents model, that the presence of incomplete information within the process of R&D cooperation may also penalize firm *A* if she is of the competent type because it may allow

(3) Favour firm *A* when she is of the less competent type, since under incomplete information she may be given a chance to cooperate with firm *E*, which could hardly happen if the latter was perfectly informed about the competences of her potential partner[53].

Proof: Given in Appendix III.1.

When information is incomplete it is hence likely that firm *E*, who is penalized by this situation, tries to restore a situation close to complete information. One way to do so would be to require, before accepting to collaborate with firm *A*, that the latter sends a signal of her competences in order to prove to firm *E* that she is of the competent type. The question we attempt to answer in the following is thus: Does it exist an opportunity for firm *A*, if she is of the competent type, to be distinguished by firm *E* from firms of the less competent type? More specifically, we explore whether or not the presence of problems due to incomplete information may induce firms to openly disclose some of their knowledge. In what follows, we assume therefore that firm *A* can send a signal of her competences to firm *E*.

III.2.2.1. Only firms of the competent type can send a signal of their competences

Assume first that firm *A* can send a signal of her competences to firm *E* only and only if she is of the competent type[54]. In this latter case, firm *A* can choose to send a signal S of her competences to firm *E* prior that firm *E* decides whether or not to cooperate with her. This signal of competences can take the form of scientific publications, patents or presentations in conferences. For simplicity, we

cooperation between firm *E* and less competent rivals of firm *A*, who otherwise would not have been given an opportunity to cooperate.

[53] Similarly to note 52, incomplete information also favours firm *A* when she is of the less competent type by eventually preventing or making it harder for rival firms of the competent type to cooperate. But, again, this cannot be proved in our two agents model.

[54] This assumption is not unrealistic in the sense that it may be hard for firms of the less competent type to send a signal because this may require to disclose knowledge that they do not hold.

assume that firm *A* has only two possible signalling strategies: Either she sends a signal S or she does not send a signal.

Furthermore, the signal sent by firm *A* must contain valuable knowledge in order to convince firm *E* that the sender is competent. Let us note therefore k^s the amount of knowledge embodied in the signal *S*. As such, the signal, or rather the disclosed knowledge embodied within the signal, may directly profit firm *A*'s rival firms who, depending on their absorption capacity, have the opportunity to use this disclosed knowledge in order to improve their technology and to reduce their production cost. When firm *A* chooses to send *S*, the stock of knowledge of her *N-1* rival firms becomes therefore: $k_j+\beta_j k^s$, in which β_j reflects firm *j*'s absorption capacity (Cohen and Levinthal, 1989)[55, 56].

Therefore, to send a signal to firm *E* is costly because if firm *A* chooses to disclose some of her knowledge, this disclosed knowledge will benefit her *N-1* rival firms, which, in turn, via the effect of competition, will affect negatively firm *A*'s profits. To openly disclose knowledge also involves other costs due, among others, to the necessity to codify knowledge prior to openly disclose it. However, these expenditures are often marginal compared with the cost that stems from the communication of helpful knowledge to competitors and hence they can be neglected without too much damage.

Before we go any further, two important assumptions need to be underlined: First, we assume that firm *E* cannot absorb the knowledge disclosed by firm *A* ($\beta_E=0$). This assumption allows dismissing cases for which firm *E* would be able to improve her technology merely by observing the signal and thus would decide not to cooperate even if the observed signal is high.

Second, we make the hypothesis that the knowledge disclosure is open, in the sense that firm *A* cannot prevent her *N-1* competitors from accessing the disclosed knowledge. At first sight, this

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[55] β_j reflects the fact that the extent to which the disclosed knowledge benefits other firms depends strongly on the ability of these firms to understand and manage the information embodied in the signal. Indeed, the signal provides only information about the technology but does not allow an immediate use of this technology. And there is still a long way to go from the reception of an information about how to solve a problem to the understanding of how to solve it oneself.

[56] The fact that knowledge released by a given firm may always benefit other firms means that firms' knowledge sets are considered as perfectly disjoined. Firm *A* and her rival firms hold completely different pieces of knowledge and therefore all the knowledge revealed by one firm may automatically benefit the other firms, depending on their ability to absorb it.

hypothesis may appear unrealistic in our model with only two agents, since in this case it is likely that firm *A* can communicate directly and exclusively with the firm to whom she wants to signal her knowledge (firm *E*). However, this assumption of openness is important because, in some sense, it is a way to give credibility to the signal in case of the eventual partner is not able to assess himself the value of the disclosed knowledge. The fact that everybody can access the disclosed knowledge ensures that the signal is not a fake.

To summarize, we have now a dynamic game with incomplete information in which firm *A*, if she is of the competent type, can eventually prove it to firm *E* by disclosing some of her competences. The sequence of the game is the following (see figure III.2. below): In the first period, firm *A*, if she is of the competent type, decides whether or not to reveal her knowledge (*S* or *0*). In the second period firm *E* observes firm *A*'s decision in the first period and then chooses whether or not to cooperate with her (*C* or *NC*).

Technically, this signalling game of incomplete information can be solved by using the concept of perfect Bayesian equilibrium (PBE) that was explained in the first part of this chapter. In our problem of R&D cooperation, a PBE requires that: *(i)* Firm *E* has some beliefs regarding the type of the firm who emits a signal *S*; *(ii)* Firm *E* takes her decision to cooperate according to these beliefs; *(iii)* Firm *A*'s signalling decision corresponds to firm *E*'s beliefs.

Let us assume the following beliefs for firm *E*: If firm *A* is of the competent type then firm *E* believes that she will play *S*, i.e. if firm *A* does not play *S* firm *E* believes that firm *A* is of the less competent type.

Proposition III.2: Consider firm *E*'s beliefs as described above. Under *condition III.1.* below, there exists a separating PBE for which firm *A* decides to disclose her knowledge if she is of the competent type and for which firm *E* accepts to cooperate with firm *A* only if the latter discloses her knowledge.

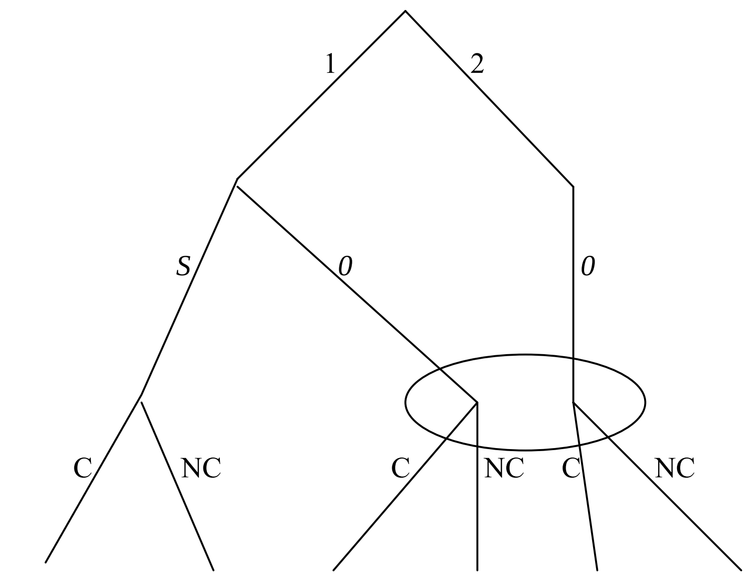
(condition III.1) $$k^S \leq \frac{\delta_{A1}\left(k_{A1}^E - k_{A1}\right) - c_{A1}^E}{\alpha \sum_{i \neq A} \delta_i \, \beta_i}$$

Proof: Given in Appendix III.2.

Under *condition III.1* we have a separating PBE because firm *E*'s beliefs are confirmed by the action they generate. Indeed, following her beliefs, firm *E* decides to cooperate with firm *A* only if the latter plays *S* (since if firm *A* does not play *S* firm *E* believes that firm *A* is not competent). Furthermore, given firm *E*'s beliefs and under *condition III.1*, firm *A* will play *S* if she is competent, thus confirming firm *E*'s beliefs.

Figure III.2: Decision tree of the signalling game

Stage	Player	Decision
1	Nature	Determines the type of firm *A*
2	Firm *A*	Chooses to openly disclose knowledge or not
3	Firm *E*	Chooses to cooperate or not with firm *A*



Payoffs firm *A*	$\pi^E_{A1}(S)$	$\pi_{A1}(S)$	π^E_{A1}	π_{A1}	π^E_{A2}	π_{A2}
Payoffs firm *E*	π^{A1}_E	π_E	π^{A1}_E	π_E	π^{A2}_E	π_E

We will come back later on the economic interpretation of this result. For the moment, it is only important to notice that it confirms the fact that open knowledge disclosure may occur in an environment of incomplete information because it may be an efficient strategy for competent firms in order to be distinguished from other less competent firms.

III.2.2.2. Firm *A* can send a signal of her competences whatever her type

Assume now that firm *A*, whatever her type, can choose to send a signal *S* to firm *E* by openly disclosing some of her knowledge. Let us note k_i^s $(i=A1,A2)$ the knowledge disclosed by firm *A* according to her type. Again, the main cost that arises from openly disclosing knowledge is to provide useful knowledge to competitors. If firm *A* decides to disclose k_i^s $(i=A1,A2)$ this knowledge benefits all other firms who, depending on their absorption capacity, are able to use it[57]. Furthermore, we assume that firms of the less competent type must support a supplementary cost *w* in order to disclose their knowledge. This supplementary cost can be explained by the fact that it is likely to be more expensive to disclose knowledge related to a technology when this technology is not perfectly understood.

Let us consider the following beliefs for firm *E*: Firm *E* believes that if firm *A* is of the competent type then she will play *S* and that if firm *A* is of the less competent type then she will not play *S*. Therefore, if firm *A* chooses to disclose knowledge firm *E* believes that cooperation with firm *A* would be profit increasing compared with the no cooperation case while if firm *A* does not disclose her knowledge firm *E* believes that cooperation with her is not profitable.

In other words, we assume that from the viewpoint of firm *E* all the observed signals are identical. Firm *E* does not make any distinction between k_{A1}^s and k_{A2}^s. If firm *A* sends a signal then she is believed to be competent and if she does not send a signal then she is believed to be less competent. Firm *E* does not rank the signals according to their quality[58]. This assumption is consistent with our

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[57] The signal must contain valuable knowledge even when less competent firms are the sender because publications in scientific reviews, presentations in conferences or patents must pass through a referring process, which should ensure the quality of the disclosed knowledge. Hence, if firm *i* wishes to publish, she is forced to reveal at least to some extent valuable knowledge in order to obtain the agreement of the referees. This referring process warrants, in some sense, that a minimal amount of knowledge is embodied in the signal. Therefore, we have here a potential lever for policy makers who could decide to ease or to take a harder line regarding the requirements to publish in scientific reviews or to be granted a patent.

[58] The fact that firm *E* cannot make any distinction among the disclosed knowledge allows interpreting k_i^s as the minimal amount of knowledge required to publish in a scientific review or to be granted a patent. Indeed, given firm *E*'s beliefs, firm *i* has no interest to disclose a higher amount of knowledge than k_i^s since this would be costly and this would have no impact on firm *E*'s decision to cooperate or not.

former hypothesis that firm *E* cannot absorb knowledge openly disclosed by firm *A* $(\beta_E=0)$. Indeed, if firm *E* is not able to make a distinction between different publications in the field it may be because she is not very competent in the field. And, if she is not competent she will also not be able to build an efficient absorption capacity.

Building over this simple framework, which is summarized in figure III.3. below, it is possible to stress the following propositions (we are only interested here in PBE for which behaviours of open knowledge disclosure may arise):

Proposition III.3: Consider firm *E*'s beliefs as described above. Under conditions (*III.1')* and *(III.2)* below, there exists a separating PBE for which firm *A* decides to disclose knowledge if and only if she is of the competent type and for which firm *E* chooses to cooperate with firm *A* only if the latter discloses her knowledge.

(condition III.1') $$k_{A1}^{S} \leq \frac{\delta_{A1}\left(k_{A1}^{E}-k_{A1}\right)-c_{A1}^{E}}{\alpha\sum_{i\neq A}\delta_i\,\beta_i}$$

(condition III.2) $$k_{A2}^{S} > \frac{\delta_{A2}\left(k_{A2}^{E}-k_{A2}\right)-c_{A2}^{E}-w}{\alpha\sum_{i\neq A}\delta_i\,\beta_i}$$

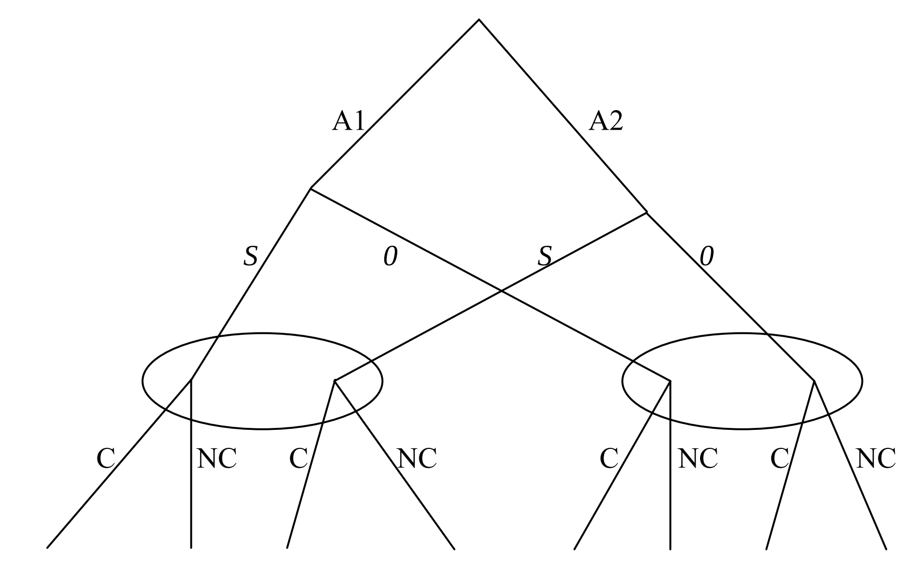
Proof: Given in Appendix III.3.

Condition III.1'. ensures that, given firm *E*'s beliefs, firm *A* chooses to play *S* if she is of the competent type. *Condition III.2.* ensures that, given firm *E*'s beliefs, firm *A* does not play *S* if she is of the less competent type. Hence, under both *conditions III.1'.* and *III.2.* firm *A* chooses to disclose knowledge if and only if she is of the competent type. Since firm *E* believes that cooperation is profitable only with a disclosing firm, under both conditions above firm *E*'s beliefs are correct and we have a separating PBE.

For this PBE the signal sent by firm *A* enables her to prove to firm *E* that she is competent. This means that competent firms can sometimes think it profitable to disclose knowledge in order to break adverse selection problems that occur when firms consider whether or not to cooperate in R&D. Open knowledge disclosure allows most competent firms to restore a situation close to complete information meaning that, by observing the signal, firm *E* can guess whether firm *A* is competent or not. This situation, in which firms can send a signal of their competences, always favours firm *E*, but it may not always be profitable to firm *A* even if she is of the competent type. Indeed, when the signal is costly firm *A* may sometimes prefer a situation of incomplete information without signalling possibility.

Figure III.3: Decision tree of the signalling game

Stage	Player	Decision
1	Nature	Determines the type of firm *A*
2	Firm *A*	Chooses to openly disclose knowledge or not
3	Firm *E*	Chooses to cooperate or not with firm *A*



Payoffs firm *A*	$\pi^E_{A1}(S)$	$\pi_{A1}(S)$	$\pi^E_{A2}(S)$	$\pi_{A2}(S)$	π^E_{A1}	π_{A1}	π^E_{A2}	π_{A2}
Payoffs firm *E*	π^{A1}_E	π_E	π^{A2}_E	π_E	π^{A1}_E	π_E	π^{A2}_E	π_E

To summarize, we showed that there may exist a PBE for which only competent firms disclose knowledge, thus enabling other firms to infer the competences of disclosing and non disclosing firms. Conversely, proposition III.4 below states that, in our model, there does not exist a possibility for less competent firms to be the only ones who disclose knowledge. Finally, proposition III.5. states that there also exists a PBE for which both types of firms disclose their knowledge.

Proposition III.4: There does not exist a separating PBE for which firm *A* discloses her knowledge if and only if she is of the less competent type.

Proof: Given in Appendix III.4.

Proposition III.5: Consider now that firm *E* believes that firm *A*, whatever her type, plays *S*[59]. Under the three conditions below there exists a pooling PBE in which firm *A*, whatever her type, chooses to disclose her knowledge and in which firm *E* decides to cooperate with firm *A*.

(condition III.1') $$k_{A1}^{S} \leq \frac{\delta_{A1}\left(k_{A1}^{E} - k_{A1}\right) - c_{A1}^{E}}{\alpha \sum_{i \neq A} \delta_i \, \beta_i}$$

(condition III..2') $$k_{A2}^{S} \leq \frac{\delta_{A2}\left(k_{A2}^{E} - k_{A2}\right) - c_{A2}^{E} - w}{\alpha \sum_{i \neq A} \delta_i \, \beta_i}$$

(condition III.3) $$\frac{n}{n+m} \pi_E^{A1} + \frac{m}{n+m} \pi_E^{A2} \geq \pi_E$$

Proof: Given in Appendix III.5.

This proposition stresses that, under specific conditions, there may exist a PBE in which both competent and less competent firms choose to disclose knowledge, i.e. the presence of incomplete information may lead all types of firms to openly disclose knowledge in order to prove or to try to dissimulate their type to the principal. In this case the signal is not informative. It is of little utility for firm *E*, who cannot, by observing the decision of firm *A*, infer her type. However, she nevertheless chooses to cooperate because the probability that firm *A* is of the competent type is high enough.

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[59] Firm *E* may believe that the requirements to get a publication, for instance, are very low and therefore that each firm, whether competent or not, can send a signal easily. The signal does not really establish a distinction between competent and less competent firms.

III.2.2.3. Discussion and extension for further works

The main result stressed by this model is that there exist parameter values that support the existence of PBE, either pooling or separating, in which open knowledge disclosure occurs, i.e. strategies of open knowledge disclosure aiming at breaking adverse selection problems may pay and it may be fully rational for firms to openly disclose knowledge in order to ease collaborations with other firms. This confirms that the presence of incomplete information within the innovation process can offer an explanation for behaviours of open knowledge disclosure.

This finding is in line with several recent observations: Von Hippel (1988, p. 77), for instance, explained that: "[knowledge] trading networks appear to be formed and refined as engineers get to know each other at professional conferences and elsewhere. In the course of such contacts, an engineer builds his personal informal list of possibly useful expert contacts by making private judgments as to the areas of expertise and abilities of those he meets". This clearly points out the role of conferences, and other meetings in which firms disclose knowledge, in order to improve firms' awareness of the competences of other firms and, *in fine*, in order to develop collaborations with other firms. The role of open knowledge disclosure in the collaboration process was also emphasised by Gambardella (1992), Callon (1998), Cockburn and Henderson (1998), Hicks (1995) and Grossetti and Bès (2002), whose works have already been displayed earlier in this chapter or in this thesis.

However, at this step a central question remains open: What are the conditions that support the emergence of behaviours of open knowledge disclosure? Even if the greatest care must be adopted, our model can provide some insights to answer this question.

For instance, a separating PBE in which only competent firms choose to reveal requires that, all other things being held equal, the degree of competition among firms must be bounded upward and downward. If competition is too sharp then competent firms may choose not to reveal whereas if it is too low then less competent firms may also choose to reveal, which will undermine the existence of the separating equilibrium. For the same reason, it also requires that, all things being held equal, the absorption capacity of rival firms and rivals' technology (the extent to which they transform their knowledge into costs reduction and profits) is bounded upward and downward. If they are too strong, disclosure may become too costly for competent firms, since it may profit too much to rival firms, but if they are too weak then less competent firms may also choose to disclose.

Moreover, the extent to which cooperation with firm *E* is profitable to competent firms must remain relatively high while it must be relatively low for less competent firms (in particular, this implies that the cost of acquiring compatibility with firm *E* remains acceptable for competent firms but is high for less competent firms in order to deter them to reveal). Last, but not least, k_{A1}^{s}, which may be interpreted as the minimum level of knowledge that firm *A*, if she is of the competent type, must accept to disclose in order to be allowed to publish in a scientific journal or to be accepted in a conference, must remain low. Conversely, k_{A2}^{s} must be relatively high. Indeed, the higher the requirements about the disclosure the less firms are encouraged to reveal, all other things being held equal, since this disclosure has no positive effect (firm *E* observing only whether or not there is a signal and not the intensity of the signal) while it is costly (it benefits competitors).

On the other hand, a pooling PBE in which both types of firms choose to disclose their knowledge requires that, all other things being held equal, the degree of competition between firms, the absorption capacity of rival firms and the rivals' technology remain low. If they are too strong, disclosure may become too costly for firms. Moreover, for both types of firms the extent to which cooperation with firm *E* is profitable must remain high and k_i^s $(i = A1, A2)$ must remain low. Finally, *n*, the number of competent firms in the industry in which firm *A* evolves, must be relatively high compared to *m* and π_E^{A1} must be high compared to π_E^{A2}, so that firm *E* is induced to cooperate knowing that both types of firms disclose their knowledge.

It is possible to draw some comparisons between the conditions under which open knowledge disclosure arises in our model and those found in other studies. For instance, the effect of competition on the emergence of disclosing behaviours was already raised by Allen (1983), who explained that knowledge disclosure may often be triggered by the fact that competition is weak and hence that to provide other firms with relevant information is not damaging for disclosing firms. However, our model adds to this analysis the fact that if competition is too weak then all firms decide to disclose their knowledge and therefore the signal looses its primary role, which is to allow disclosing firms to be distinguished from other firms.

Harhoff *et al.* (2003) considered a simple model of open knowledge disclosure with one manufacturer firm and two user firms, in which the latter may decide to openly disclose knowledge in order to trigger pecuniary spillovers from the manufacturer firm (see chapter II). In this framework they identify three variables that have an impact, either positive or negative, on users' decision to disclose or not their knowledge. All other things being held constant, the degree of competition between user firms and the cost to adopt the improved input play negatively on the decision to reveal while the extent to which the manufacturer firm improves the product affects positively the decision to reveal. Finally, the degree of generality of the new technology, which reflects the extent to which the revealed technology is specific to the firm who discloses, has an undetermined effect on the decision to reveal or not. This effect of generality of the innovation has no equivalent in our model. But the effects of competition, of the cost to adopt the improved product (which is equivalent in our model to the cost to acquire compatibility with the principal) and of the degree of improvement of the product (which can be compared in our model to the extent to which cooperation with firm *E* is profitable) are similar.

Furthermore, Eaton and Eswaran (2001) focused on the effect of the indivisibility of knowledge and of the stochasticity of the innovation process on the decision whether or not to disclose knowledge. They find out that the less divisible the knowledge and the more stochastic the innovation process, the less firms are encouraged to reveal. In our model, one way to interpret k_i^s is that it is the minimal level of knowledge that must be disclosed in order to be published or accepted in a conference. This means that in some sense we made so far the assumption that knowledge is a perfectly divisible good and therefore that each agent can disclose exactly the amount of knowledge k_i^s $(i=A1,A2)$. This assumption can be softened, which enables us to concur with the conclusions reached by Eaton and Eswaran. For instance, let us assume that firm *A* does not have the opportunity to disclose an amount of knowledge exactly equal to k_A^s because knowledge is not a perfectly divisible good. In such a case, firm A must reveal an amount of knowledge $k_A^{s'}$ such that $k_A^{s'} = \min_{k_A \geq k_A^s}(k_A)$. This means that the less divisible the knowledge, the higher the probability that firm A must send a signal far above k_A^s. But, as it was stressed earlier, to disclose more knowledge than k_A^s has no positive effect on firm A's profit while it is costly, i.e. the less divisible the knowledge the higher the probability that firm A decides not to disclose it.

Finally, it is interesting to remark that our work suggests that the disclosure must remain, if possible, a signal that is hardly exploitable by other firms but that indicates clearly that the sender possesses other resources that have not been disclosed. Conversely to many studies on the topic that was presented in chapter II and in which disclosing firms want other firms to use the disclosed knowledge, in our model disclosing firms only aim at signalling their knowledge. It is hence likely that firms choose to reveal only knowledge that is not applicable by other firms. The difficulty of the exercise consisting for firms to disclose enough knowledge in order to send a strong signal but not as much knowledge as to enable other firms to reproduce the innovation. An analogy can be drawn with firms' patenting strategies. The aim when applying for a patent is to provide a description of the innovation just sufficient to be granted the exclusive exploitation right on this innovation but not detailed enough to allow competitors to imitate it easily. Yet, it must be underlined that the explanation of open knowledge disclosure in terms of signalling we gave here does not exclude the disclosure of very valuable knowledge. It is indeed possible that firms decide to disclose core competences if they expect that the cooperation that may be triggered by this disclosure is worth it.

To summarize, we considered here a model with two agents (firms A and E) who had the choice between cooperating together in R&D or not. It was assumed that firm A was possibly of two types: Either competent or less competent. And of course cooperation with firm A was profitable for firm E only if firm A was of the competent type. But we assumed that firm E did not know the type of firm A and hence did not know whether cooperation with firm A was profitable or not (while we assumed that firm A knew that cooperation with firm E was profitable). Therefore, the problem for firm *E* was to infer the type of firm *A*. We assumed also that firm *A* had the opportunity to openly disclose some knowledge in order to show to firm *E* that she is competent. We solved this signalling game of incomplete information by using the concept of perfect Bayesian equilibrium (PBE). Among other results, we have been able to show that under specific conditions there exists PBE that support the existence of behaviours of open knowledge disclosure.

This model presented several shortcomings conceded mainly for simplicity but that also indicate directions that should be taken in further works. For instance, we assumed that the principal's absorption capacity is always equal to zero. This assumption was convenient since it allowed dismissing cases for which a given firm reveals an important amount of knowledge but for which firm *E* has nevertheless no interest to cooperate with this firm because she can use alone the disclosed knowledge. To soften this hypothesis may enable to take into account situations in which firms would have to be careful not to reveal a too important amount of their knowledge to firm *E*.

Also, we did not consider here the possibility to send fake signals that do not contain any useful knowledge and that only aim at misleading competitors. A framework that would take this feature into account would permit to underline more strategic behaviours. It is the role of the referee of a scientific journal or of the patent office to warrant the quality of the signal and hence to prevent the above situation from occurring. But it is widely acknowledged nowadays that referees do not always do a thorough work, which implies that many scientific articles and patents do not contain very valuable knowledge[60]. This observation may give some strength to the fake signal hypothesis.

Beside these possibilities, many other extensions are possible. Among others, it would be interesting to specify a dynamic model that would last several periods (an attempt toward this direction is made in the next chapter), to consider more than two agents in order to make the assumption of open knowledge disclosure more realistic, to allow firms choosing exactly the amount

[60] We learn in the French newspaper *les échos* that regarding patents in biotechnologies: "some patent offices tend more easily to accept a patent rather than to refuse it, all the more that in the former case they do not have to justify their decision. It is also the case that the examiner is remunerated only if the patent is accepted" (M. Ciprut, *Brevet : une réforme du système international en 2003* ?, "Les échos", 13.01.2003, translation is mine).

of knowledge they want to disclose and not to impose a binary choice, to introduce the qualitative dimension of knowledge (its generality, its importance), etc.

To conclude, we believe that the track that was followed here is worth pursuing since the link between adverse selection and open knowledge disclosure can be extended to many situations. It is not only limited to situations for which firms attempt to set up R&D collaborations. For instance, a similar model may apply in the following cases: As a government decides to distribute grants to encourage innovation within particular industries, as private investors decide to finance industrial projects, as graduate students choose their future employer, as a firm wants to take-over spin-offs or to enter new markets.

In all these situations the principal must select between different contractors, each of them yielding different returns depending on their competences, which are usually unknown to the principal (at least partly). It follows that in all these situations the most competent firms may be induced to reveal widely some of their knowledge in order to reduce the problems caused by incomplete information and, for instance, to be granted public contracts or subsidies, to hire promising young graduate students, to gather capital on financial markets or to dissuade potential competitors from entering a given market.

Conclusion of the chapter

This chapter was a first attempt to provide an explanation to open knowledge disclosure behaviours by using the economic literature on incomplete information. It was proposed that the presence of adverse selection problems during the early stage of R&D cooperation may induce firms to openly disclose part of their knowledge in order to convince other firms or public institutions to begin a collaboration in R&D with them.

We first established that, since innovation is a collective process, it is essential for firms who want to remain innovative to develop R&D collaborations. Specific emphasis was put on the importance of collaborations to access knowledge held by other firms. However, a major challenge for firms involved in this collaborative process is to identify appropriate partners. Indeed, we argued that since the process of finding competent partners with whom to cooperate in R&D occurs in an environment of incomplete information, firms may not be able to identify the partners that fit them best.

This conclusion led us to focus on the role that open knowledge disclosure may play in order to solve these problems of incomplete information. We showed, with the help of a signalling game under incomplete information, that due to adverse selection problems firms may be induced to disclose widely parts of their knowledge in order to signal their competences to potential partners (who would wonder whether or not to cooperate with the disclosing firm) and to facilitate cooperation in R&D. Our work gives therefore some strength to the idea that the existence of adverse selection problems within the process of knowledge production can provide an explanation for behaviours of open knowledge disclosure.

In this chapter we used the theoretical background provided by game theory in order to link behaviours of open knowledge disclosure and the formation of R&D collaborations. In the next chapter we investigate this link by using the framework provided by numerical simulations, which should permit to raise different points than those highlighted here.

CHAPTER IV:

WHY DO FIRMS DISCLOSE KNOWLEDGE AND HOW DOES IT MATTER?[61]

[61] This chapter is based on a paper realized in collaboration with Paul Muller. This paper was presented at the Druid 2004 summer conference in Copenhagen and at the International Schumpeter Society 2004 conference in Milan, where the authors were awarded the ISS best poster prize, sponsored by *Industrial and Corporate Change*.

We propose in this chapter a theoretical framework based on social network analysis in order to describe the formation and dynamics of innovation networks, with particular emphasis put on the role of open knowledge disclosure within this process.

In the former chapter we stressed that being member of innovation networks (and *a fortiori*, having a central position in those networks) is essential for firms because it allows, first sharing the costs and the risks of doing research and second accessing knowledge held by partners and which would not be available otherwise. But we also emphasized that the process of finding partners with whom to collaborate in R&D may be impeded by adverse selection problems regarding the competences of firms. We therefore suggested that firms may sometimes think it a profitable strategy to disclose some of their knowledge -even the most valuable- in order to break the uncertainty with regard to their competences. In other words, firms' reputation, by contributing to solve adverse selection problems, may facilitate access to innovation networks and help to improve firms' position within those networks.

Here, we investigate the role of open knowledge disclosure on the formation and evolution of R&D collaborations and on firms' profitability by using numerical simulation techniques. At the start of each simulation, firms, symbolized by nodes located on an empty graph, are endowed with different amounts of specific knowledge and with different strategies in terms of knowledge disclosure (high frequency of knowledge disclosure and low frequency). The profit of each firm is positively related to the amount of specific knowledge she holds, which in turn depends on her position within the network (since this position determines the amount of external knowledge that the firm can absorb). It is also assumed that firms' activity of open knowledge disclosure increases their reputation and that the probability for a given firm to build up new connections is an increasing function of her reputation.

Firms have therefore to face the following trade-off: Either they choose to frequently disclose knowledge to all the other firms (including to their direct competitors), thus decreasing their current profit but also increasing their reputation, or they decide to keep their knowledge secret, thus favouring their current profitability but eventually impeding their ability to create new connections, since they will suffer from a lack of reputation.

A major result of our simulation is the setting of a particular network shape where some firms acquire a central position in the innovation network while others adopt more "peripheral" positions. Moreover, we find that firms' status within innovation networks and firms' profitability are highly sensitive to the strategy of open knowledge disclosure (low or high frequency) they adopt. It may not only be the firms endowed initially with higher amounts of specific knowledge that acquire a central status but also the most active ones in terms of knowledge disclosure. In other words, a reasonable strategy of open knowledge disclosure enables firms to catch up with firms initially endowed with higher amounts of specific knowledge.

This chapter is structured as follows: In the next part we present the frame of our model of innovation networks morphogenesis. Then, in the second part, we display the results of the numerical simulations and we discuss these results. We conclude with remarks and indications for further work.

IV.I. A model of innovation networks morphogenesis

To put it shortly, the model of network morphogenesis decomposes as follows. At the beginning of the simulation a population of firms is located on an empty graph. This graph symbolizes an innovation network at its beginning, when there is no connexion between firms. At the outset, each firm has a scalar knowledge endowment that is composed of specific knowledge and of public knowledge (knowledge shared by all the firms of the model). Since those firms are supposed to be knowledge intensive, specific knowledge constitutes their main and even their only source of profits.

At each time step, firms engage in R&D activity, which is aimed at building up new pieces of specific knowledge. The probability of success (the probability of producing a new piece of specific knowledge) depends on the total level of knowledge a firm has access to (such knowledge may be internally mobilized as well as it may stem from external sources through inter-firm R&D agreements).

After having performed such an activity, each firm faces the decision whether or not to disclose or not part of the specific knowledge she holds which, if disclosed, would become general knowledge. Such an action, although it decreases her current profit, allows the firm to build up her reputation.

Then, periodically, each firm considers the decision of linking up with an other firm. Such a connexion process is driven by reputation effects. Since reputation mitigates the uncertainty associated with a first interaction, firms aiming at connecting with an other business tend to give priority to firms enjoying higher levels of reputation. Furthermore, the main interest of being connected with an other firm is to be offered access to part of the specific knowledge held by this firm, through joint ventures or any type of cooperation agreement. Connections therefore increase the stock of knowledge of connected firms, which in turn enhances the performances of their R&D.

In other words, we take into account in this model that, by openly disclosing knowledge, firms not only provide competitors with useful information about their own research but also improve their reputation, which helps them to build R&D collaborations with other firms and therefore to increase the efficiency of their research.

IV.1.1. Basic assumptions of the model

At time t, n firms are located on a graph $G_t = (V, \Gamma_t)$, where $V = \{1,...,n\}$ is the set of firms (vertices) and $\Gamma_t = \{\Gamma_t^i, \forall i \in V\}$ is the list of connections in the graph. $\Gamma_t^i = \{j \in V / \{ij\} \in G_t\}$ constitutes the neighbourhood of firm *i* at time *t* or, put differently, the set of R&D agreements enjoyed by firm *i* at time *t* and *{ij}* represents the tie binding two firms *i* and *j* at time *t*. For $t = 0$, $\{\Gamma_0\} = \{\varnothing\}$, the graph forming the innovation network is empty. Furthermore, at the beginning of each simulation firms may differ through two things: The quantity of specific knowledge they hold and their strategy of open knowledge disclosure.

Broadly speaking, the model relies on the coexistence of two types of knowledge. The first type of knowledge is accessible to all firms and may therefore be qualified as "general" or public. This general knowledge is constituted by knowledge produced by universities and other public institutions but also, and this is a main focus of the model, by knowledge produced within firms and openly disclosed by these firms to all the other firms, through scientific publications for instance.

The second type of knowledge is assumed to be proper to each firm and not available to all the other firms. In this manner, this type of knowledge may be qualified as firm specific. Such knowledge may be made of particular know-how, pieces of knowledge subject to secrecy policies, etc. By specific knowledge it is important to understand that we mean pieces of knowledge held secret by firms (or communicated only to some partners). Therefore, specific knowledge in this model does not mean that this knowledge can only be used, that it makes sense only in the context of the firm. Rather, specific knowledge corresponds to unrevealed knowledge, i.e. it can be used by other firms if only the owner chooses to disclose it and to make it available to those firms.

Furthermore, each firm, when she develops R&D partnerships is assumed to make a share β of her specific knowledge available to other members of the collaboration. This knowledge is therefore half kept secret and half disclosed, since it is made available to partners but not to non-members of the collaboration. As such, we should qualify this type as knowledge of collective knowledge (in the sense we gave to this term in the first chapter), since it is shared only by firms who are members of R&D partnerships. However, for sake of simplicity, we still regard this knowledge as being specific knowledge, i.e. when a given firm makes some of her specific knowledge available to her partners, we assume that her stock of specific knowledge does not decrease. In other words, this means that specific knowledge corresponds to knowledge held only by the firm and eventually made available to her partners.

The total knowledge held by each firm comes therefore from three sources: Specific knowledge that has been internally produced, public knowledge that has been absorbed and specific knowledge held by partners and that is made available to the firm through joint-ventures or any other type of cooperation agreement. Moreover, it is assumed that pieces of knowledge produced by firms are perfect complements. There are no redundancies between knowledge held by each firm and their partners. It follows that the total knowledge a firm may mobilize to perform R&D is given by:

$$K_{i,t}^{Tot} = K_t^{Gen} + K_{i,t}^{Spe} + \beta \sum_{j \in \mathrm{T}_t^i} K_{j,t}^{Spe}, \qquad 0 \leq \beta \leq 1$$

where K_t^{Gen} represents the general knowledge of the economy at time t (this stock of public knowledge is common to all firms), $K_{i,t}^{Spe}$ the specific knowledge held by firm i at time t, β the share of specific knowledge made accessible by firm's i partners to their R&D collaborators and T_t^i firm's i set of R&D partners at time t. It is assumed that β is set as fixed and equal for every firm. Furthermore, for sake of simplicity we neglect here the problems relative to the absorption of external knowledge, which would imply that firms cannot mobilise the totality of the stock of public knowledge but only a fraction, depending on their absorption capacity[62].

[62] However, it should be noted that, in some sense, β can also be viewed as representing the absorption capacity of firms and not only the share of knowledge made available to them by partners.

Each firm $i \in V$ is also characterized by a strategy of open knowledge disclosure, which is assumed to be given and fixed over time. Such a strategy reifies through the frequency φ_i at which firms choose to openly disclose knowledge. To openly disclose knowledge means, for a given firm, to make this knowledge available to all the other firms. Hence, specific knowledge that is disclosed becomes automatically public knowledge. In other words, the act of openly disclosing knowledge decreases the stock of specific knowledge of the firm, while it increases the stock of public knowledge of the economy. Firms may be of two types: Firms of the first type adopt an active strategy of knowledge disclosure, giving thus rise to high values for φ_i, whereas firms of the second type tend to adopt a more passive strategy associated with low φ_i values. As our results will confirm, firms adopting the latter strategy are thus giving priority to the maximization of current profit whereas firms of the first type favour a more long-term strategy.

Lastly, the objective of each firm is to generate profits. Revenues mainly stem from the monopolist rents provided by the use of the specific knowledge each firm has produced through past R&D. Such a rent may come from licensing agreements, patent rights, etc. Therefore, we assume that profits are a linear function of the amount of specific knowledge held by the firm. The more a firm holds specific knowledge, the higher her profits. Moreover, we assume that profits are not function of the general knowledge firms' have access to. Since public knowledge is, by definition, available to each firm, it is assumed to give no competitive advantage to firms and hence it does not increase their profit. But, as we will see below, it increases their probability to innovate and therefore to generate further specific knowledge in the next periods.

On the other hand, firms have to bear costs related to the production of knowledge. The first type of costs gathers internal R&D expenditure, administrative costs and all other type of costs related to the activity of the firm. The second type of costs stems from inter-firm partnerships. This issue has been widely discussed, notably in the frame of Transaction Costs Economics (Williamson, 1975). Indeed, any inter-firm relationship involves costs from both partners in order to develop compatibility, to build common assets, etc. Here we assume that firms must bear a constant unitary cost per collaboration noted α[63]. Therefore, profit function of a firm *i* at time *t* is given by:

$$\Pi_{i,t} = \gamma K_{i,t}^{Spe} - \alpha k_{i,t} - c$$

Where $k_{i,t}$ represents the degree (or, similarly, the number of partnerships) of firm *i* at time *t*. The parameters γ, α and *c* represent, respectively, the income generated by 1 unit of specific knowledge, the unitary cost of an inter-firm relationship and internal costs (R&D expenditure, administrative costs, etc.). For the sake of simplicity, those parameters have been set as fixed and equal for every firm at any time.

An important consequence of the fact that, in our model, specific knowledge made available to partners is still considered to be specific knowledge for the firm who revealed it is that the action of making knowledge available to partners has no negative effect on firms' profit. Indeed, only specific knowledge serves to determine firms' profit. Hence, since knowledge made available to partners is considered as remaining specific knowledge, it does not decrease firms' current profit. Conversely, this is not true for knowledge that is openly disclosed. As soon as it is openly disclosed, specific knowledge becomes public knowledge, i.e. the action of openly disclosing knowledge has a direct negative effect on disclosing firms' current profit.

IV.1.2. The dynamics of the model

Our model incorporates the fact that, for knowledge intensive firms, signalling competences through open knowledge disclosure constitutes a way to improve the performances of their R&D (and, in fine, their profitability) by easing the formation of R&D partnerships and hence by allowing enlarged access to knowledge held by partners and which would not be available otherwise. As it is

[63] We could also assume a decreasing or an increasing unitary cost. The first would be motivated by the existence of economy of scale that make R&D partnerships less costly for a firm when this firm has many partnerships. Conversely increasing unitary cost would reflect the fact that firms can only manage a finite number of collaborations and that the more they develop collaborations the more expensive each collaboration is. These two assumptions would be also acceptable from a theoretical point of view but, for simplicity, we neglect them and we assume a constant unitary cost.

summarized in figure IV.1. below, the dynamics of the system decomposes into 3 main steps, namely knowledge production, knowledge disclosure and partnership binding.

First step: Production of specific knowledge. At each time step, each firm undertakes R&D activity, i.e. each firm mobilises her total stock of knowledge $K_{i,t}^{Tot}$ in the perspective of increasing her stock of specific knowledge. In order to produce new pieces of specific knowledge through R&D activity, each firm has to rely on the total knowledge she has access to, which is the sum of firm's specific knowledge, public knowledge and specific knowledge made available by partners. The main input in the production of specific knowledge is hence constituted by knowledge itself. In other words, this means that firms who have a higher stock of total knowledge (either because they have more specific knowledge or because they have more fruitful partnerships) are more likely to produce specific knowledge, which increases their total stock of knowledge and which, in turn, increases again their probability to produce specific knowledge. However, knowledge creation is also considered as a stochastic process. Firms with a higher total stock of knowledge are not certain to produce more specific knowledge than firms with a lower total stock of knowledge, they only have a higher probability. At each period, we assume that a new unit of specific knowledge is created with a probability $p_{i,t}$, which is positively correlated with $K_{i,t}^{Tot}$. This probability is given by the distribution function of an exponential law:

$$p\left[K_{i,t}^{Spe}=K_{i,t-1}^{Spe}+1\right]=F\left(K_{i,t-1}^{Tot}\right)=1-\exp\left(-\lambda K_{i,t-1}^{Tot}\right),$$

with $\lambda>0$, $\frac{\partial F}{\partial K}>0$ and $\frac{\partial^2 F}{\partial K^2}<0$

One can therefore observe that the probability to produce specific knowledge at a given period is increasing with the firm's total stock of knowledge at this period but with decreasing returns to scale. To summarize, we assume that at each period firms have a certain probability, which is an increasing function of their total stock of knowledge, to produce one more unit of specific knowledge.

Second step: Disclosure of specific knowledge. During the second stage of the process, each firm faces the decision whether to openly disclose or not a fraction δ of the specific knowledge she holds. This action of knowledge disclosure is turned towards all other firms. Therefore, open knowledge disclosure triggers two opposite effects for disclosing firms:

- On the one hand, it decreases their instant profit. Indeed, once disclosed, the fraction δ of specific knowledge turns instantly general, i.e. it transfers from the firm's stock of specific knowledge to the stock of public knowledge, thus decreasing the current profit of the disclosing firm.
- But, on the other hand, knowledge disclosure induces an increase in the reputation R_t^i of the emitting firm, which may enable her to enjoy in the future more inter-firm R&D cooperative relationships and hence to have access to extra sources of external knowledge. A central assumption of the model, which will be discussed in more depth later, is that whatever the amount of specific knowledge that is disclosed by a given firm *i* at a moment *t*, the reputation of this firm increases of 1 unit from period *t* to *t+1*.

During that stage of knowledge disclosure one important constraint is put on firms, namely their funding after having disclosed a fraction of the specific knowledge must remain positive. For a given firm *i*, her funding at time t_0 is given by the sum of her past profits and her initial funding $\Psi_{i,0}$ such as: $\Psi_{i,t_0} = \Psi_{i,0} + \sum_{t=1}^{t_0} \Pi_{i,t}$, where $\Pi_{i,t}$ stands for firm *i*'s profit at time *t* and $\Psi_{i,0}$ for firm *i*'s initial funding. Firms who violate this survival condition are considered as bankrupt and therefore are removed from the simulation.

The parameter φ_i plays here a crucial role by influencing the decision to engage into the knowledge disclosure process. Indeed, we interpret φ_i as being the probability for firm *i* to openly disclose knowledge at any period, which means that firms who have adopted higher φ_i are more likely to disclose knowledge, i.e. they disclose knowledge more frequently than firms who have adopted lower φ_i [64]. Moreover, the fraction δ of specific knowledge that is disclosed is assumed to be the same for each firm. In other words, we assume that at any period, each firm has a probability φ_i to openly disclose a share δ of her specific knowledge, which hence becomes public.

Third step: Formation of R&D partnerships. Periodically, the third stage of the process, corresponding to partnership binding, takes place. During that stage, one firm has to link up a partnership, which will last over Θ periods, with an other firm of the network. The formation of R&D partnerships occurs as follows:

First, we draw randomly from the global population of *n* firms the firm who will have to initiate the partnership and to choose a partner with whom to cooperate in R&D. The probability of picking firm *i* depends on firms' strategy φ_i. We assume indeed that firms endowed with an active disclosing strategy are more likely to be drawn than less active firms. The reason is the following: The main goal of an active knowledge disclosure strategy is to increase the firm's reputation, which in turn increases the likelihood of binding numerous inter-firm partnerships. But the same type of reasoning may be turned the other way round. Whereas, a firm endowed with a high reputation may be the recipient of more partnership proposals than less active firms, active firms may also be more motivated to initiate new partnerships than passive firms. Therefore, it is expected that firms who actively disclose knowledge are more willing to initiate R&D partnerships. It follows that the probability $P_{ini}(i)$ for a firm *i* to initiate a new relationship is given by:

$$P_{ini}(i) = \frac{\varphi_i}{\sum_{j \in V} \varphi_j}, \text{ where } i \in V$$

Then the firm that has been drawn to initiate the R&D partnership has to select among all the other firms (excluding firms with whom she is already engaged) a partner with whom to collaborate in R&D. In this process of partnership binding, firms' reputation plays a central role (Muller, 2003).

[64] It is straightforward to observe that φ_i can be interpreted either as the frequency at which firm *i* discloses a fixed amount of knowledge or as the amount of knowledge disclosed by firm *i* at a fixed frequency. In the following we will therefore use both terminologies and refer to φ_i as reflecting alternatively the frequency of the disclosure and the amount of disclosed knowledge.

Indeed, we assume that the choice of the partner is made according to firms' reputation, i.e. in function of their disclosing strategy. A firm initiating a new partnership links up with an other firm with a probability proportional to the reputation of the latter[65]. It follows that for a firm *i* initiating a new inter-firm relationship the probability to choose an other firm *j* who does not already belong to firm *i*'s set of current partners is given by:

$$P\left[\{ij\}\in G_t \,/\{ij\}\notin G_{t-1}\right]=\frac{R_t^j}{\sum_{k\in V-\{\Gamma_{i,t-1}\}}R_t^k}$$

With R_t^j the reputation of firm *j* at time *t*.

Finally, after Θ periods partners are assumed to automatically end the collaboration.

IV.1.3. Numerical analysis

Since network models are particularly hard to deal with in an analytical way, the methodology provided by numerical simulation will be applied. Ultimately, we focus on the evolution of an innovation network and the condition under which, starting from a situation where no firms are connected to each other, such a network develops (through the accumulation of inter-firm partnership agreements). We focus specifically on the role of open knowledge disclosure on firms' connections and profitability.

[65] This point was stressed in chapter III, in which we established a link between open knowledge disclosure, the formation of R&D collaborations and problems of incomplete information. This link can be summarized as follows: Since the formation of R&D collaborations takes place within an environment of incomplete information (agents do not know perfectly which partner it would be preferable to cooperate with), firms who openly disclose knowledge are more likely to be admitted within R&D partnerships.

Figure IV.1: Dynamics of the model

At time $t = 0$ the network, where the nodes figure firms, is empty. Initially, firms differ through 2 dimensions:

- Their stock of specific knowledge
- Their strategy of disclosure

At time t, each firm is characterized by her stock of knowledge $K_{i,t}^{Tot}$ as well as by her profit $\Pi_{i,t}$

Production step

At any period, each firm produces a new piece of specific knowledge with a probability that is function of her total stock of knowledge: $p\left[K_{i,t}^{Spe}=K_{i,t-1}^{Spe}+1\right]=F\left(K_{i,t-1}^{Tot}\right)=1-\exp\left(-\lambda K_{i,t-1}^{Tot}\right)$

Disclosure step

At any period, each firm has a probability φ_i to disclose a share δ out of her specific knowledge

No

Yes

The disclosed pieces of specific knowledge become public (decrease in instant profit)

Increase of 1 unit in firm i's reputation R_t^i

Linking step

Drawing of a firm i wishing to engage in a partnership (drawing depending on the disclosure strategy)

Choice of the partner according to its reputation:

$$P[\{ij\}]=\frac{R_t^j}{\sum_{k\notin j} R_t^k}$$

Partnership binding for Θ period

After Θ periods: relationship breaking

Survival condition

If at any period t_0 her funding $\Psi_{i,0}+\sum_{t=1}^{t_0}\Pi_{i,t}$ becomes negative then firm i bankrupts and will be left away for the rest of the simulation run.

The interest of methods using numerical simulation, compared to analytical methods, rests first in the possibility to study the evolution of complex dynamic systems, which cannot be solved analytically. It is widely accepted nowadays, even among the most conservative scholars, that numerical methods can be very useful to observe and characterise the evolution of systems of equations that have no analytical solutions. But beyond this practical aspect, in economics it is more and more often the philosophy of the researcher rather than the complexity of the problem he is facing that determines the use of numerical simulations or of analytical methods. Nowadays simulation methods are often used to model economic situations for which analytical solutions would exist if only some basic hypotheses were made.

Indeed, numerical simulations were introduced (or rather popularised) in economics of innovation at the beginning of the 1980s with the work of Nelson and Winter (1982). Nelson and Winter main objective was the rejection of two central assumptions of mainstream economic: The notion of equilibrium and the notion of rational maximising agents. Only under these two hypotheses can a model describing economic situations be solved analytically. Hence, the rejection for ideological reasons of these two hypotheses called automatically for the use of another tool to study dynamic economic models. This tool was numerical simulations.

This short introduction to numerical simulations calls for two important remarks that must be kept in mind: First, numerical simulations do not help to solve a system. They do not give us equilibrium values. Numerical simulations only help describing the trajectory of a system. Second, due to bounded rationality agents are not supposed to maximise, on the contrary, they are supposed to make mistakes and to need time to change their strategies when they realise those strategies failed, if they realise it at all.

IV.1.3.1. Statistics

Our main interest lies in the emergence of inter-firm differentials arising from differences in knowledge disclosure strategies (either active or passive). Hence, we focus mainly on inequalities indicators related to firms' performances in terms of profits and in terms of number of R&D partnerships.

The first indicator, related to inequalities in firms' performances, is provided by Herfindahl Index for funding. Herfindhal Index for profits may have been more interesting in order to focus on the evolution in firms' inequalities but since profits are sometimes negative it was not possible to compute such a Herfindhal Index. Herfindahl Index for funding at time *t* is thus given by:

$$Herf(\Psi_t) = \sum_{i \in V} \left(\Psi_{i,t} \Big/ \sum_{j \in V} \Psi j,t \right)^2$$

It follows that the higher the Herfindhal at a period *t*, the higher the inequalities among firms' funding at this period.

In order to focus on the link between firms' performances and their disclosing strategy, we also use indicators comparing the average profit of firms according to their disclosing strategies. In this manner, we compute a ratio comparing, at any period *t*, the average profit for high disclosing firms with the average profit for low disclosing firms (Average Profit Ratio - *APR*). Moreover, in order to assess the relative number of R&D partnerships contracted by high disclosing firms versus low disclosing firms, we also compute an other statistics comparing at any period *t* the average degree for high disclosing firms versus the average degree for low disclosing firms (Average Degree Difference - *ADD*).

$$APR_t = \frac{\frac{1}{n-m}\sum_{i \in I} \Pi_{i,t}}{\frac{1}{m}\sum_{j \in J} \Pi_{j,t}},$$

$$ADD_t = \frac{1}{n-m}\sum_{i \in I} k_{i,t} - \frac{1}{m}\sum_{j \in J} k_{j,t},$$

where k_i represents the number of R&D partnerships contracted by firm *i*, *I* is the set of firms who disclose a high amount of knowledge (*n-m* firms are in this set) and *J* the set of firms who reveal a low amount of knowledge (*m* firms).

It is straightforward to observe that an *APR* statistics higher than one indicates better average performance of high disclosing firms compared with low disclosing firms. Similarly, a positive *ADD* statistics indicates that high disclosing firms built on average more links than low disclosing firms.

Finally, our last statistics is related to the global stock of knowledge of the economy. To assess the effect of different strategies of open knowledge disclosure on the evolution of the global stock of knowledge we compute the latter in the following way:

$$K_t^{Tot} = K_t^{Gen} + \sum_{i \in V} K_{i,t}^{Spe}$$

IV.1.3.2. Settings

We consider an economy with *n = 100* firms. For the sake of simplicity in the interpretation of the effects and mostly, in order to concentrate on the effects of strategies of open knowledge disclosure, some individual parameters are set as equal for all firms. Those parameters are provided in Table IV.1. Such parameters may be merged into two main categories. The first type of parameters deals with the performances of R&D activity and may therefore be coined as "knowledge parameters". The second class of parameters is linked to the generation of profit. Those parameters may therefore be viewed as "financial parameters".

Each simulation runs for 60,000 periods during which knowledge production and open knowledge disclosure processes at any period. Periodical inter-firm relationships bindings are also performed but only every 40 periods on average. The reason behind such a periodicity lies in the fact that, for the simulation to provide significant results, the graph has to feature the sparseness condition[66]. Under the hypothesis that partnerships bindings occur on average every 40 periods this condition is met since, at the end of the simulation we obtain a graph that contains on average 1,000 distinct ties (for a complete graph, the total number of edges would be of 9,900 ties, so that only 10 % of the connections are active on average).

[66] The sparseness condition states that $D_{full} >> D_{sparse}$ where D_{full} corresponds to the density of a fully connected graph and D_{sparse} to the density of a sparsely connected graph (Watts, 1999).

The parameters we vary are three: The proportion of high disclosing firms, the frequency at which firms openly disclose knowledge φ_i and firms' initial endowment of specific knowledge $K_{i,0}^{Spe}$.

Table IV.1: Simulation - General parameters

Parameters	Definition of the parameters	Values
Knowledge parameters		
$K_{i,0}^{gen}$	Firm's *i* ($\forall i$=1,…,100) endowment of general knowledge at time *t=0*	500
β	Share of specific knowledge made accessible to partners through R&D agreement	0.5
δ	Fraction of specific knowledge openly disclosed to the industry	0.1 %
λ	Coefficient for the exponential law providing the probability of generating 1 new unit of specific knowledge through R&D	10^{-5}
Θ	Duration of R&D partnerships (in time steps)	7500
Financial parameters		
γ	Marginal income stemming from the use of specific knowledge	0.75
α	Unitary cost for maintaining an inter-firm relationship	0.3
C	Fixed costs that each firm must support at any period	5
$Fund_{i,0}$	Firm's *i* ($\forall I$=1,…,100) monetary endowments at time *t=0*	2000

In a first series of simulation runs we set firms' initial endowments of specific knowledge as equal for all firms. As such, firms only differ in their disclosing strategies. We consider only two types of firms: High disclosing firms, who have a high value for φ_i, and low disclosing firms, who are firms having adopted a less active strategy of open knowledge disclosure and thus who have a lower value for φ_i. We assume that low disclosing firms have always a probability of 0.1% to disclose knowledge (φ_i^{low}=0.1%) and we vary the probability to disclose knowledge for high disclosing firms (φ_i^{high}=0.5%–1%–2%–3%–5%–10%). The objective being to observe what happens when high disclosing firms intensify their activity of knowledge disclosure and to observe if there is a threshold beyond which knowledge disclosure becomes unbearable, i.e. high disclosing firms all disappear in the first periods of the simulation.

Table IV.2: Simulation - specific parameters

Definition of the parameters	Values
Frequency of open knowledge disclosure for low disclosing firms	0.1 %
Frequency of open knowledge disclosure for high disclosing firms	0.5 % - 1 % - 2 % - 3% - 5% - 10%
Proportion of high disclosing firms in the economy	10 % - 30 % - 50 %
Initial endowments of specific knowledge for slightly endowed firms	5
Initial endowments of specific knowledge for highly endowed firms	10 – 100 – 500
Proportion of highly endowed firms	30 %

Moreover, in this first series of simulation we also vary the proportion of high disclosing and low disclosing firms in the economy. As such, we observe how the system evolves when we have only 10% of high disclosing firms, when we have 30% of high disclosing firms and when we have 50% of high disclosing firms.

Table IV.3: Proportion of firms by type

<table>
<tr><td colspan="2"></td><td colspan="2">Strategy of open knowledge disclosure</td></tr>
<tr><td colspan="2"></td><td>High</td><td>Low</td></tr>
<tr><td rowspan="2">Initial endowments of specific knowledge</td><td>High</td><td>9%</td><td>21%</td></tr>
<tr><td>Low</td><td>21%</td><td>49%</td></tr>
</table>

In a second series of simulation runs we wish to compare the effects of open knowledge disclosure on firms' performances with those stemming from initial endowments of specific knowledge. For this purpose, we set the proportion of high disclosing firms as fixed and equal to 30% and we allow firms to differ in their initial endowments of specific knowledge. Again, we consider here two types of firms with respect to their initial endowments of specific knowledge: Firms highly endowed with specific knowledge and firms slightly endowed (see Table IV.2. above for details about the numerical values given to these parameters). During this second series of simulation, we are therefore confronted with 4 types of firms: High disclosing firms with high endowments of specific knowledge, high disclosing firms with low endowments of specific knowledge, low disclosing firms with high endowments of specific knowledge and low disclosing firms with low endowments of specific knowledge. The proportion of firms with respect to the previous typology is given in Table IV.3.

IV.2. Simulation results and discussion

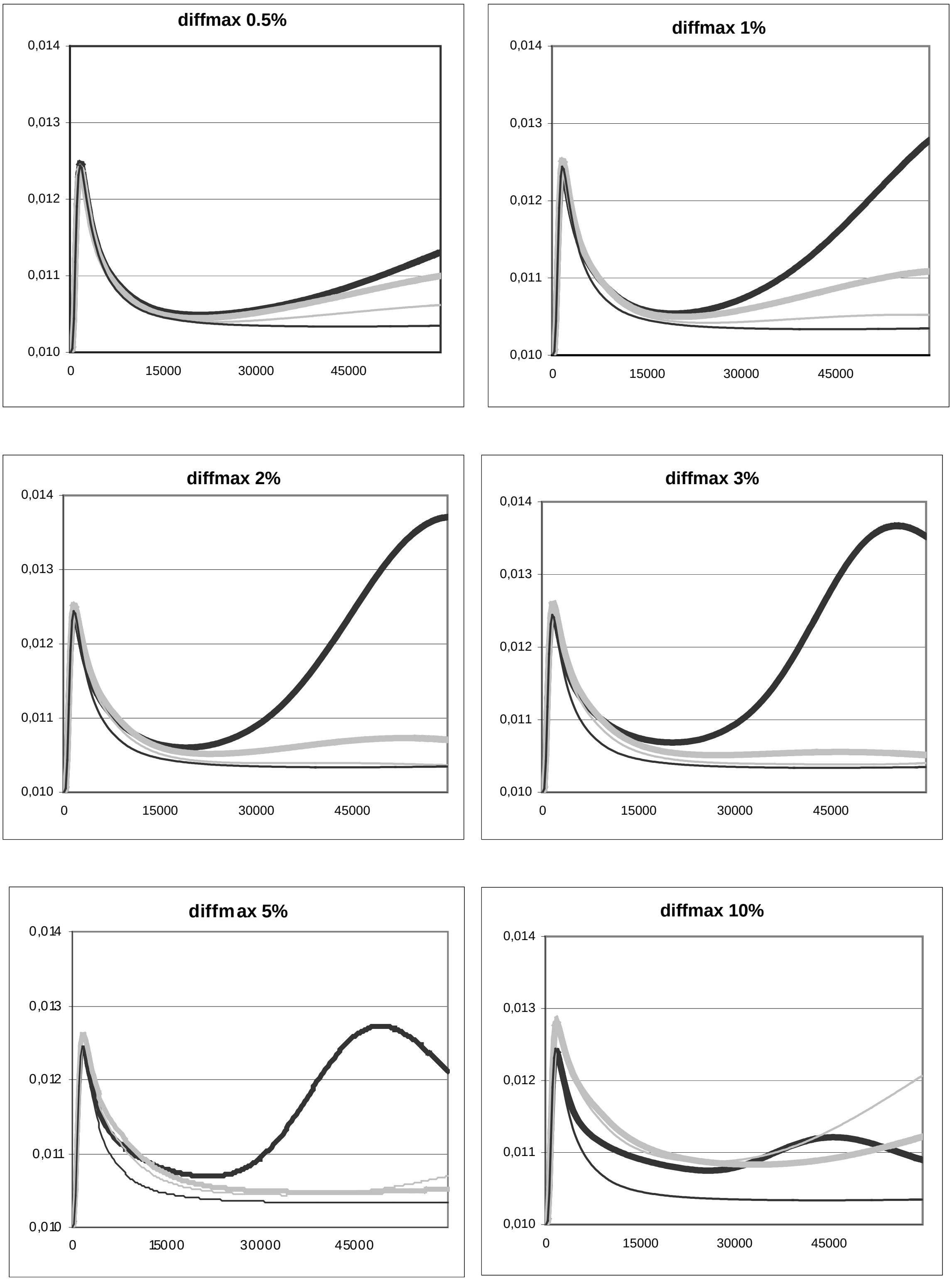
IV.2.1. When firms differ only in their disclosure strategy

Let us consider first the case in which firms differ only with respect to their disclosure strategy. For each simulation run we have thus two types of firms: the LD firms (as low disclosing firms) and the HD firms (as high disclosing firms). One can therefore observe the evolution of the industry and the individual performances of firms according to different values of the gap between HD and LD firms and according to different proportion of these two types of firms. Specifically, this may enable us to draw some conclusions regarding the effect of open knowledge disclosure on firms' performances.

Figure IV.2. describes the evolution of inequalities in firms' performances (approximated by the Herfindhal Index of firms' funding). First, we observe that Herfindhal Index for funding rises sharply at the very beginning of the simulation and this for all disclosure strategies and proportions of HD firms, indicating that inequalities between firms emerge quickly but somehow are not linked to the presence of HD firms. The presence of HD firms begins to affect the differential of performances between firms only after approximately 10,000 periods. And the higher the frequency of open knowledge disclosure of HD firms, the earlier differences in Herfindhal Index emerge. Differences emerge after 15,000 periods for a frequency of disclosure of HD firms equal to 0.5% and only after 10,000 periods for a frequency of disclosure equal to 10%. Overall, we observe also that the presence of HD firms tends to increase performances inequalities in the industry (this point will be confirmed later when comparing the performances of HD firms with those of LD firms).

Furthermore, when HD firms disclose low amount of knowledge (the frequency of disclosure of HD firms is less than 5%), inequalities tend to decrease with the proportion of HD firms. The lower the proportion of HD firms the higher the Herfindhal Index and hence the stronger the inequalities among firms. Conversely, when HD firms disclose high amount of knowledge (the frequency of

Figure IV.2. Herfindhal of firm's funding



Legend: proportion of HD firms: Thick and dark: 10%; Thick and clear: 30%; Thin and clear: 50%; Thin and dark: 0%.
Note: Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

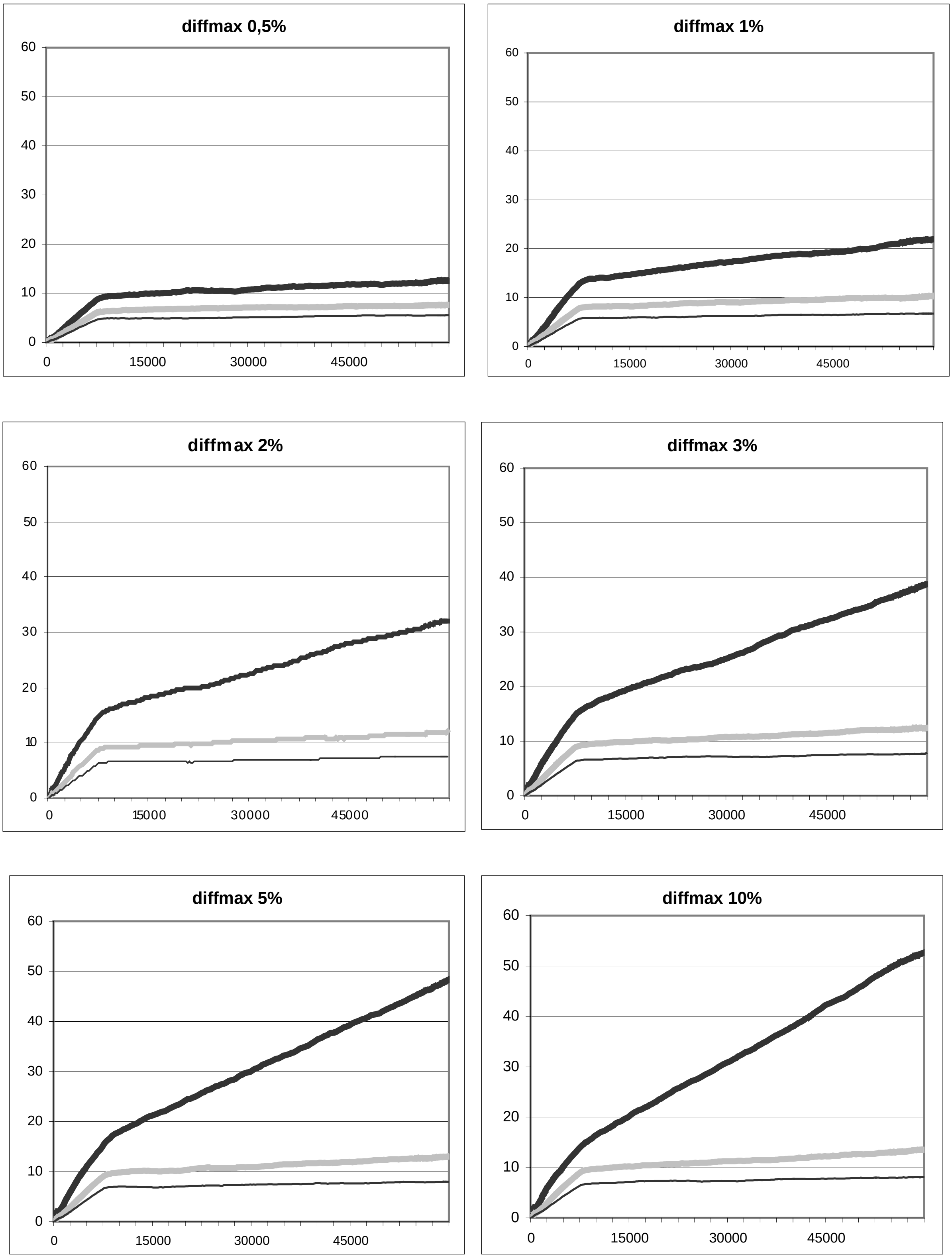
disclosure of HD firms is more than 5%) then inequalities tend to rise with the proportion of HD firms. The lower the proportion of HD firms the lower the Herfindhal Index.

Figure IV.3. depicts the average number of R&D partnerships set up by HD firms versus LD firms by displaying the evolution of the ADD statistics. The first thing we observe is that, whatever the proportion of HD firms and the frequency of the disclosure of HD firms, the ADD statistics remains always positive and displays an increasing trend, indicating that HD firms tend to develop more R&D partnerships than LD firms and that this feature reinforces through time. As the simulation goes on the difference between the average number of R&D agreements set up by HD firms increases compared to the average number of partnerships set up by LD firms. The ADD statistics increases sharply at the beginning of the simulation and then, after approximately 10,000 periods, increases more slightly. This break in the increasing trend of the ADD statistics is likely to be due to the connection breaking condition, which starts to be effective after 7,500 periods. Hence, at the beginning of the simulation HD firms contract R&D partnerships and do not break any partnerships. Then, after 7,500 periods, although HD firms still contract many partnerships, partnerships contracted earlier in the simulation come to an end, implying a slow down in the increase of the ADD statistics. However, the fact that the ADD statistics remains always positive indicates that, not surprisingly, to openly disclose knowledge has a positive effect on the formation of R&D partnerships. HD firms tend to develop more research agreements than other firms.

This point is confirmed by the graphs in Appendix IV.1., which represent the evolution of the network of R&D relationships all along one run of simulation (after 4,000, 12,000, 20,000 and 40,000 periods). Even if conclusions based on these 4 graphs must be taken with the greatest care, those graphs nevertheless tend to indicate that HD firms acquire a central position in the network compared to LD firms and this from the beginning of the simulation (the central position tends to get stronger as the simulation goes on).

Figure IV.3. also stresses the role played by the frequency of open knowledge disclosure on the average degree difference between HD and LD firms. Overall the ADD statistics increases when

Figure IV.3: ADD of high disclosing firms versus low disclosing firms



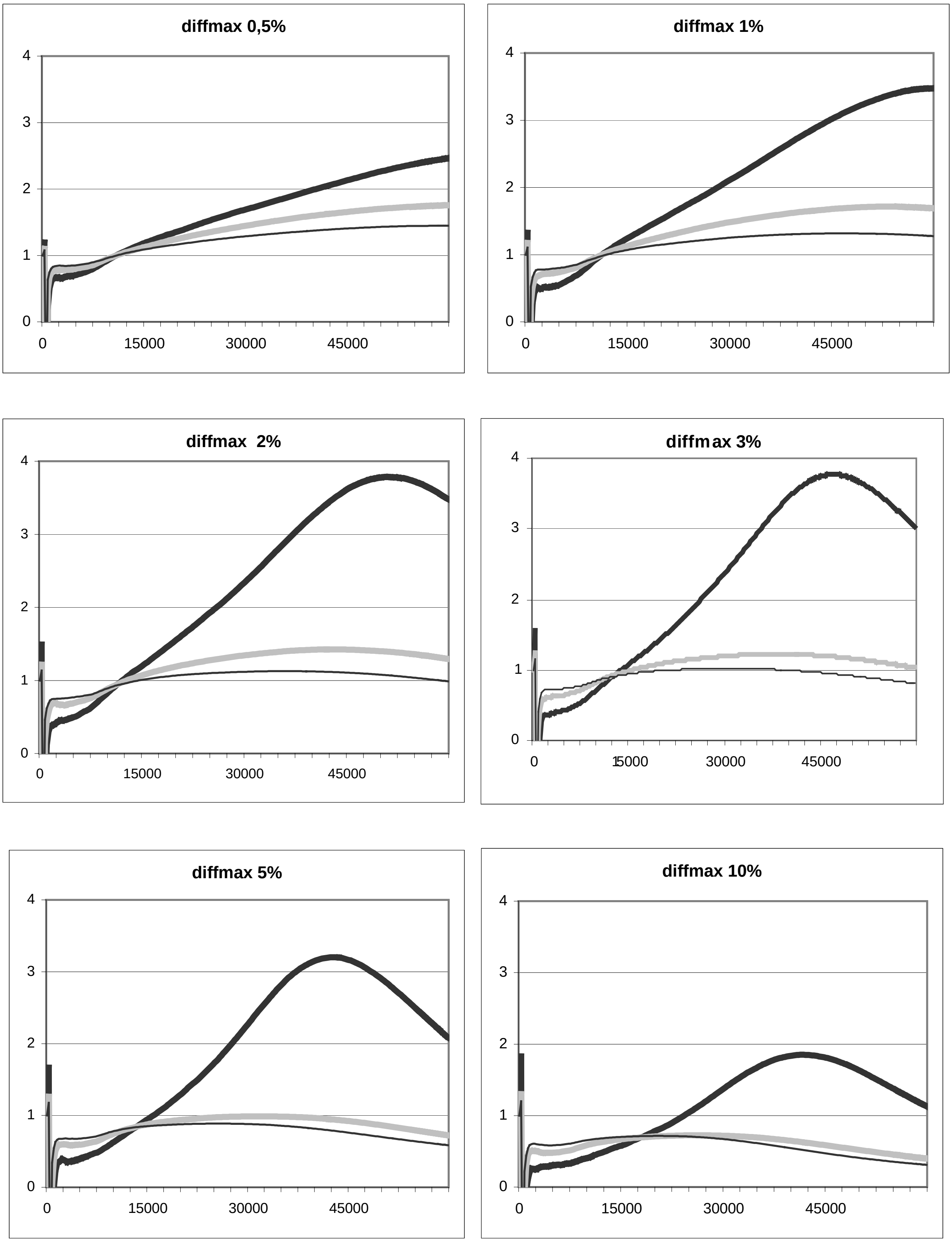
Legend: proportion of HD firms: Thick and dark: 10%; Thick and clear: 30%; Thin and dark: 50%.
Note: Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

the frequency of the disclosure for HD firms passes from 0.5% to 10%. In other words, it comes out that the more a firm discloses knowledge the higher the number of R&D agreements in which she is involved. But the effect of the frequency of knowledge disclosure on the ADD statistics is also very sensitive to the proportion of HD firms. Indeed, clearly the ADD increases only very slowly with the frequency of knowledge disclosure when the proportion of HD firms is high (30 and 50%) but increases sharply when the proportion of HD firms is low (10%).

Furthermore, the value of the ADD statistics decreases with the proportion of HD firms. Whatever the frequency of the disclosure, we observe that the less numerous the HD firms the more they develop R&D partnerships compared to LD firms. Indeed, for any value of the frequency of disclosure for HD firms, the ADD statistics is higher when the proportion of HD firms is 10% than when this proportion is set up to 30 or 50%. This point can easily be explained in the frame of our model: We consider open knowledge disclosure as a signal of competences that aims at identifying potential R&D partners with whom to cooperate in R&D. When firms think about establishing a new link with another firm, they include in their decision the reputation of other firms, which is positively linked with the disclosing strategy of these firms. The higher a given firm's reputation (compared to the other firms), the higher her probability to be proposed R&D partnerships. Hence, when too many firms disclose knowledge, it becomes harder for one disclosing firm to be distinguished from other firms. It follows that disclosing firms will be able to enter fewer R&D agreements. Put differently, when too many firms disclose knowledge, disclosing firms cannot display their differences with other firms and hence the disclosure strategy looses some of its interest since its primary aim is to enable the disclosing firm to be distinguished from other firms. Conversely, if only few firms reveal, these firms will attract all the R&D agreements and hence on average will have far more R&D partnerships.

To summarize, our simulations indicate that, overall, HD firms tend to develop more R&D agreements than LD firms. The next step is to explore the consequences of this feature in terms of profit. Does this tendency of HD firms to develop more R&D agreements materialise into profit? Or, put it differently, are disclosing firms also more profitable than LD firms? Undoubtedly, if we trust

Figure IV.4: APR of high disclosing firms versus low disclosing firms



Legend: proportion of HD firms: Thick and dark: 10%; Thick and clear: 30%; Thin and dark: 50%.
Note: Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

figure IV.4., it seems that in the short run disclosing knowledge is always profit decreasing for firms. But in the long run, HD firms tend to be more profitable than LD firms if they adopt reasonable strategies of disclosure, i.e. if they do not disclose too much knowledge.

First, we observe that in all cases, i.e. whatever the frequency of the disclosure and the proportion of HD firms, in the short run it is not profitable to adopt a strategy of open knowledge disclosure. Figure IV.4. clearly shows that at the very beginning of each simulation the average profit ratio is always less than one, indicating that HD firms are less profitable than LD firms. We can see further that this profit ratio is sometimes negative because HD firms may even experience losses in the short run. This result, which points out the risk of a disclosure strategy, is still reinforced by analysing the mortality of HD firms versus LD firms. It appears indeed that, on average, HD firms are more likely to disappear than LD firms at the beginning of the simulation and that the more firms disclose knowledge, the higher their bankruptcy probability (see below). This point stresses the risk of too active a disclosure strategy.

However, if open knowledge disclosure is a risky strategy in the short run, it may become quickly a profitable strategy (for firms who manage to remain alive). In all our simulations one may observe that, after approximately 12,000 time steps, when HD firms adopt a frequency of disclosure lower than 2%, the average profit ratio becomes higher than one, indicating that, on average, HD firms are more profitable than LD firms. Furthermore, this threshold of 12,000 periods does not seem to be affected neither by the proportion of HD firms nor by the frequency of the disclosure. In other words, whatever the frequency (yet lower then 2%) and the proportion of HD firms, after approximately 12,000 periods disclosing knowledge tends to be profitable for firms. Hence, we can make the following, apparently robust, proposition: Knowledge disclosure leads to profit reduction in the short run but may lead to higher profits in the long run, provided that HD firms do not disclose too much of their knowledge and that the proportion of HD firms remains low.

Indeed, the profitability of adopting a strategy of high knowledge disclosure depends strongly on the frequency of the disclosure and on the proportion of firms who disclose knowledge. First, we observe that when firms adopt reasonable strategies of open knowledge disclosure, i.e. when the frequency of the disclosure for HD firms is less than 2%, disclosing knowledge is profitable whatever the proportion of HD firms. It seems also that disclosing knowledge is the more profitable for a frequency of approximately 2-3%, when the proportion of disclosing firms is set up to 10%, and for a frequency of disclosure of 0.5-1%, when the proportion of disclosing firms is set up to 30 and 50%. For instance, for a frequency of 3% and when the proportion of HD firms is set up to 10% we observe a peak of profitability after approximately 45,000 periods. At this time, HD firms are on average almost 4 times more profitable than LD firms. Then the APR statistics decreases again but remains above 1.

Hence, to disclose knowledge may be a profitable strategy in the long run provided that disclosing firms do not disclose knowledge too frequently. As soon as HD firms disclose too frequently their knowledge, their profitability decreases compared to LD firms. When the frequency of disclosure becomes more than 5% then the APR is always lower than 1 (unless the proportion of HD firms remains very low), indicating that disclosing knowledge is not profitable.

Furthermore, it appears that the proportion of HD firms affects sharply their performances. We pointed out earlier that the less numerous the disclosing firms, the more they set up R&D agreements. It comes out here that the less numerous the HD firms, the more profitable they become in the long run, compared to LD firms. Conversely, the higher the number of highly disclosing firms, the less profitable it is to adopt a strategy of high knowledge disclosure. Yet, this conclusion is inversed in the short run, where we observe that the less numerous the HD firms, the lower the APR.

Therefore, when few firms adopt a high disclosing strategy it is more risky in the short run but also more profitable in the long run. For instance, for a frequency of disclosure above 5% for HD firms we saw above that in the long run HD firms are always less profitable than LD firms when the proportion of HD firms is set up to 30 or 50%. Yet HD firms remain more profitable than LD firms in the long run when their proportion is set up to 10%. This shows clearly that firms' performances are highly sensitive to the proportion of HD firms.

To summarize, our simulations show that to adopt a strategy of open knowledge disclosure can sometimes be profitable in the long run but, in any case, is never profitable in the short run. Furthermore, HD firms may experience negative profits in the short run, which may lead them to bankruptcy. Indeed when studying the mortality statistics, it comes out that HD firms are not only less profitable than LD firms in the short run, they are also more likely to disappear because they do not satisfy the survival condition (to have a positive funding).

Table IV.4: Percentage of bankruptcy for high disclosing firms

Frequency of the disclosure	Proportion of high disclosing (HD) firms								
	10%			30%			50%		
	Percentage of bankruptcy	Average time to the last firm's death	Average time to 90% of realised bankruptcy	Percentage of bankruptcy	Average time to the last firm's death	Average time to 90% of realised bankruptcy	Percentage of bankruptcy	Average time to the last firm's death	Average time to 90% of realised bankruptcy
0.5%	17.44%	3500	2000	7.13%	4250	1750	4.67%	3000	1750
1%	27.99%	4250	2250	10.49%	4000	2000	5.81%	4250	2000
2%	39.35%	5000	2500	12.78%	3000	1750	6.42%	3000	1750
3%	48.07%	4500	2500	13.99%	3500	2000	6.99%	3000	2000
5%	50.71%	6250	2000	14.32%	4000	2000	7.36%	3000	2000
10%	56.19%	5500	2750	18.70%	3250	2000	10.45%	4000	2000
20%	67.95%	14250	4000	-	-	-	-	-	-
30%	83.37%	17750	5750	-	-	-	-	-	-
40%	95.54%	18250	4750	-	-	-	-	-	-

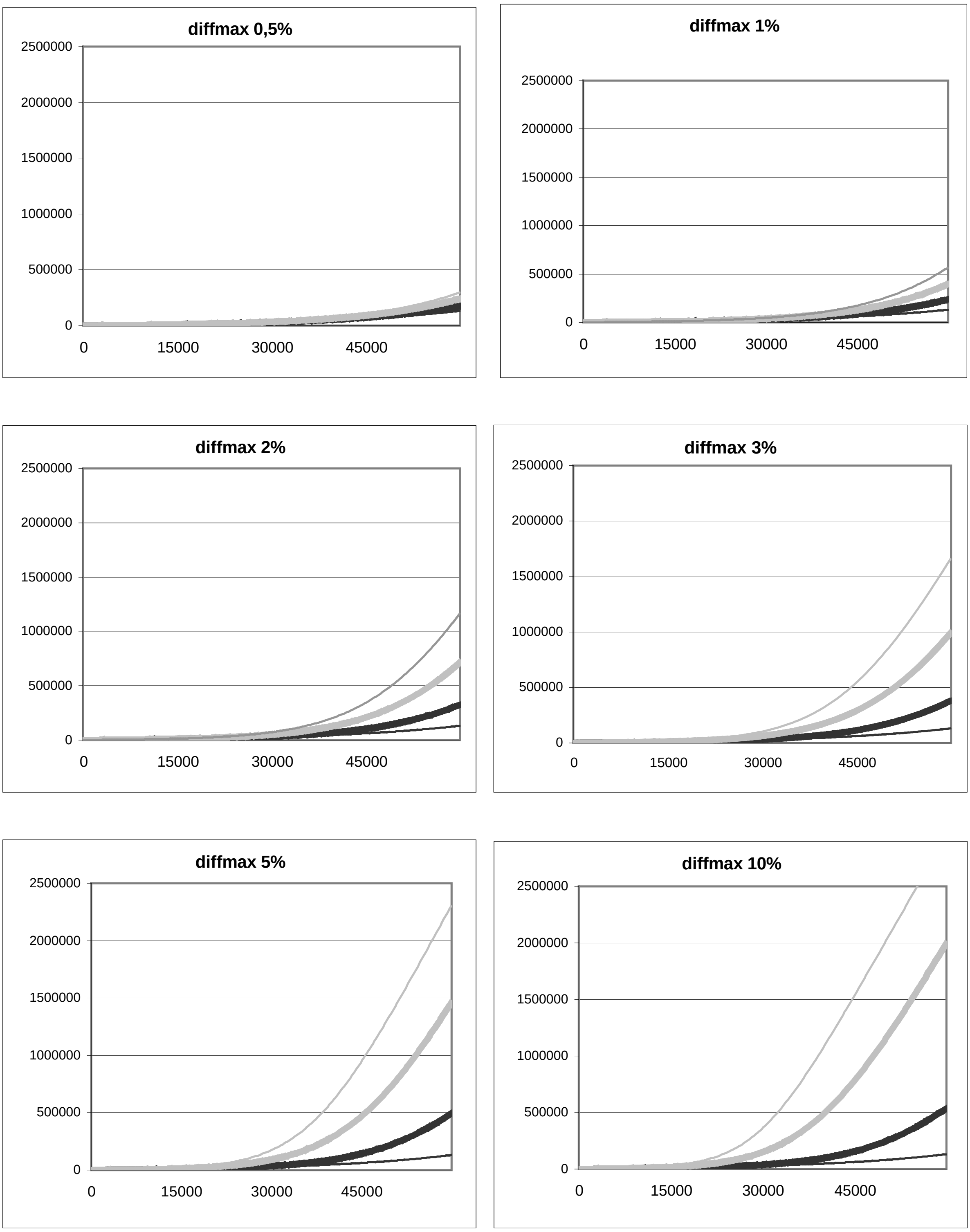
Note: Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

Indeed, Table IV.4. clearly indicates that the more firms disclose knowledge, the higher they are likely to go bankrupt. Similarly, the lower the proportion of HD firms, the higher their probability to go bankrupt. It seems that there exists a threshold with respect to the frequency of knowledge disclosure above which high disclosing firms all go bankrupt. Indeed, when the proportion of HD firms is set up to 10% and when those firms adopt a disclosure frequency higher than 40%, then approximately 95% of HD firms go bankrupt, indicating that firms can hardly survive with a frequency of knowledge disclosure above 40%. Furthermore, it also appears that there exists a threshold in time above which firms do not go bankrupt. Indeed, bankruptcy occurs in general early in the simulation. For instance, when the frequency of disclosure is lower than 10%, 90% of all the bankruptcy occurs within an interval of 2000-2500 periods on average. Furthermore, when the frequency of disclosure is lower than 10% the last bankruptcy never occurs after 5500 periods. Hence, HD firms who survive after the first 5,000 steps of the simulation are almost always certain to remain alive for the rest of the simulation.

Our last focus lies in the total sum of knowledge produced by firms in the economy. This statistics may be interpreted as a proxy of the pace of technological progress and could even be considered as a first indicator of the effect of open knowledge disclosure on social welfare.

Figure IV.5. allows us to observe two phenomena. First, the evolution of knowledge follows an exponential trend, which is in line with the theoretical view that knowledge production follows increasing returns. Knowledge is a cumulative good, meaning that the more knowledge an economy holds the more knowledge it will produce in the future (Scotchmer, 1991). Second, not surprisingly, one can see clearly that open knowledge disclosure tends to accelerate this process. Higher knowledge disclosure intensity and higher proportion of disclosing firms enhance the production of knowledge in the industry. However, this is true only in the limit of the survival condition. Firms must not disclose too much knowledge if they want to remain alive. Hence, after a certain threshold in the frequency of knowledge disclosure, disclosing knowledge may have a negative effect on the aggregate stock of knowledge since, although firms who remain alive produce more knowledge, less firms survive. Hence, our finding indicates that in the limit of the survival condition, disclosure strategies have a strong positive effect on the stock of knowledge of the industry. Interpreting this result as evidence that open knowledge disclosure is welfare increasing and, as such, constitutes a socially desirable behaviour may be premature but, at least, our result does not contradict this possibility.

Figure IV.5: Total sum of knowledge in the economy



Legend: proportion of HD firms: Thick and dark: 10%; Thick and clear: 30%; Thin and clear: 50%; Thin and dark: 0%.
Note: Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

IV.2.2. When firms differ both in their disclosure strategy and in their initial endowments of specific knowledge

In this second part, we allow firms to differ also with respect to their initial endowments of specific knowledge, which means that we consider now 4 types of firms: small (in the sense of having low initial endowments of specific knowledge) high disclosing firms (SH firms in the following), small low disclosing firms (SL firms), big (in the sense of having high initial endowments of specific knowledge) low disclosing firms (BL firms) and big high disclosing firms (BH firms). Furthermore, in order to focus more clearly on the comparison between high disclosing and low disclosing firms and on big and small firms we fix the proportion of high disclosing firms and big firms to 30% (see table IV.3).

Our aim is to compare the performances of firms according to their disclosing strategy and their initial endowments of specific knowledge. We wish to explore in more depth the consequences of open knowledge disclosure on firms' performances and to compare the effects of this strategy relatively to other variables that may affect firms' profitability. Specifically, we expect big firms to perform better both in terms of profitability and in terms of R&D partnerships than other firms. As we put it in our model, initial endowments of specific knowledge should matter for long run firms' profitability, since firms endowed with high level of specific knowledge enjoy higher probability to produce further specific knowledge. Hence higher initial endowments of specific knowledge should provide firms with a self-reinforcing advantage through time, firms with high level of specific knowledge producing more specific knowledge than others. Put it plainly, big firms have an initial advantage over small firms.

Therefore, our interest here lies in the comparison of the performances of SH firms versus BL and BH firms. This comparison may allow us to draw some conclusions regarding the relative importance of knowledge disclosure as compared with merely "being big". Hopefully we will show that, whereas enjoying low initial endowments of specific knowledge is indeed a handicap for long run profitability, adopting an active strategy of open knowledge disclosure can compensate it.

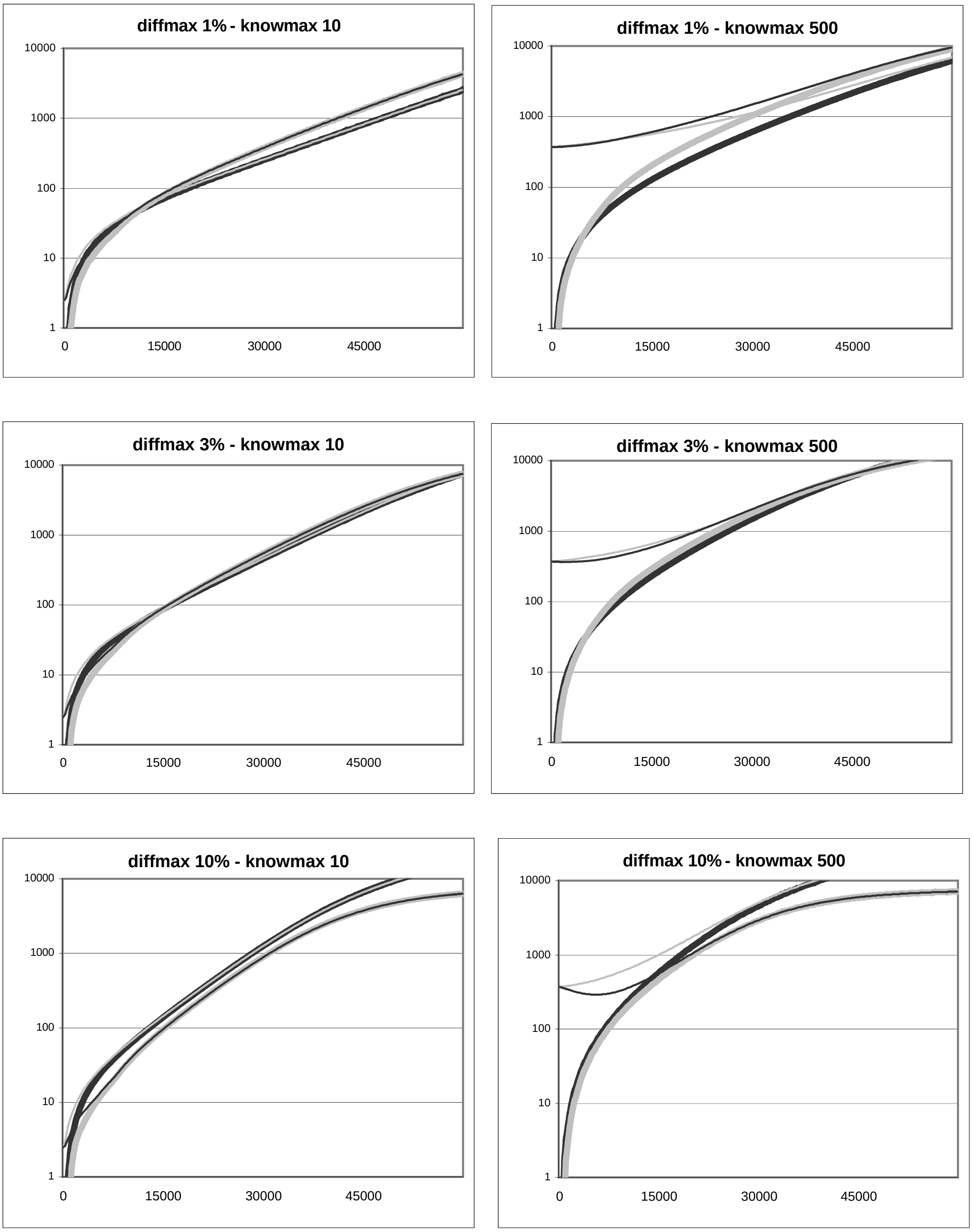
Figure IV.6. displays firms' average profitability according to their type. Three cases can be distinguished: When high disclosing firms adopt low frequency of knowledge disclosure (lower than 2%), when they adopt a frequency of approximately 2 or 3% and when they adopt a frequency higher than 3%.

First, when high disclosing firms adopt a frequency of knowledge disclosure lower than 2%, one may observe from the two upper graphs that firms' long run profitability is mainly determined by their disclosure strategy (either low or high). Initial endowments of specific knowledge play a role in the short run but not in the long run. Overall, we observe that in the first periods of the simulation both BH and BL firms exhibit higher profits than SH and SL firms but quickly firms who disclose a low amount of knowledge (BL and SL firms) are outperformed by those who disclose a high amount (BH and SH firms). In the long run, initial endowments of specific knowledge do not affect firms profitability since it appears that BH and SH firms on the one hand and BL and SL firms on the other hand, follow exactly the same evolution, i.e. they have exactly the same profits on average. It is therefore only the strategy of knowledge disclosure that counts in the long run in order to determine firms' profits. Furthermore, one can observe that when SH firms have joined BH firms and BL firms SL firms the differential of profits between low and high disclosing firms increases slowly but steadily (this may not appear as obvious on the graph since the scale is logarithmic).

Therefore, when firms adopt low frequency of knowledge disclosure (lower than 2%) initial endowments of specific knowledge do not play any role to explain firms' long run profitability compared to firms' disclosing strategy. But initial endowments of specific knowledge may nevertheless affect firms' profitability in the short run quite consequently. Furthermore, initial endowments of specific knowledge affect the time needed for SH firms to offset BL firms and to catch up with BH firms.

For instance, when initial endowments of specific knowledge are set up to 10 for highly endowed firms, we observe that high disclosing firms quickly becomes the more profitable. After

Figure IV.6: Firms' profits according to the frequency of knowledge disclosure and to initial endowments of specific knowledge



Legend: type of firms: Thin and dark=BH; Thick and dark=SL; Thick and clear=SH; Thin and clear=BL.
Note: The scale is logarithmic. Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

approximately 5,000 periods SH firms outperform BL firms and after 10,000 time steps SH firms converge toward BH firms and BL firms toward SL firms. Then, SH and BH firms on the one hand and SL and BL firms on the other hand follow exactly a similar pattern of evolution. When initial endowments of specific knowledge are set up to 500 for highly endowed firms we observe exactly the same trend but the time needed to catch up is more important. This point puts apart, the results previously emphasized do not change significantly. SH firms still become relatively quickly more profitable than SL firms, they still catch up and even outperform BL firms (but only after approximately 30,000 periods) and they still tend to catch up in the very long run with BH firms (but only after 40,000 periods), even if they never outperform them. Similarly, SL and BL firms' profitability still converge in the long run, even if BL firms manage to keep a slightly higher profit.

Therefore, if differences with respect to initial endowments of specific knowledge only affect the time needed for catching up, they can nevertheless affect it in a very consequent way. The process of catching up may be very hard and long for firms who started with relatively low endowments of specific knowledge. But, in general, our simulations indicate that when the frequency of disclosure is lower than 2%, disclosing firms will catch up with highly endowed firms. Moreover, the smaller the initial difference of specific knowledge, the faster the catching up.

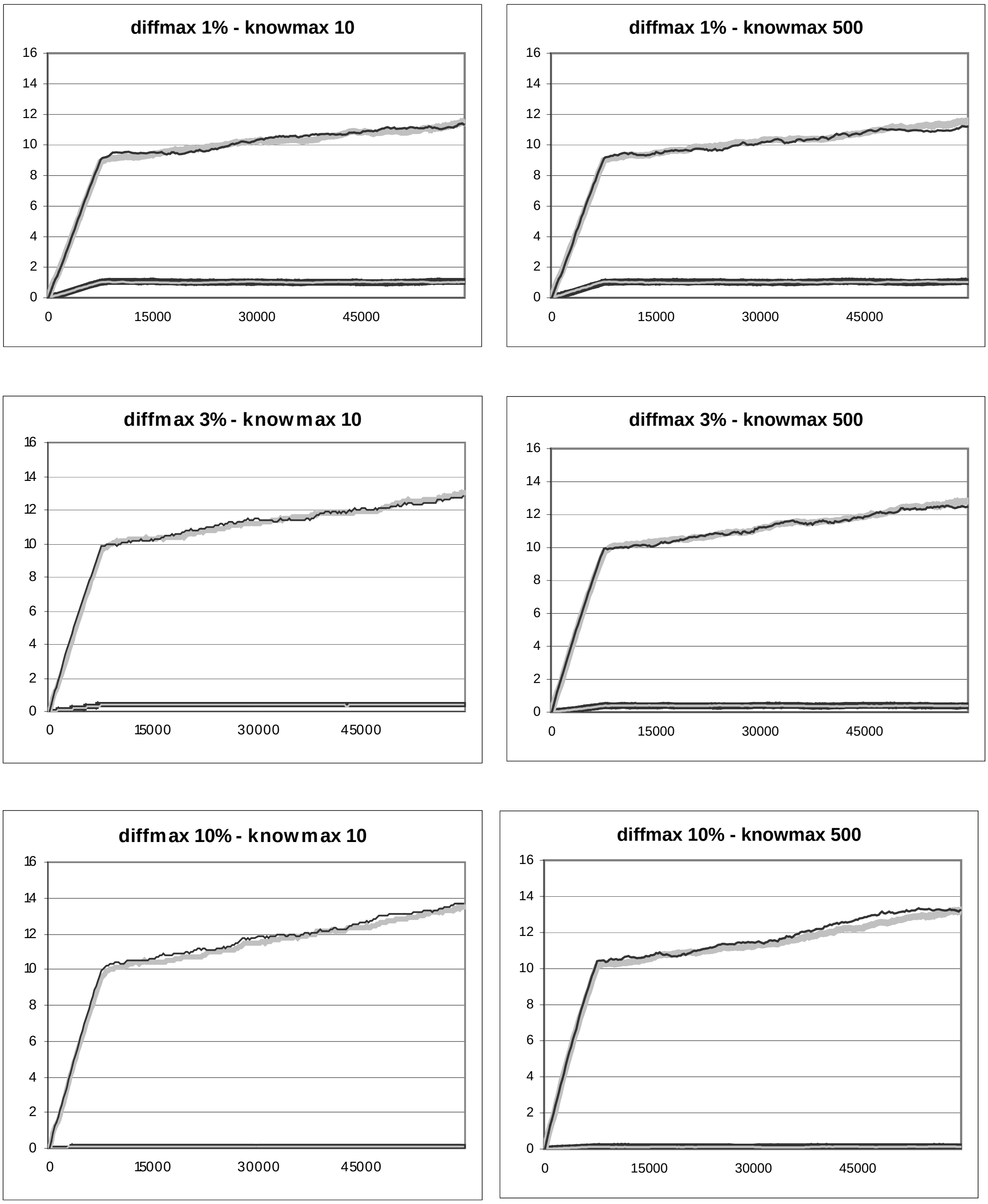
When firms adopt a frequency of knowledge disclosure of approximately 2 or 3%, the above conclusion changes. In the short run firms highly endowed with specific knowledge still remain more profitable than firms slightly endowed, the latter still catch up with the former in a relatively short spell of time (depending on the difference in initial endowments of specific knowledge) but then all the four types of firm converge and follow the same trend. It appears therefore that neither the initial endowment of specific knowledge nor the strategy of disclosure play a role on firms' profitability in the long run when the frequency of disclosure is equal to 2 or 3%.

Finally, when firms adopt a frequency of disclosure higher than 3%, one may observe from the two lower graphs in figure IV.6. that conclusions stressed above are inversed in the long run. In the short run it is still BH and BL firms who perform better, but this initial advantage provided by higher initial endowments of specific knowledge is quickly overcome by the strategy of knowledge disclosure. In the long run SL and BL firms experience higher profits than BH and SH firms, indicating that to disclose knowledge too frequently does not provide firms with competitive advantage on the contrary. Furthermore, here again, in the long run, initial endowments of specific knowledge do not play any role to determine firms' profit. The latter are only affected by whether or not firms' adopt high strategy of knowledge disclosure. But, this time, firms who adopt high strategy of knowledge disclosure are less competitive than others. In other words, when the frequency of disclosure is higher than 3%, adopting a high strategy of open knowledge disclosure is profit decreasing for firms. Moreover, as in former cases, initial endowments of specific knowledge do not affect firms' long run profits but only the time needed for SH and SL firms to catch up with BH and BL firms. The higher the difference in endowments of specific knowledge, the longer the time needed to catch up.

To summarize, our simulations indicate that in the short run firms highly endowed with specific knowledge always perform better than firms slightly endowed, whatever the frequency of the disclosure. But, in the long run firms' profitability is not affected by firms' initial endowments of specific knowledge. It is only sensitive to firms' strategy of knowledge disclosure. Initial endowments of specific knowledge only affect the time firms need in order to achieve their long run position. Firms' long run profits are highly dependant on the strategy of knowledge disclosure they adopt but according to the frequency of the disclosure, conclusions are different. When the frequency of disclosure is lower than 2%, firms who adopted a strategy of high level of knowledge disclosure perform better in the long run than firms who adopted a strategy of low level of knowledge disclosure. When the frequency is approximately of 2 or 3%, the strategy of knowledge disclosure does not seem to affect firms' long run profitability. And when the frequency of disclosure is higher than 3%, firms who adopted a strategy of low level of knowledge disclosure perform better, thus indicating that if disclosing knowledge can be profitable to firms in the long run, disclosing knowledge too frequently is harmful.

Prior to conclude, it is worth stressing an important assumption of the model, which may explain most of the above results. It was assumed here that firms disclose a fraction of the specific

Figure IV.7: Firms' degree according to knowledge disclosure intensity and to initial endowments of specific knowledge



Legend: type of firms: Thin and dark=BH; Thick and dark=SL; Thick and clear=SH; Thin and clear=BL.
Note: Although it is not clear on this graph, BL and SL curves on the one hand and BH and SH curves on the other hand follow the same path, i.e. only two curves appear clearly on the graph. Each simulation was repeated 50 times and results displayed here represent the average outcome of the 50 simulations.

knowledge they hold but, whatever the "quantity" or the "quality" of knowledge that is disclosed, firms' reputation increases always of one unit. Hence we assume that it is only the act of disclosing knowledge that counts in order to build the firm's own reputation and not "what" is disclosed. Notice that in order to support this assumption, it can be argued that firms, when they assess other firms' reputation consider only the act of disclosing knowledge because to consider other indicators would be more time consuming and more expensive.

However, this assumption alone may be sufficient to explain why, when the frequency of disclosure is lower than 2%, SH firms always tend to catch up with big firms. Indeed, if reputation is only based on the act of disclosing, it implies that reputation of SH and BH firms, on the one hand, and of BL and SL firms, on the other hand, follows exactly the same trend, which means that BL firms develop as many partnerships as SL firms and BH firms as many as SH firms (since R&D partnerships are mainly function of firms' reputation). Figure IV.7. above clearly confirms that firms' degree depends mainly on their disclosing strategy and is almost independent of their initial endowment of specific knowledge.

If it was assumed that reputation is a function not only of the act of disclosing knowledge but also of the quantity of disclosed knowledge, BH firms would see their reputation grow faster than SH firms and it is hence probable that the latter would have more difficulties to catch up. It would also become harder for SH firms to catch up with BL firms since the latter hold initially more knowledge than SH firms, which implies that the quantity of knowledge they disclose, although they do not disclose knowledge as frequently as SH firms, may be more important than the quantity of knowledge disclosed by SH firms and hence that their reputation may grow faster than the one of SH firms. However, this point will have to be tested in further works.

This work was only a first step in our attempt to describe the formation of innovation networks by putting the main emphasis on the relationship between open knowledge disclosure and the creation of new R&D partnerships. In our next research, many points will deserve a more in depth treatment. Here are three suggestions that may be worth including in further developments: First, we may consider a different reputation function that would take into account the "quantity" of knowledge that is disclosed and not only the act of disclosing. This, as it was discussed shortly above, may affect our results in an important way.

Second, it may be necessary to explore how our conclusions evolve if α, which is the unitary cost of maintaining a link with another firm, was not assumed to be constant. Indeed, instead of being constant, α may as well be increasing with the number of relationships since it is likely to be more and more expensive for a firm to maintain her network when the size of the latter is increasing. Our guess is that to include this feature in our model may render behaviours of knowledge disclosure less profitable than they are in our current model.

Third, it may be worthwhile to lay more emphasis on behaviours of closed knowledge disclosure, which was introduced in chapter II. In our model, it appears clearly that we regard open knowledge disclosure as a prerequisite to closed knowledge disclosure, as a first step that allows the firm to join innovation networks and hence that may lead to knowledge trading within the innovation networks that have been joined. But we do not really focus on the role of knowledge trading, which is considered as exogenous, each firm communicating at each period a fixed fraction β of her knowledge to partners. It may be interesting to explore how these two types of knowledge disclosure, open and closed, co-evolve in the development of innovation networks.

Conclusion of the chapter

This chapter aimed at providing a theoretical model describing the formation of innovation networks by allocating a central role to behaviours of open knowledge disclosure. More generally the model exposed in this chapter is concerned with the fact that a strategy of open knowledge disclosure constitutes not only a gift made by disclosing firms to other firms but also contributes to an increase in the reputation of disclosing firms, thus allowing them to increase their individual profitability. It is indeed argued that firms who widely disclose knowledge to other firms are more likely to enter innovation networks and to acquire a central position within those networks because the act of disclosing knowledge increases the reputation of the firm, which constitutes the main criterion firms take into account when deciding whether to start a cooperation with another firm.

Firms are therefore confronted with the following trade-off: Actively disclosing knowledge is penalising on the one hand, since it provides competitors with valuable knowledge, but, on the other hand, it is profit increasing since disclosing firms are also more prone to form new links with other firms, enabling them to access external sources of knowledge.

Some implications of our model have then been tested by using numerical simulations. To summarize, let us emphasise the following results that have emerged from these simulations: *(i)* Open knowledge disclosure tends to increase the number of R&D partnerships contracted by high disclosing firms. The less numerous the disclosing firms, the higher the number of R&D partnerships they are involved in; *(ii)* In the short run, open knowledge disclosure is not profitable, whatever the frequency of the disclosure and the proportion of disclosing firms; *(iii)* Conversely, in the long run, open knowledge disclosure can become a profitable strategy, provided that the frequency of the disclosure remains low (lower than 2%); *(iv)* Open knowledge disclosure is a more profitable strategy if few firms adopt it; *(v)* Open knowledge disclosure increases the probability of bankruptcy in the short run. The less numerous the disclosing firms, the higher the probability that they go bankrupt; *(vi)* When the frequency of the disclosure for high disclosing firms is not too high (lower than 2%), adopting a strategy of open knowledge disclosure allows firms who started with low endowments of specific knowledge to catch up with and to outperform (in terms of profitability) firms who started with higher endowments of specific knowledge and who adopted a strategy of low knowledge disclosure. Furthermore, it also allows those firms to catch up with (but not to outperform) firms who started with higher endowments of specific knowledge and who adopted a strategy of high level of knowledge disclosure, tending to support the view that the disclosure strategy counts more than initial endowments of specific knowledge in order to explain firms' long run profitability.

Our model provides therefore a rationale to behaviours of open knowledge disclosure by showing that such strategies, although risky in the short run, may pay in the long run because they enable firms to access external sources of knowledge more easily. In chapter III and in this chapter we studied behaviours of open knowledge disclosure either by using game theory or by using numerical simulation methods. Let us now, in the next and last chapter of this thesis, attempt to asses the empirical relevance of our theory. In this respect, we will first discuss the role of patents as empirical devices to disclose knowledge and then we will focus on biotechnologies in order to see whether or not firms openly disclose knowledge in this industry and, more specifically, whether they regard patents as an efficient device to openly disclose knowledge and to signal their competences.

CHAPTER V:

THE ROLE OF PATENTS AS COORDINATION DEVICES: THEORETICAL DISCUSSION AND APPLICATION TO BIOTECHNOLOGIES FIRMS IN THE UPPER-RHINE BIOVALLEY[67]

[67] An important part of this work was realised in collaboration with Rachel Levy, Sandrine Wolf, Antoine Bureth and Séverine Baverey.

The objective of this chapter is to study the role of patents in the innovation process, with specific emphasis on their function of “open knowledge disclosure”. We attempt to answer the following question: Are patents only useful to protect their owners from competition or are they also devices that facilitate interactions and collaborations among agents involved in the innovation process? Furthermore, should this second hypothesis be confirmed, what is the importance of strategies of open knowledge disclosure in this coordination process and, more specifically, of patents as devices to openly disclose knowledge? We handle these questions by combining a theoretical discussion with the first elements of a case study in the field of biotechnologies.

In theory, patents have a double function, since they both protect an innovation and widely disclose the knowledge related to this innovation. Economists have focused essentially on the protection function associated with a patent. However, our conviction is that the function “disclosure of codified knowledge”, which operates through the automatic publication of the description of the innovation by the national patent office, plays a role at least as important as the protection function. It is the combination of the disclosure and protection functions and not one single function taken separately that gives its strength and its strategic importance to a patent.

According to how these two functions are tuned, patents can serve two different logics of utilisation: A logic of exclusion and a logic of coordination and even of cooperation among agents. Indeed, more than a simple guarantee of a monopoly position, in some industries where innovation is strongly systemic and the risk of patent overlap is high (it is the case of the semi-conductors but also more and more of biotechnologies), patents can play a fundamental role of coordination in the innovation process, by easing the exchanges of knowledge and R&D collaborations for instance.

Our theoretical discussion is followed by an empirical study in the field of biotechnologies. Exploring the role of patents in this field should prove particularly interesting, since biotechnologies are a young industry in which, almost paradoxically, the patent system and publicly funded research play equally a central role. Those features suggest that patents may be used in a very specific manner in this sector. Overall, our inquiry confirms the strategic importance of patents in biotechnologies and not only in order to exclude rivals but also to improve firms' bargaining power, to ease access to financing and to signal competences.

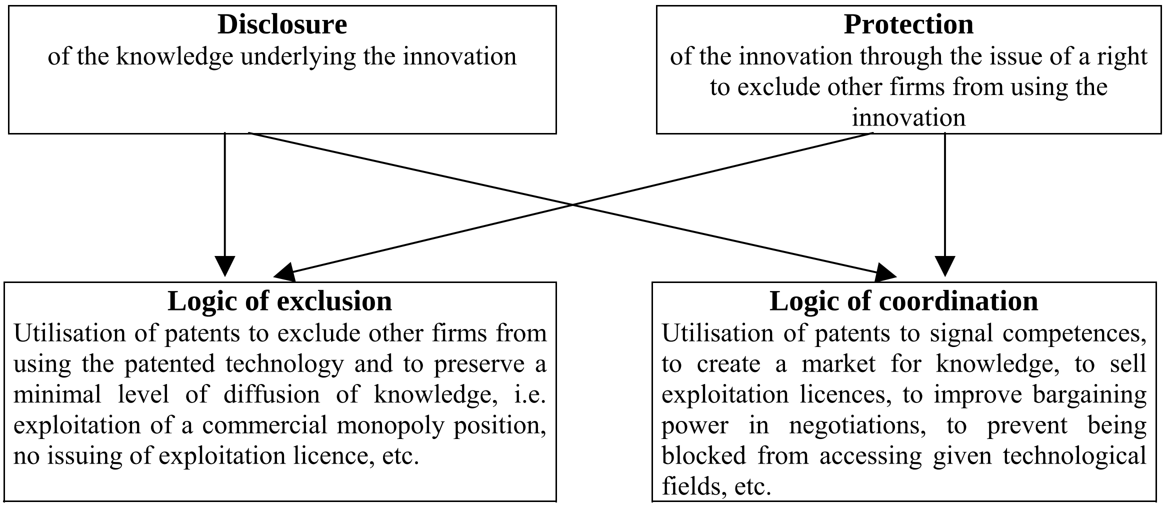
The structure of the chapter is the following: In the first part we explain how the theory about the role of patents has evolved from an approach that used to view patents as a way to appropriate the return of innovation and to preserve a minimal diffusion of knowledge towards a vision that regards patents as devices to ensure coordination and collaboration. In the second part we present the results of a questionnaire-based inquiry for which we collected the answers of 18 biotechnologies firms located in the Upper Rhine BioValley. Specific attention is paid to behaviours of open knowledge disclosure and to their consequences on R&D collaborations.

V.I. The patent system: From a logic of exclusion to a logic of coordination

> "Instead of being driven by a desire to win strong legal rights to a stand alone price, these firms are driven by broader motives […] The classical role of patents seems to be dominated by this broader use of patents as "legal bargaining chips" that enable the firms to avoid being excluded in a particular field of use, to obtain more favourable terms to their licensing agreements, to safe guard against costly patent litigation or to gain access to external technologies or more favourable terms of trade"
>
> Hall and Ziedonis (2001, p. 104)

A patent has two main properties or functions: A function of protection of innovations and a function of disclosure of the knowledge underlying the innovations. In terms of protection, a patent provides its owner with an exclusive property right over his patented innovation. This function of protection is always accompanied by the disclosure of some information about the innovation, since a description of the patented innovation is automatically published by the patent office and hence becomes available to everybody (see part II.1.2.3.).

Figure V.1: Patents: A combination of two properties that can serve two different logics of utilisation



Traditionally economic scholars have been essentially interested in the monopoly power granted by a patent, i.e. in the protection function. However, we argue here that it is the combination of the two functions of a patent, the disclosure one and the protection one, that gives its strategic importance to a patent. Depending on how these two functions are tuned, they can lead to two different logics of utilisation of the patent system: A logic of exclusion (exploitation of a monopoly position and preservation of a minimal diffusion of knowledge), which is usually put forward by economic textbooks, and a logic of coordination (transfer of licence, R&D collaboration, etc.) which until very recently was widely neglected by scholars[68].

In other words, we argue here that a patent cannot be considered as being merely a device to exclude potential rivals or imitators. Combined with a function of disclosure, the protection offered by a patent transforms it into a powerful instrument to facilitate coordination and inter-firm collaborations.

V.I.1. The empirical denial of the logic of exclusion

V.I.1.1. Protection and divulgation in a logic of exclusion[69]

Economic scholars usually describe patents as devices that can reconcile two apparently opposite but equally necessary goals: To provide innovators with a high level of incentives to innovate and to ensure a wide dissemination of the results of their research.

Indeed, knowledge is traditionally considered as a non-rival, non-appropriable and cumulative good. On the one hand, non-appropriability is not desirable, since it decreases firms' incentives to invest in knowledge production but on the other hand, non-rivalry and cumulativeness imply that the

[68] A third logic of use of patents is the logic of liberation, i.e. when a patent owner gives up his rights about his patent and hence lets everybody use it for free. Here the patent is just a device that ensures that nobody will appropriate the disclosed innovation. In some sense, within this logic of use, the innovator, by applying for a patent, liberates his innovation.

[69] Since this point was already treated in chapter I, we provide here only a short summary of the role of patent in a classical perspective.

produced knowledge must remain as much as possible non-appropriable. A direct consequence of this dilemma is that non-market mechanisms must be implemented in order to increase both the incentives to invest in knowledge production and the dissemination of the produced knowledge. This statement is at the origin of the implementation of the patent system.

In theory, a patent ensures its owner with a monopoly position, limited in time and in space, over the applications of the patented innovation. This issue of a monopoly position aims at increasing firms' expected returns of innovation, which in turn should increase their incentives to innovate. Moreover, in theory patents ensure a wide diffusion of the knowledge (codified) underlying the patented innovation, since they force inventors who apply to provide a description of their inventions that is then made available to everybody. At the very least, even if patents do not disclose important technical results, they still remain an indicator of which field may be worth exploring and which one may not. Such information about the map of the technological field is also quite valuable.

This traditional view of the patent system calls for one essential remark: It assumes that innovation and commercialisation are two distinct steps and that patents stand at the frontier between them. Firms innovate, apply for patents and then commercialise their patented innovation. Furthermore, this view also assumes that innovations are autonomous, that they are not embodied in a wider system and hence that they can easily be sold on a market. What would be the role of patents in a more complex context in which innovation is the outcome of a cumulative and interactive process and in which it is integrated within a wider system and cannot be considered independently of this system? Does the view that considers patents as providing exclusive monopoly rights of exploitation over innovations make sense in a context in which innovations are not completed and not ready to be exploited? In such a complex, systemic context the traditional view of patents may be useless.

To summarize, patents, because they combine the functions of protection and disclosure, are traditionally considered as major instruments of innovation policy. They restore the incentives to invest in knowledge production, since they allow to some extent the appropriation of the innovation, and they ensure the necessary dissemination of the research results, since the knowledge enabling the reproduction of the patented innovation is published. However, the confrontation of these two aspects of the patent system with empirical works on the topic contradicts this classical picture of the role of patents.

V.I.1.2. Patents are not central to appropriating the returns to R&D in most industries

This part draws heavily on Jaffe's survey (2000), which underlines that classical explanations of the economic role of patents present serious dysfunctions. More specifically, in most industries, firms do not rely on patents to protect their inventions. This conclusion appears quite robust in the sense that it is based on several empirical studies, concerning different periods, countries and industries, that all converge to similar results.

The pioneer empirical evaluations of the role of patents for firms are due to Scherer *et al.* (1959) in the US and to Taylor and Silberston (1973) in the UK. Both studies conclude similarly that, with the notable exception of the pharmaceutical industry, firms do not consider patents to be efficient to ensure a monopoly position on a given market or even to be a necessary condition to make an innovation profitable. This was considered as quite surprising then but it has been confirmed by all further studies from then until very recently.

In the 1980s, Levin, Klevorick, Nelson and Winter (1987) displayed the results of a questionnaire-based survey administered in the US to 650 manufacturing firms (The *Yale survey*; see also Levin, 1986 and 1988). Among other important results, they notice that firms report that they value many methods of protection from imitation (such as secrecy, lead time or superior services) higher than the patent system. Only firms located in industries that involve chemical based knowledge (pharmaceuticals, organic and inorganic chemicals, petroleum, plastic materials) report to rely strongly on the patent system in order to protect their innovations from imitation. These conclusions hold both for process and product innovations, except for secrecy that is rated below the patent system for product innovation (which is not surprising since in this case secrecy can easily be broken through reverse engineering).

Mansfield, Schwartz and Wagner (1981) reached similar conclusions by studying 48 major innovations in 4 industries (chemicals, drugs, electronics and machinery). They report that when firms are asked whether or not their inventions would have been achieved in the absence of the patenting institution, more than half of the firms answer positively, suggesting that patents do not really play the incentive role that is traditionally attributed to them. When firms in the drug industry are excluded, it is less than one quarter of the innovations that would not have been implemented without patents.

Mansfield (1986) also attempted to assess the extent to which the rate of development and commercialisation of inventions would decline in the absence of patent protection. He uses data about 100 firms in 12 industries over the period 1981-1983. His conclusions are similar to those reached by Mansfield, Schwartz and Wagner (1981): Pharmaceuticals apart, patents are not essential to the development and introduction of more than 70% of the innovations.

In the 1990s, studies carried out in the USA (Cohen, Nelson and Walsh, 2000), Japan (Goto and Nagata, 1996) and Europe (Arundel and van de Paal, 1995; Arundel, 2001), reached similar conclusions. For instance, Cohen *et al.* (2000) present the results of a questionnaire-based inquiry administered to 1478 R&D labs in the US manufacturing sector in 1994 (The *Carnegie-Mellon University survey*) and report that, on average, for both product and process innovations firms rate patents and other legal devices far below the following methods of protection of an innovation from imitation: Secrecy, lead time advance, technological complexity, complementary sales and services and complementary manufacturing.

For Europe, Arundel (2001) used the data of the 1993 European Community Innovation Survey (CIS) that includes information about 2849 European firms from 1990 to 1992. He focuses specifically on 3 questions: What is the importance of patents compared to secrecy to protect innovation in Europe? Do small firms find patents more efficient than secrecy to protect their innovation? How do these conclusions evolve through time? His conclusions are unambiguous: Firms of all sizes find secrecy to be relatively more important than patents but small firms find secrecy to be of greater importance than larger firms[70]. Furthermore, these conclusions appear to be reinforced through time, as firms tend to value secrecy higher than patents nowadays than some years ago.

All the studies that have been reviewed so far tend to suggest that the pharmaceutical industry is an exception. In this industry patents seem essential to spur innovation and firms could hardly be innovative without the patent system. This point is confirmed by a study of the *Federal Trade Commission* (2003), which interviewed several panellists on the topic. Some argue that without patents, the innovation rate would decline by approximately 60% in pharmaceuticals while others assess that innovation would merely disappear. This peculiarity, the fact that patents play a central role in pharmaceuticals, must be kept in mind. It may be useful in the second part of this chapter when we study the role of patents in biotechnologies because this field has much in common with pharmaceuticals.

Not only questionnaire based studies but also econometric studies come to this somehow unquestionable conclusion that patents are not central to appropriate the benefits of innovations. For instance, Sakakibara and Branstetter (2001) examined the macro effects of the patent laws reinforcement and the patent scope broadening that occurred in 1988 in Japan. Following the mainstream theory, this event should have increased the number of patent applications as well as the rate of innovation in the country. However, the authors' findings do not confirm this traditional view: "Our evidence suggests that the responsiveness to changes in patent scope is limited. […] These results challenge the notion that broader patents will induce additional innovation" (Sakakibara and Branstetter, 2001, p. 78 and p. 98). Jaffe concludes in the same way for the US: "Despite the significance of the policy changes and the wide availability of the data relating to patenting, robust conclusions regarding the empirical consequences for technological innovation of changes in patent policy are few" (2000, p. 531).

[70] The explanation of this finding is likely to deal with the overall cost of a patent (application, defense, etc.). Of course, patent offices do not price discriminate in favor of big firms. On the contrary, legislations sometimes even attempt to facilitate patenting for small firms, for instance by decreasing the application fees as does the *Canadian intellectual property office* (CIPO). The major problem is that a patent does not ensure a monopoly *de facto* but only offers a right to exclude competitors, which the owner will still have to defend. A patent is no more than a license to sue (Silberston, 1967). Yet, small firms often do not have the capacities, financial or others, to defend their monopoly right in court, which means that a patent is absolutely useless for them. As Polanyi (1944) argued, under the patent law justice is available only to millionaires.

Rarely did such a number of empirical reports, over a 40-year period, reach so similar conclusions. It seems therefore that one can take for granted that patents are not effective to secure monopoly rents in almost all industries[71]. And this conclusion holds for many industries regarded as high-tech, such as computers and semi-conductors (chemicals and pharmaceuticals are exceptions).

Let us add to this categorical denial of the classical role of patents another one, less robust but nevertheless meaningful, concerning the role of patents as knowledge carriers. Empirical studies tend to confirm that patents do indeed convey some technical information but they nevertheless mitigate the optimistic view that patents disclose the knowledge underlying an innovation perfectly.

V.I.1.3. Patents do not disclose 'enough' knowledge

A first element that suggests that patents do not disclose as much knowledge as argued by the traditional view is that firms report that they value patents badly as a means to collect external knowledge. Levin *et al.* (1987), for instance, pointed out that firms find it more efficient to access external knowledge through reverse engineering, by hiring employees who worked in other firms, by scanning scientific publications, by participating in meetings and conferences rather than by scanning patent databases. This finding strongly suggests that patent databases contain little valuable technical information as compared with other channels such as conferences, publications or marketable artefacts. Only informal discussions between employees are perceived as less efficient than patents to collect external knowledge. Yet, Schrader (1991) in another study showed that firms often praise informal conversation between employees as an efficient way to access other firms' know-how.

[71] Another explanation of these somewhat struggling empirical results was suggested by Mazzoleni and Nelson (1998), who remark that all the above studies concern mostly big firms who may be able to defend their innovations even without patents, which may not be the case of small firms. Hence, all the results presented above would be mainly due to a selection bias. The authors suggest that conclusions may change if only smaller firms, who would rely more on the patent system (because they do not have any other protection), were included in the studied samples. However, as it was stressed by Arundel among others, small firms do not rely more on the patent system than big firms. This finding seems therefore to invalidate the explanation proposed by Mazzoleni and Nelson.

Furthermore, when asked about their motives for not patenting their innovations, firms mostly refer to the weakness of the protection, which can usually be easily circumvented by competitors, and to the cost of the application rather than to the harm caused by the disclosure of valuable knowledge. It seems therefore that firms do not consider the disclosure requirement as a reason for not patenting. This finding may be interpreted as an indicator that patents do not disclose valuable knowledge to competitors and as such do not penalize the firm who patents. However, an alternative explanation, which is the central idea of our work and which was extensively treated in previous chapters, is that firms want to disclose because the indirect benefits of this disclosure exceed the costs stemming from the communication of valuable knowledge to competitors.

It is possible to give at least two explanations to the fact that patents do not convey much useful information to other firms: The first is that the requirements (regarding the novelty, the usefulness and the minimum disclosure) to be granted a patent have been sharply relaxed since the 1980s (Thurow, 1997). It is now possible to be granted a patent even if the disclosed knowledge related to the patented innovation is not sufficient to enable the understanding and the reproduction of the innovation (it is the case for patents on software for instance). Furthermore, it is important to notice that the patent law requires disclosing only the level of knowledge sufficient to replicate the innovation and not the level that would enable other firms to understand how it works. This distinction is not only semantic, it may have important repercussions since usually what is important is to understand how things work and not merely how to replicate them.

The second reason explaining why patents may not contain much valuable knowledge is that they disclose only codified knowledge. All the tacit knowledge, such as the know-how or the organisational knowledge, is not disclosed in patents and remains relatively inaccessible to potential imitators. Therefore, far from favouring the circulation of knowledge, patents may even impede it. Indeed, tacit knowledge can only be acquired by learning, which means that it requires a repeated practice in order to be absorbed. But patents prevent other firms from selling the patented innovation and thus, although they do not forbid those firms to do their own experiments, they deter them from reproducing these experiments regularly. In other words, only the repetition of experiments could enable other firms to acquire an in depth learning but this repetition is rendered quite costly by the presence of patents. To put it plainly, since patents prevent firms from using the knowledge, they deny access to the huge amount (or supposed such) of tacit knowledge located behind the codified form[72].

Patents may hence not be a good knowledge carrier, in the sense that they may not disclose so much useful knowledge to other firms. However, when considering the tremendous amount of patent citations, how could it be possible that patents do not convey at least a minimum level of information? Are citations not supposed to indicate knowledge flows? Jaffe, Fogarty and Banks (1998) and Jaffe, Trajtenberg and Fogarty (2000) attempted to answer this question.

Jaffe, Fogarty and Banks (1998) aimed at studying the relationship between the citations of patents held by the NASA Electro-Physics Branch, Cleveland, Ohio, and the knowledge flows that occurred between this lab and the citing agent. Such a study was made possible because one of the authors, B. Banks, was also the director of the lab and hence had a good idea of the relevance of the knowledge flows that may have occurred between his lab and the institution that cited the patent. The authors are hence able to distinguish citations that reflect a real knowledge flow from those that do not (the 'type 1' error according to the authors: citations occur but not spillovers) and also to identify cases in which a spillover occurred but no citation (the 'type 2' error). Although the outcome of this qualitative study must be taken with the greatest care due to the limited representativeness of the sample (restrained for time constraint to 7 patents granted during the period 1980-1986 and to 53 citing patents with at least 4 citations), some results are highly suggestive for us: For instance, approximately two thirds of the quotes were evaluated as involving spillovers. The authors therefore conclude that citations are a valid but noisy measure of knowledge spillovers. This finding may suggest that somehow patents disclose valuable information.

Jaffe, Trajtenberg and Fogarty (2000) found similar results by using the answers to a questionnaire sent to 166 inventors who applied for a patent in year 1993 and who cited other patents in their patent applications. They conclude the following: "The results suggest a 'half full cup' with respect to the validity of patent citations as indicators of knowledge spillovers […] typically one

[72] They may be equivalent to denying access to the "shoulders of the giants" mentioned by Sir I. Newton. Yet, where is the need to give strong incentives to innovate if at the same time the raw materials needed to innovate -existing knowledge- are removed? For instance, are we sure that Bill Gates would have built his Microsoft empire, which began with the development of MS-DOS, if BASIC and CP/M (that were the raw materials of MS-DOS) had been protected as Microsoft is today?

quarter responses correspond to a fairly clear spillover but a large fraction of citations, perhaps one-half, do not correspond to any apparent spillover" (p. 218). These two studies tend therefore to suggest that patents do contribute somehow to disclosing knowledge. But it must also be noticed that these studies only demonstrate that patent citations reflect a knowledge flow, i.e. that the citing patent learned something from the cited patent. They tell us nothing about the channels through which the disclosure operated. It is quite possible that knowledge spillovers occurred not because the citing patent had read the cited patent but because researchers from both firms had met at conferences, for instance, or had read papers written by researchers working for the cited firm.

To conclude, the traditional view of the patent system presents serious signs of malfunctioning: Most of the time patents are not efficient to restore appropriation and do not ensure a sufficient diffusion of the produced knowledge. The logic of exclusion does not seem to be relevant in most cases. In the following it is therefore argued that patents must be understood through a logic of coordination rather than through a logic of appropriation and minimal diffusion.

V.I.2. Patents in a logic of coordination

The knowledge production process does not involve so much an appropriation failure as a coordination failure (due to the difficulty to gather all the pieces of knowledge needed to implement a given innovation). This idea was already introduced in the first chapter, in which we explained that scholars changed their vision of the innovation process: Innovation is not perceived anymore as a linear and individual process that involves isolated and anonymous agents linked only through market relationships and the outcome of this process (new knowledge) is not considered as a pure public good. Rather, innovation is viewed as a collective process in which agents collaborate and develop non-market relationships and knowledge is viewed as a collective or club good.

This shift has many repercussions on public policies required to assist the innovation process (see part I.2.4.). Within the traditional framework, policies aiming at restoring appropriation and incentives to invest in R&D are essentially required and this may explain why economists have focused for so long on the protection function of patents. Yet, within the new vision of innovation, the role of public policy is not so much to provide incentives but rather to ensure the coordination of the innovation process. In this context, we believe that patents can play a central role, not because they increase incentives and ensure a minimum level of diffusion of knowledge, but because they facilitate cooperation and knowledge exchanges among agents who are part of the innovation process.

This idea of patents as a means to ensure coordination may help to explain a curious paradox, which was underlined by many authors (Hall and Ziedonis, 2001, for instance). Indeed, results displayed in the previous section indicate that firms report to rely weakly on patents in order to protect their innovations. But as a denial of this result the number of firms who apply for patents has sharply increased since the mid-eighties. The USPTO received 60,000 patent applications in 1983 and more than 120,000 in 1999[73]. The question one may ask is therefore the following: If firms do not rely heavily on patents then why are they patenting so much? Several explanations of this apparent paradox have been proposed:

Kortum and Lerner (1999) identified and tested four assumptions that may help to explain the recent patent application surge: *(i)* The first one is called the "friendly court hypothesis" and attributes this surge to new legislations that favour patent holders and make it more profitable to patent innovations; *(ii)* The second is called "fertile technology hypothesis" and attributes the patent application surge to the emergence of new knowledge intensive technologies such as biotechnologies and software that widened the technological opportunities set; *(iii)* The third assumption to be tested is called "regulatory capture hypothesis" and ascribes the surge to incumbents' over patenting strategies aiming at increasing the barriers to potential entrants; *(iv)* Finally, the last hypothesis attributes this surge to a change in the way firms manage their patent portfolios. It is to be noted that other motives not explored by Kortum and Lerner can be added to these four reasons, such as a shift to more applied research (which could be more easily patented) or a higher R&D efficiency.

After a thorough check Kortum and Lerner rejected the first three hypotheses and concluded that the recent patent application surge is due to a change in firms' management of their patent portfolios. It is also the conclusion we adopt here: In a knowledge based economy, in which

[73] see www.uspto.gov

coordination problems may be more important than appropriation ones, firms may value patents not because they give them strong legal rights to exclude others but rather because they enable them to avoid being excluded from using a particular technology, to obtain more favourable terms in negotiations, to safeguard against patent litigation or to gain access to external technologies (Rivette and Kline, 2000; Hall and Ziedonis, 2001; Reitzig, 2003). Furthermore, patents also signal to firms where the competences that they may need are located.

Hence, we see that in parallel to the classical role of patents in a logic of exclusion, a new role of patents emerges, a role that focuses on patents as means to facilitate interactions and coordination between firms.

Before entering into the details of this logic of coordination let us say a word on a third logic of utilisation of patents, which we call the logic of liberation. Indeed, firms may sometimes apply for patents, not in order to appropriate knowledge or to ease collaboration with other firms but merely in order to be sure that nobody will appropriate their innovations. To patent an innovation without any intention to use the exclusive property right associated with the patent is equivalent to placing this innovation into the public domain. In a sense, firms who apply for patents without any claim liberate their knowledge. Theoretically, one may not need to apply for a patent in order to liberate knowledge. To publish this knowledge in a scientific journal should be sufficient to prevent other firms from appropriating it. However, in practice firms may prefer to patent, although it is more expensive, because in case of litigation a patent may give them more strength than a publication in order to defend their claim in court. A prominent example of a researcher who used the patent system in a logic of liberation is the case of Louis Pasteur, who in the 1860s gave up his rights over a patent about the production of vinegar by acetic fermentation. Yet, such a patent would have been highly profitable since, as Dubois (1995) puts it, it allowed the replacement of the traditional acidification, which was slow, random and not reliable, by a regular acidification for vinegar of better quality with a decrease of 90% of the production cost. However, we do not want to insist on this logic of liberation here because such behaviours remain quite rare and therefore we prefer to focus on the opposition between the logics of coordination and of exclusion.

There are many ways through which patents may be used in a logic of coordination. All along our presentation of these different ways, we insist on the role played by the open knowledge disclosure dimension of patents. Indeed, our claim is that it is the combination of the disclosure and protection functions that make patents useful to ensure coordination among agents and not one of these two functions taken apart.

(i) Patents signal where competences are located. First, the disclosure function associated with a patent allows signalling to industrial and scientific communities that the owner holds given competences. As argued by Mazzoleni and Nelson (1998), the focus here is on the advertising value of patents. Therefore, patents, by signalling where competences are located, enable firms to find partners, to collect funds, to hire bright students, etc. In other words, they facilitate the coordination among agents involved in the innovation process. This signalling role of patents within the innovation process corresponds exactly to the role of open knowledge disclosure that was emphasized in chapters III and IV.

At first sight one may underline a contradiction between this view of patents as devices to signal competences and what was argued earlier about the shortcomings of patents as knowledge carriers. However, these two points can be reconciled easily by noticing that even if patents do not disclose valuable knowledge, they nevertheless disclose some information that may be sufficient to signal to other firms where competences are located. In other words, patents may not disclose technical knowledge but only information about who holds specific competences.

Patents also encourage firms to publish their results in the scientific literature and hence, in this sense too, they help to break secrecy and to signal competences. Indeed, firms are usually reluctant to let their researchers publish before they have been granted a patent. Hence, patents, by protecting the disclosed knowledge encourage the publication of research results, which in turn also improves the coordination among agents. This was clearly stressed in a report of the *Federal Trade Commission* (2003), which concluded that in the field of biotechnologies: “the information transfer happens in the scientific literature rather than in the patent literature, but quite a bit of the scientific literature is enabled by the fact that there has been a patent filed on it" (p. 18).

(ii) Patents help technology trading. The existence of the patent system also contributes to the creation of a market for knowledge. Firms specialized in research can produce knowledge, patent their results and then sell them as licensing contracts that specify the price and the terms of the transaction. Such a market for knowledge could not emerge without the existence of the patent system since only the combination of the two properties of a patent permits it. On the one hand, the disclosure dimension allows firms to advertise their products, which is a necessary condition for a market to exist since no agent would ever agree to buy a product without knowing what he is buying. On the other hand, the exclusive right of exploitation makes it possible to dismiss problems of free rider and hence, in a sense, supports the disclosure dimension which would not be possible otherwise. In other words, the combination of a signal and a property right allows firms to reveal information about their innovation while keeping some guarantee about this innovation, i.e. it allows them to trade this innovation. It should be noticed, however, that in this perspective patents are still perceived as concerning completed and independent innovations and hence are still considered in an a-temporal way.

Beyond this logic of minimal coordination among agents, we believe that patents can help to the development of innovations not yet completed, by easing collaborations and interactions at an early step of the innovation process. In this perspective, a patent is more than a guarantee of immediate profit. It becomes an essential input in the innovation process.

(iii) Patents prevent firms from being blocked in their research. Patents are often used in a defensive way, to protect their holders from uncertain and risky lawsuits. In sectors in which technologies are overlapping and in which innovations are most of the time incremental (i.e. built upon other firms' innovations), firms who are doing research are likely to be blocked during their research by other firms who hold patents that are necessary to the continuation of this research. Since firms expect such situations, they are induced to gather important patent portfolios that will serve as

"legal bargaining chips" and will be traded when firms need to be granted licenses to use technologies that are protected by patents. To amass patent portfolios enables therefore firms who are notified that they are infringing other patents to propose cross-licensing agreements rather than engaging costly and uncertain patent litigations. In this way, patents allow their owners to access domains that would be forbidden otherwise. This point is illustrated by Von Hippel (1988), who describes the following situation:

> "Firm A's corporate patent department will wait to be notified by attorneys from firm B that it is suspected that A's activities are infringing B's patents. Because possibly germane patents and their associated claims are so numerous, it is in practice usually impossible for firm A – or firm B – to evaluate firm B's claims on their merits. Firm A therefore responds - and this is the true defensive value of patents in industry – by sending B copies of « a pound or two » of its possible germane patents with the suggestion that, although it is quite sure it is not infringing B, its examination shows that B is in fact probably infringing A. The usual result is cross licensing, with a modest fee possibly being paid by one side or the other. Who pays, it is important to note, is determined at least as much by the contenders' relative willingness to pay to avoid the expense and bother of a court fight as it is by the merits of the particular case."

Von Hippel (1988, p. 53)

In such situations of patent litigations, the negotiation of an agreement is facilitated by the fact that to defend a patent in front of a court involves important costs and uncertainties. Even when a firm is almost certain that her patent is valid there remains a risk about the outcome of the judgment, which means that agents eager to dismiss risks will always prefer to negotiate an agreement. Agreements are also encouraged by the fact that in a trial it is the patent holder who is in charge of the proof, i.e. who must demonstrate that the other firm is infringing one of her patent. And to prove an infringement can sometimes be very difficult and costly. Furthermore, in some countries, legal battles may even involve preliminary injunctions that allow a patent holder to close down his competitors' operations for some time. When two firms pretend that the other infringes one of her patents the danger represented by a mutual injunction is a powerful incentive for both firms to find an agreement (Lanjouw and Lerner, 2001).

Practices of cross licensing are also motivated by the cumulative and collective nature of the innovation process. In a context in which innovations are all inter-dependent, if patent holders are not willing to grant licenses the technological progress may come to an end or at least be seriously slowed down because no firm may be able to innovate without infringing a patent held by one of her rivals. Indeed, a patent does not grant a right to use a given technology but only a right to exclude others from using it. A situation in which many patents protect each a fraction of a single technology and in which all firms use their exclusive rights to exclude others is hence likely to lead to a point in which no firm can use the technology. Therefore, most of the time, firms have a strong interest to set up cross-licensing agreements and to use their exclusive rights only with parsimony in order to prevent such dead-end from occurring.

Historically, we have examples of situations in which the multiplicity of patents and the unwillingness of their owners to collaborate and to grant licenses damaged the technological pace of the industry seriously. It occurred, for instance, in the semi-conductor industry in the early days of radio at the beginning of the century. Radio is a multi-technology product and the problem was that a number of firms had important patent positions and could block each other's access to key components. These firms refused to cross-license each other and the result was a deadlock that lasted until 1919, when pioneers of the electronic industry (American Marconi, General Electric, American Telephone and Telegraph (AT&T) and Westinghouse) formed the RCA (Radio Corporation of America) and agreed to sell their patents to the RCA. This cross-licensing agreement, which led to the creation of the RCA, became a model for the future and nowadays firms in the semi-conductor industry still nurture a tradition of knowledge exchange and cross-licensing (Grindley and Teece, 1997).

The foundation of the RCA is one of the first examples of a patent pool, which is an agreement between two or more patent owners to license one or more of their patents to a third party, such as a joint venture for instance, set up specifically to administer the patent pool[74]. Patent pools may be essentially useful because they allow the solution of the problem of the "tragedy of the anticommons", an expression used in opposition to the "tragedy of the commons" raised by Garett Hardin in 1968[75]. A tragedy of the anticommons may occur when multiple owners have each a right to exclude the others from the exploitation of a given resource but none of them has an effective privilege to use it. In such a case, firms willing to use the technology have to gather exploitation licenses from all the other owners, which may involve huge transaction costs and hence may eventually prevent the use of the technology. It is therefore straightforward that the formation of patent pools can help to solve this problem of anticommons since in this case firms willing to use a given technology have to be granted a license from one single firm (the administrator of the patent pool) and not from many fragmented owners.

(iv) Patents ease collaboration among firms. More than a defensive use that aims at protecting firms' against lawsuits and at exchanging technologies through cross-licensing agreements, patents can also be used in an explicit cooperative way, in order to ease collaborations among firms. For isolated actors who need to develop collaborations with other firms, patents can be precious devices to signal competences and to bargain favourable agreements. In this respect, patents clearly play a role at an early stage of the innovation process. They are used in a perspective of knowledge creation and not only in a perspective of allocation of resources once the innovation has been implemented. In the process of inter-firm or inter-organisation collaborations, patents are susceptible to play a role at several stages:

First, before a collaboration patents help to identify potential partners since they signal the competences of the patent holders to potential partners. This signalling dimension of patents, which was already raised earlier, puts forward the importance of the disclosure function of patents within the

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[74] Other examples of patent pools are, for instance, the creation of the Sewing Machine Combination in 1856 (which gathered many sewing machine patents), the creation of the Manufacturer's Aircraft Association in 1917 (which gather almost all aircraft manufacturers in the US) or the creation in 1998 by Sony, Philips and Pioneer of a patent pool consisting of patents related to the DVD standard specification (for further information about patent pools and their history, see the USPTO report, 2000).

[75] Heller and Eisenberg (1998) were the first to refer to the expression "tragedy of the anticommons" to qualify a situation in which the multiplicity of property rights on a single innovation prevent the implementation of this innovation.

collaboration process. Furthermore, before the beginning of the collaboration patents are also useful because they induce firms to participate. Indeed, R&D cooperation is a risky process in the sense that participants must often share some of their most important intellectual assets. R&D cooperation gives access to the firm's most precious knowledge. Hence, since patents protect the knowledge held by a firm from the plundering by her cooperation partners, they decrease the risk of opportunistic behaviours and of hold up of competences. It follows that firms protected by patents will be more willing to be involved in R&D cooperation. Patent protection decreases risks inherent to R&D cooperation and hence stimulates this cooperation (Ordover, 1991).

At a later stage, during the negotiations aiming at setting up the terms of the collaboration, patents may also play a very important role, since they place their owners in a more favourable position by reinforcing their bargaining power as compared with partners who would not have central patents. In other words, patents may entail a distortion of the terms of the entente in favour of the firm who holds the most important patents. For instance, they may allow a firm to obtain more favourable terms in a collaboration since this firm can threaten to block the collaboration process if her claims are not satisfied. But also, in a more friendly perspective, patents that are transferred to joint ventures as wedding presents (i.e. when a firm gives up her rights over a patent and transfers them to the newly created joint venture) represent a strong and credible sign of commitment to the collaborative process and may hence improve and fasten the negotiations.

After the collaboration, patents may also be used as instruments to share the outcome of the collaboration, through a joint application for instance.

Finally, it is worth noting that patents, all along the collaboration, help the coordination between sometimes very different actors because they represent a common language that can be understood by all of them (public labs, big multinationals, consulting agencies, financing organisations, etc). Patents are an element of culture shared by all the actors and in this sense they may ease the collaboration.

Be it in order to trade knowledge through licensing agreements, to improve bargaining power in negotiations with other firms or to signal firms' specific competences, the main reason for patenting is often triggered by other considerations than a mere appropriation and exclusion motive. The two functions of patents (protection and disclosure) can serve two very different logics: A logic of exclusion and a logic of coordination.

In the remaining of the chapter we investigate which logic dominates in the field of biotechnologies, with specific emphasis put on strategies of open knowledge disclosure and on their role in the formation of R&D collaborations. Hopefully, this focus on biotechnologies will contribute to confirming the existence of strategies of signalling in reality and, among others, it will help to understand better the role of patents as devices to signal competences and to ensure coordination among agents.

V.2. Application to biotechnologies companies in the Upper-Rhine BioValley

In the current context of strengthening intellectual property rights (Coriat and Orsi, 2002) and of extending the patent domain to living organisms it is essential to develop an exact vision of the role of patents in biotechnologies. Many questions regarding patents on living organisms remain unanswered so far from a legal point of view (Orsi, 2002) and before taking any decision to modify the patent legislation in this sector it would be preferable to gather a comprehensive understanding of the nature of the utilisation of patents by biotechnologies firms. Among others, are patents only instruments to limit competition or are they are also used by biotechnologies companies to facilitate coordination among agents? What is the importance of the function of "open knowledge disclosure" of patents? Our case study in the Upper Rhine BioValley, although modest, provides some first elements to answer these questions.

V.2.1. Introduction to biotechnologies

Biotechnologies companies are defined as those using modern biological techniques to develop products, services or knowledge. R&D in the biotechnology industry focuses on cells and large biological molecules such as DNA and proteins (conversely to the traditional pharmaceutical industry that works on small molecules). An indicative (but not exhaustive) list of biotechnologies is the following: DNA coding and sequencing, proteins and molecule sequencing, culture and engineering of cells and tissues, process biotechnologies (fermentation, biofiltration, bioprocessing, bioreactors, etc.), gene therapy, etc. (see the OCDE website). Domains in which those technologies may be used are essentially human healthcare, animal health, agriculture productivity, food processing, renewable resources and environmental affairs.

The birth of the biotechnology industry is usually associated with the verdict of the Diamond versus Chakrabarty case pronounced in 1980 by the US Supreme Court, which in some sense allowed firms to patent living organisms[76]. This fact alone (that the birth of the industry is linked to the introduction of patents in the field) proves how much the link between biotechnologies and patents is strong. It is indeed often believed that biotechnologies could not have emerged and survived without the patent system. Most biotechnologies companies are small and young firms who do mostly basic research, who do not commercialise any product and who rely strongly on collaborations with other organisations in the field. Those firms could hardly survive without patents because patents represent often their unique tangible assets. Without patents firms would have no guarantee to offer to potential partners and to financing institutions. But on the other hand, we will see here that biotechnologies firms can usually not afford to use patents in an exclusive way, since they do not have the means to carry out their research alone.

Patents in the biotechnology industry can concern three types of innovations: One type relates to newly discovered and isolated genes or proteins or to pharmaceutical inventions based on those genes or proteins. Although one cannot patent a naturally occurring gene or protein as it exists in a plant, animal, or human, one can patent it when it has been isolated from the organism and is useful as such in that form as a pharmaceutical drug or other applications. Another class of biotechnology patents relates to methods of use of specific genes or proteins. Even if someone has already a patent on a gene, a researcher who discovers a new method for using that gene can patent the new method of use. The third class of biotechnology patent is related to research tools. A research tool is a technology that is used by pharmaceuticals or biotechnologies companies to find, refine, design and identify potential products or properties of potential drug products. As such, it serves as a springboard for follow up innovation. Users of research tools (biotechnologies firms) need to be granted a license to use the research tool but do not need to be granted a license to use the ensuing innovation.

[76] In 1974 M. Chakrabarty applied for a US patent on a bacterium genetically modified. His demand was first rejected for the motive that living organisms cannot be patented. However, the case was brought in front of the US Supreme Court and therefore it is the highest court of the most powerful country in the world that decided in 1980, by 5 votes against 4, that living organisms can be patented under some conditions. Since this event, it is considered that everything that is built (and not only invented) by men can be patented.

In the domain of life and healthcare sciences, empirical studies carried out until very recently show that, regarding the way firms use the patent system, it is a strict logic of exclusion that dominates (see the first part of this chapter). In the pharmaceutical industry specifically, the propensity to patent is higher than in all the other industries and patents are usually perceived as efficient to appropriate the returns of an innovation (Arundel and Kabla, 1998)[77]. The pricing of medicines, for instance, reflects perfectly this logic of rent seeking, i.e. of exploitation of a commercial monopoly position. Hence, at first sight it seems that the new patent paradigm mentioned earlier and that insists on the role of coordination of a patent may not hold in life and healthcare sciences.

However, the technological and organisational breakthroughs linked to the emergence of biotechnologies may bring considerable changes to these conclusions. Indeed, we explained earlier that biotechnologies companies strongly rely on patents, but this does not mean that they automatically use them in an exclusive way. Innovation in biotechnologies is typically a collective process, involving a heterogeneous network of firms and organizations (Thumm, 2001). Usually, isolated actors do not possess the financial and technological capacities required to lead a project from its beginning (basic research) to its end, which is the commercialisation of the product (Powell, 1996). Consequently, biotechnology and pharmaceutical industries experienced until the end of the 1970s an extraordinary burst of technological inter-firm collaborations, which has continued until very recently. For instance, in 1998, collaboration agreements signed between biotechnologies and pharmaceutical companies represented approximately 30% of the total of the collaborations in all industries (Hagedoorn, 2002).

This finding is hardly surprising once one knows that biotechnology and pharmaceutical industries have many synergies and complementarities to bring a new drug on the market.

[77] This specificity of the pharmaceutical industry can easily be explained by its technological characteristics. Drugs are based on small chemical molecules. Usually, one molecule results in one drug product. Therefore, pharmaceutical firms do not have to gather many exploitation licences in order to commercialise a drug as it is the case for complex, overlapping technologies. Furthermore, patents in the pharmaceutical industry are usually efficient to exclude potential competitors, which is often not the case in other sectors in which imitation around is easy. The production of me too drugs (drugs based on different molecules, i.e. protected by different patents, but that have similar therapeutic effects) is difficult because the effects through which a molecule is efficient to cure a symptom remain largely unknown. After many trials firms know that a molecule has a positive effect but do not know why because the search for new molecules is made randomly, by screening, rather than rationally. This explains that, as von Hippel (1988, p. 53) puts it: "Potential imitators cannot gain much helpful insights from examining a competitor's patented product". To summarize, imitating around a patented drug is almost impossible; combined to the fact that drugs are based on a discrete technology, this means that a patent on a drug leads automatically to a steady monopoly (Juès, 1998; Smith-Hansen, 1999; Mahlich and Roedinger-Schluga, 2001).

Traditionally, the search for new active molecules in the pharmaceutical industry is done through a process of random drug design, meaning that firms screen and test thousands and thousands of molecules in order to discover the ones that may have some effects. Such a process is long, costly and uncertain. However, the emergence of biotechnologies has tremendously changed this way of doing research. Biotechnologies enable a rational search for new active molecules rather than random screening. Therefore, biotechnologies have led pharmaceutical research from an old paradigm of random drug design, which relies on financial power, towards a new paradigm of rational drug design, which relies more on technological excellence. However, if small biotechnologies companies can compete and be more efficient than pharmaceutical companies in basic research that leads to the discovering of new active molecules, they still cannot compete in the following stages of drug production, which are the trials, the granting of the FDA and the commercialisation. Hence, the emergence of biotechnologies has in some sense triggered a new division of labour in the pharmaceutical industry with small biotechnologies companies conducting basic research to identify promising products and then partnering with big-pharmas to test and commercialise the new drugs. And, of course, it is our opinion that patents facilitate this collaboration process.

The genesis of new drugs relies therefore strongly on the combination of the competences of three types of actors: Big-pharmaceutical groups, public research centres and small biotechnologies companies, who are often start-ups founded by researchers coming from the academic world. For these last companies, intellectual properties and more specifically patents represent the major part of their assets, if not the totality, since their main activity is basic research and they usually do not have any marketable products. This means, among others, that the protection function of patents may be absolutely essential for small biotechnologies firms, since without this protection their main asset would be freely available to competitors. The importance of the protection function of patents is still increased by the fact that, due to their small size, biotechnologies companies usually do not have any alternative means of protection. In parallel, the disclosure function is also essential since it allows them to signal competences to potential partners such as big pharmaceutical firms, public research labs, funding institutions, etc. (Teece, 1986).

Furthermore, another feature that may be central to explain why a logic of exclusion may not dominate in the biotechnology field is the importance of academic research in this sector. For instance, biotechnologies companies are often founded by academic researchers who, although they enter the industrial world, keep some of their old habits and continue to publish in scientific journals, to attend conferences and to fulfil their teaching duties. The importance of the academic sector in biotechnologies, the fact that most of the basic research is still conducted by public labs must somehow influence patenting strategies. It is indeed clear that despite recent changes (the Bayh-Dole Act in the US) that allow public research to be patented, academic research is still guided by a system of open science, which relies strongly on quick knowledge disclosure, on reputation and on the validation of research not by a patent application but rather by the referring by peers (Dasgupta and David, 1994). Although important pressures are exerted due, among others, to the huge financial interests at stake, many researchers from the academic world are still reluctant to patent their results and to use their patent rights to prevent any research in the protected field.

Finally, the nature of the technology used in the field may also explain why biotechnologies firms cannot exploit patents as pharmaceutical firms do. Conversely to pharmaceuticals, technology in biotechnologies is not discrete, meaning that biotechnologies firms will often need to combine several different research results, which are for most of them protected by patents. In other words, in biotechnologies, one single patent usually does not allow the production and sale of a product because it protects only a fraction of this product (example: a patent on a portion of a gene). This technological characteristic may also contribute to the emergence of a utilisation of the patent system in a logic of coordination rather than of exclusion.

To summarize: *(i)* Biotechnologies firms are often small companies who need to develop collaborations with other actors; *(ii)* Biotechnologies firms strongly rely on the patent system, since they do not have any other tangible assets; *(iii)* The academic sector and the practices related to it have a central place in the biotechnology industry; *(iv)* The technology used by biotechnologies firms is often overlapping. These four features suggest that biotechnologies firms may use the patent system in a collaborative way: Biotechnologies companies should seek patent protection alternatively to appropriate the return of their inventions, to attract investments from capital markets and to facilitate inter-firm relationships.

However, this hypothesis still needs to be investigated empirically. In this respect, we present now the first results of a case study based on the answers to a questionnaire dealing with firms' patenting strategies, activities of collaborations and signalling strategies, and sent by e-mail to biotechnologies companies who are parts of the Upper-Rhine BioValley. Let us now give some details about the mode of the inquiry and the characteristics of the population prior to displaying and analysing the results.

V.2.2. Presentation of the inquiry

V.2.2.1. On the Upper-Rhine BioValley

Founded in 1996, the Upper-Rhine BioValley is a trinational network strategically located in the Upper-Rhine region, which extends over northwest Switzerland, South-Baden in Germany and Alsace in France. The main objective of the network is the promotion of greater cooperation between companies involved in the biotechnological and biomedical sectors and the scientific public institutions. For us, a major interest of the BioValley network lies in its directory that gathers the addresses of most of the biotechnologies actors in the region and that is freely available on the Internet[78]. At present, the network gathers approximately 600 partners subdivided according to four categories: R&D companies, service and consulting companies, supply companies and research institutions.

R&D companies account for 20% of the enterprises in the network. They include enterprises that apply genetic and biotechnological methods and techniques in the field of research, development and/or production. Service companies, which represent 27% of the total, are those that provide

[78] For further information about the Upper-Rhine *BioValley* as well as its French part *Alsace BioValley*, the reader may consult the websites at the following addresses: http://www.biovalley.com/ and http://www.alsace-biovalley.com/. Figures given in this part are mainly drawn from these websites.

services and consulting support for the life sciences industry (such as legal support for contract research, licensing and patenting operations, marketing and business development services, informatics and communication consulting). Venture capital funds and financial consulting companies are listed in this category. Supply companies, which account for 19% of the population, are those firms supplying the life sciences industry sector with products and goods such as equipment and research tools. Finally, research institutions, which represent 34% of the total population, relate to all public actors using modern genetics and biotechnology in their research activities.

Clearly, since we want to explore firms' patenting strategies and their effects on R&D collaborations, only firms who do R&D in biotechnologies interest us. Therefore, we can focus only on R&D companies and neglect the other categories, either because they do not do R&D at all, or because they do research but not in biotechnologies, or because they are not private firms. As mentioned above, R&D companies account for approximately 135 companies. It should be noticed also that 22% of these 135 companies are located in Switzerland, 47% in France and 31% in Germany. Let us now present the questionnaire and introduce the major points that it deals with.

V.2.2.2. On the questionnaire

The questionnaire is reproduced in Appendix V.1. in English and V.2. in French. It is semi-directive (for each question we suggest some answers and ask the respondent to mark each proposition on a scale from 0 to 4) and addressed by e-mail either to the CEO, the R&D director or the intellectual property director of the company, who was hence required to send it back via e-mail or fax. The choice of the Internet to send our questionnaire was driven by financial constraints but also because it is direct, flexible and quick. Furthermore, since biotechnology is a high-tech industry, people in the sector are likely to be used to working through the Internet and hence few respondents may have been reluctant to answer because we used this media. The questionnaire includes three main parts:

One related to general information about the firm, such as the age of the company, its activity, its type, the total number of employees, the number of employees with a PhD, the function of the respondent, etc.

The second part aims at gathering information related to firms' patenting strategy. We question firms about the number of patents they hold, the number of patent applications they have filed in the last three years, their main motivations for applying for a patent, the main deficiencies they attribute to the patent system, the methods they use to prevent imitation, the methods they use to signal competences and the consequences they have experienced after having been granted a patent.

The third part aims at gathering information related to the R&D collaborations the firm is involved in and to the eventual role played by patents in these collaborations. Therefore, we question firms about the number of R&D partnerships they have been engaged in within the last three years, the types of the partnership, the types of the partner, the terms of the collaboration, and the role played by the patent system in the collaborative process.

V.2.2.3. On the sample

18 firms answered the questionnaire. It corresponds to a response rate of approximately 15%, which is not below the average for comparable studies. Most of our respondents are small (less than 50 employees) French young start ups specialised in pharmaceuticals. As we can see in Table V.1, which displays the general information about our sample, out of the 18 firms, 13 are start ups, 10 are located in France, 11 are specialised in pharmaceuticals and only 2 have more than 50 employees. This unbalance of the sample in favour of French firms may be explained both by the language of the questionnaire -in French for French firms but in English for German and Swiss firms- and by the reputation of our university, which is well-known in the region and hence which may have induced French firms to answer more promptly than foreign firms. Furthermore, it is also worth noticing that more than one half of the firms in our sample were founded within the last 6 years.

Firms in the sample all do R&D and are almost all currently engaged in patenting activities and in R&D collaborations. The ratio number of employees with a PhD divided by the total number of employees is expected to give indications about firms' R&D activities because it is likely that firms hire employees with a PhD mostly in order to do research. For 11 firms out of 18 this ratio is higher than 25%. It is lower than 10% only for 2 firms, which we interpret as a sign that firms in the sample are all currently engaged in R&D activities. This confirms merely the classification established by BioValley, since we sent questionnaires only to firms belonging to the category R&D companies.

Table V.1: Profile of the 18 enterprises

type	nationality	activity	number of employees	ratio phD/ employees	patent applications within the last three years	R&D collaborations within the last three years	role of patent in R&D collaborations
SME-1	France	pharmacy	1 to 10	50%	1 to 5	0	
SME-2	France	pharmacy	50 to 250	10 to 25%	>10	>5	Yes
SME-3	Germany	pharmacy	10 to 50	10 to 25%	1 to 5	>5	Yes
FIL-1	France	agriculture	10 to 50	<10%	1 to 5	1	Yes
FIL-2	France	pharmacy	>250	<10%	>10	1 to 5	No
START-1	Switzerland	expertise	1 to 10	100%	0	1 to 5	Yes
START-2	Switzerland	agro diagnostic	10 to 50	10 to 25%	0	1 to 5	Yes
START-3	Switzerland	research tools	1 to 10	>50%	1 to 5	1	Yes
START-4	France	pharmacy	10 to 50	25 to 50%	>10	>5	No
START-5	Germany	pharmacy	10 to 50	50%	1 to 5	1 to 5	Yes
START-6	Germany	not precised	1 to 10	25 to 50%	0	1 to 5	No
START-7	Germany	Bio informatics	1 to 10	not precised	1 to 5	0	
START-8	Germany	research tools	1 to 10	10 to 25%	0	1 to 5	No
START-9	France	pharmacy	10 to 50	>50%	5 to 10	>5	Yes
START-10	France	pharmacy	10 to 50	25 to 50%	1 to 5	1 to 5	No
START-11	France	pharmacy	1 to 10	100%	1 to 5	not precised	
START-12	France	pharmacy	1 to 10	50 to 100%	5 to 10	1 to 5	No
START-13	France	pharmacy	1 to 10	50%	0	1 to 5	No

13 firms out of the 18 applied for at least one patent within the last three years, which means that most of the firms in our sample are actively engaged in patenting activities. This finding seems to confirm the importance of patents for biotechnologies firms. Finally, only two firms report that they were not engaged in any R&D partnership within the last three years, which is also in line with the theoretical developments exposed earlier in the chapter that biotechnologies companies are not isolated actors but are engaged in a collective process of knowledge production.

V.2.3. First results

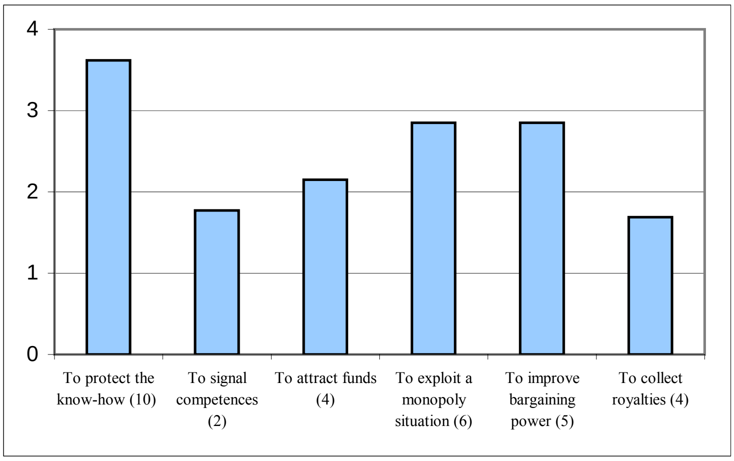
At first sight patents and R&D collaborations seem to play an important role for biotechnologies companies. Let us now examine the nature of this role. Although it will not be possible to draw significant conclusions from our sample of only 18 firms, this case study may nevertheless enable us to highlight specific points that will deserve to be explored in more depth in further works. Therefore, our objective is not to validate empirically the hypotheses underlined earlier in the chapter but, more modestly, to illustrate them and to verify whether or not the questions we raised, among others regarding the role of patents as signalling devices, are relevant?

V.2.3.1. Motivations for patenting

When questioned about their motivations for applying for patents, firms answer almost unanimously that, first of all, it is in order to protect their know-how from free riders. Of the 13 firms who were concerned by the question, 10 rated this motive first, indicating that it is by far the most important reason for applying for a patent. Furthermore, on a scale from 0 to 4, the average answer is above 3.6. This finding strongly confirms the central role of the protection dimension of patents in biotechnologies.

However, we have seen earlier that this protection function can serve two different logics, one of exclusion and one of coordination. It may hence be interesting to explore how firms use the protection provided by patents. Is this protection only aimed at excluding rivals or is it used in a more collaborative way? In this respect our results are more contrasted. Indeed, the motives of exploiting the innovation in a monopoly position and of improving bargaining power are both ranked second with an equal average mark of 2.9. An equal number of firms (8 firms) gave a mark of 3 or 4 to these motives. Furthermore, the motive of collecting funds, which we consider as being part of a logic of coordination, is also rated rather high with an average mark of 2.2.

Graph V.1: Average mark given to reasons to apply for a patent



NB: n= 13. Only firms who had already applied for a patent were asked to answer this question. Figures in brackets beside each proposition indicate the number of time the proposition was ranked first.

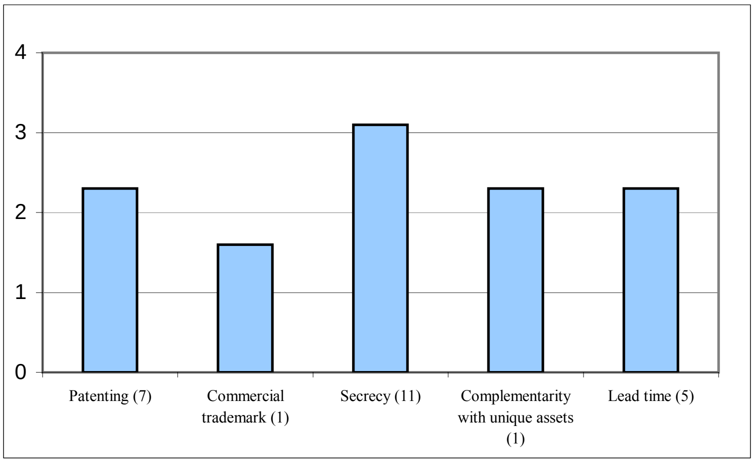
The motives of collecting royalties and of signalling competences are not rated high on average. Only 4 firms out of 13 consider the willingness to signal competences as an important reason for patenting (i.e. gave a mark of 3 or 4 to this item). Hence, it seems that to signal competences is not an important reason to explain why firms apply for a patent. At first sight this may be a disappointing finding, which contradicts the hypothesis that the disclosure function of patents plays a central role. However, we will see later that this may not necessarily be the case and that signalling strategies may nevertheless be important.

The central reason for applying for a patent is therefore the willingness to be protected. This protection is often used for very different purposes: To exclude rival firms, to improve bargaining power and to attract funds more easily. In other words, biotechnologies companies do indeed use patents as coordination devices but this use has not replaced the use of patents in an exclusive way. These two logics may be complements, biotechnologies firms combining one with the other in a complex manner.

Graphs V.2. and V.3. provide further information to analyse the role of patents. Graph V.2. displays firms' answers to a question about the efficiency of methods to prevent imitation and Graph

V.3. displays the main deficiencies that firms attribute to the patent system. Graph V.2 indicates that patents are not perceived as the most efficient device to prevent imitation. Firms consider secrecy as being much more efficient than patents to prevent imitation but overall patents are nevertheless perceived as relatively efficient. They are ranked second with an average mark equals to that of lead-time advance and complementarities with other assets. When we compare this result with conclusions reached by big innovation inquiries (Levin *et al.*, 1987; Cohen *et al.*, 2000), the importance granted to patents in our sample places it closer to the pharmaceutical industry than to other industries for which patents usually come far beyond the other methods to prevent imitation.

Graph V.2: Average mark given to methods to prevent imitation

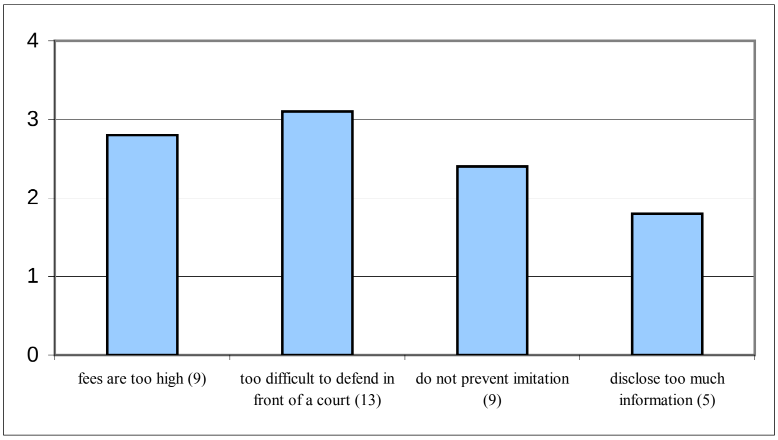


NB: n= 18 firms. Figures in brackets beside each proposition indicate the number of time the proposition was ranked first.

Hence, firms find patents to be a method of protection relatively efficient as compared with other means of protection. Yet, they regard the protection granted by patents as not sufficient and they would like to strengthen it if it was possible. Indeed, figures displayed in Graph V.3. indicate that firms consider the lack of protection as one of the most important problems of the patent system. Half of the firms in our sample (9 firms) consider the fact that patents do not prevent imitation as the most important deficiency of this system. Overall, these results appear consistent with our previous finding that protection is the main motive to apply for patents.

Other information that can be learned from Graph V.3 are the following: Most firms consider that the main deficiency of the patent system is its cost and, above all, the difficulties to defend a patent in court. This answer may be explained by the profile of the firms in our sample, constituted mainly of small firms who, for the most part of them, do not have the financial power to use the patent system in a logic of exclusion efficiently. This would be too costly for them. Moreover, most firms in our sample do not consider that patents disclose too much information, which is in line with other empirical studies. This can mean, as we already explained, either that patents do not disclose key information or, if they do, that firms do not find this disclosure too damaging (and maybe they even appreciate it).

Graph V.3: Average mark given to potential deficiencies of the patent system



NB: n= 18 firms. Figures in brackets beside each proposition indicate the number of time the proposition was ranked first.

V.2.3.2. The role of patents in R&D collaborations

We have seen that some firms apply for patents to improve their bargaining power during negotiations with other firms, to attract funds or even sometimes to signal competences, which are signs that patents play a role of coordination in the collective process of innovation. However, we would like to go further and to explore in more depth this role of patents in the process of R&D

collaborations. Ideally, we would like to determine at which step of an R&D collaboration patents play an important role.

To investigate this point, we first questioned firms about their R&D collaborations. We can see in Table V.1 that almost all firms reported that they had been engaged in R&D collaborations within the last three years. Then we asked these firms whether or not the patent system played a role at any step of their R&D collaborations. The answer was positive for more than half of them. 8 firms out of the 15 who were engaged in R&D collaborations within the last three years report that patents played a role at a given stage. This strongly suggests that, as expected, patents play a role within the collaboration process.

Then we questioned these 8 firms who reported that patents played a role on the nature of this role. We asked them whether or not the patent system played a role before the collaboration (if patents enabled one partner to identify the other), when firms had to define the terms of the collaboration (if patents helped to determine the term of the entente), or after the collaboration (if patents allowed a better share of the returns of the collaboration)? The answers do not enable us to pick up one stage in which patents would have played a more important role than at the other stages, although the role of patents during negotiations seem to be slightly more important than at the two other stages. Patents do play a role at the three steps of the collaboration. For instance, the fact that patents played a role before the collaboration was ranked first by 4 firms out of the 8 and obtained 4 times a mark of 3 or 4. Similarly, the fact that patents played a role after the collaboration was ranked three times first and 3 firms gave at least the mark of 3 to this proposition. Finally, the fact that patents played a role when defining the terms of the collaboration was ranked 6 times first and obtained 6 times a mark equal to or higher than 3.

These results are in line with the theoretical developments presented earlier. Patents seem to play an important role in the collaboration process by distorting the terms of the entente in favour of firms who hold central patents. Firms may therefore be induced to apply for patents just in order to obtain more favourable agreements. Furthermore, these results give also some strength to the signalling hypothesis. Patents can sometimes play a role of signal and therefore enable firms to enter in contact with potential partners.

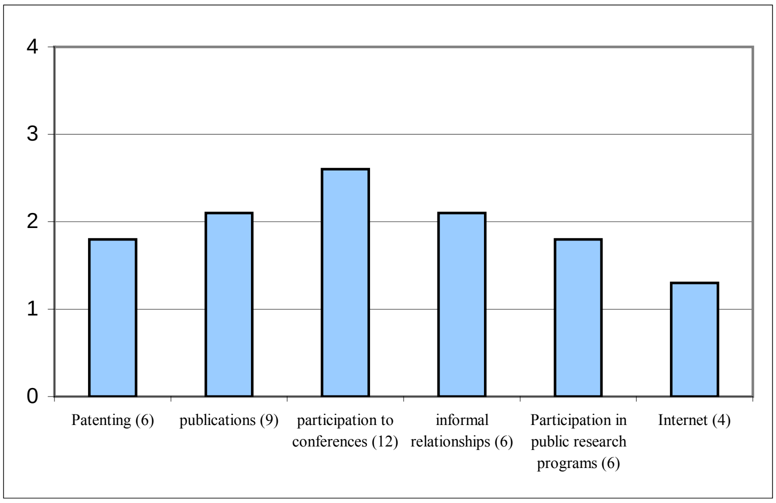
At the very least, these answers allow us to stress the following point: Whereas the analysis of the role of patents within the inter-firm collaboration process is not very important in the economic literature, it seems that this question is relevant and would deserve more attention in the future.

V.2.3.3. The relevance of the signalling hypothesis

Although firms do not regard the motive of signalling competences as a major reason for applying for a patent, we have seen that some firms do apply for patents in order to signal their competences to the industrial and scientific communities (see Graph V.1). 7 firms out of 13 give this reason a mark equal to or higher than 2 on a scale that goes from 0 to 4. Furthermore, we have seen above that patents can facilitate R&D collaborations between firms because they signal the location of potential partners before the collaboration. However, it may be interesting to evaluate how patents perform as compared with other devices to signal competences. In this respect, we asked firms to mark several methods that may be useful to signal competences according to the perceived efficiency of these methods. Results are displayed in Graph V.4.

Graph V.4 shows that firms' preferred method to signal competences to the scientific and industrial communities is participation in conferences, which obtains an average mark of 2.6 and is ranked 12 times first. Then come publications in scientific reviews (which we expected to find largely at the first position but we will attempt to explain below why it is not the case) and the encouragement of informal relationships between researchers, with both an average mark of 2.1. And then only come the patent system and participation in public research programmes with an average mark of 1.8. 6 firms ranked patents at the first position, which is far below conferences (12 times) and scientific publications (9 times), and equal to informal relationships and participation in public programmes. However, this tends to confirm our first finding that some firms (approximately 6 out of 18) do use patents to signal competences to academic and industrial communities. Finally, it is worth noticing the somehow disappointing rank of the Internet, which obtains an average mark of 1.3. We may have expected that in a high-tech industry such as biotechnology, firms would use the Internet more often to disclose and to gather information.

Graph V.4: Average mark given to methods to signal competences

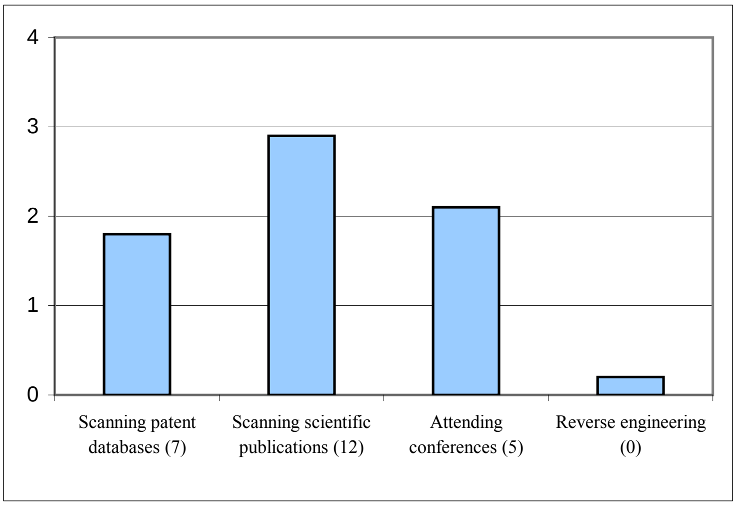


NB: n= 18 firms. Figures in brackets beside each proposition indicate the number of time the proposition was ranked first.

Although to signal competences is not a major motive for patenting, it seems that patents do help to signal competences but to a lesser degree than publications and conferences. Moreover, even if patents do not seem to play directly a central role to signal competences, it must not be forgotten that they are likely to play indirectly an essential role. Indeed, it is often only when an innovation is patented that firms allow their researchers to participate in conferences or to publish. Before being granted a patent, researchers are required to keep a tight secrecy over their research.

Graph V.4, which displays results about how firms signal competences, may usefully be completed by Graph V.5, which displays results about where firms search in order to obtain useful technical information. In some sense, these two questions deal with two sides of the same problem: The emission of knowledge for Graph V.4. and the absorption of knowledge for Graph V.5. It is therefore expected that firms look for external knowledge where most of them report that they disclose it, i.e. in scientific journals and at conferences.

Graph V.5: Average mark given to methods to achieve technological intelligence



NB: n= 18 firms. Figures in brackets beside each proposition indicate the number of time the proposition was ranked first.

This hypothesis is confirmed at least in part. Graph V.5. indicates that firms' preferred strategy to achieve technological intelligence is to scan scientific publications, which obtains an average mark just below 3 and is ranked first 12 times, and to allow their researchers to participate in conferences, which obtains an average mark just above 2. To scan patent databases comes just after with an average mark just below 2. However, it is nevertheless interesting to observe that 7 firms ranked the scanning of patent databases first. Finally, firms do not practice reverse engineering, which may somehow be due to the fact that only few products are commercialised in the domain so far.

These findings suggest therefore that patents do disclose some information but not really valuable technical results. To scan patent databases may be useful for firms in order to observe what others are doing but not to acquire complex technical knowledge. This point also confirms our previous finding that firms do not regard the fact that patents disclose knowledge as a major deficiency of this system.

Another explanation to this relative low ranking of the scanning of patent databases as a method to achieve technological intelligence, beside the fact that patents do not disclose enough information, is the long lag between the patent application and the disclosure of the description of the innovation. One of the firms in the sample answered that she does not scan patent databases because there is too important a lag between the filling of the application and the disclosure. Hence information displayed in patent description are often useless at the time they are published. This point may be specifically relevant in a sector such as biotechnology in which the technological pace is rapid.

However, this remark should also apply to scientific journals, since it is well known that the publication process is not really fast. This fact may explain why biotechnologies companies do not consider scientific publications as being the most efficient method to signal competences. Firms who need to signal competences may wish to do it quickly and hence may prefer to use conferences, which is the fastest way to signal recently produced knowledge (quicker than the publication process). However, and this stresses clearly the difference between signalling and disclosing valuable knowledge, firms who want to achieve technological competences scan publication databases rather than conference proceedings. This may suggest that conferences are used only as a signal and that knowledge disclosed in conferences is not directly exploitable by other firms. Conversely, publications contain valuable knowledge but the publication process may be too slow to be used properly as an efficient signal of competences.

A last result that deserves to be emphasised is the central role played by public institutions and by public norms. Most firms report that they disclose knowledge in scientific journals and conferences, which are practices usually reserved to public institutions. How can we explain the importance of strategies of open science in a sector as competitive as biotechnologies? Our guess is that this point is due to the prominent place occupied by public research in biotechnologies. It was indeed underlined before that biotechnologies firms still strongly rely on publicly produced knowledge. Public and private research seem to be highly interdependent. Many public researchers work for private companies, many private researchers carry out teaching duties, etc. Therefore firms may adopt practices specific to the public domain either because they come themselves from the public sector or because they aim at facilitating the links between public and private research.

To conclude, it comes out that biotechnologies firms mostly apply for patents in order to protect their knowledge. Furthermore, biotechnologies firms also consider patents to some extent as devices to signal competences. Yet, this function is not perceived to be as important as the protection function and firms can also use other devices to signal competences, such as publications in scientific journals and participation in conferences.

This work about the role of patents in biotechnologies is part of a wider debate about the role of the public sector and the possible changes to be brought to the patent system in life sciences. Indeed, many questions regarding the patent system remain unanswered so far in this sector. Specifically, an important motive of concern is the fact that the multiplicity of patents may affect negatively the relationships between the actors of the domain (public research organisations, start ups and big-pharmas) and leads, for instance, to decreasing the rate of innovation.

A famous example of problems that may arise due to over patenting in biotechnologies is the case of Myriad Genetics. In 1997, this firm was granted American patents covering all the methods that used the two genes BRCA1 and BRCA2, which are central to diagnose breast cancer (Henry, Trommetter, Tubiana, 2003). Hence, whatever the method used, if this method is based somehow on the gene BRCA1 or BRCA2, laboratories cannot diagnose breast cancer without Myriad's permission. And Myriad does not grant this permission. Rather, she compels all labs to send her the samples in order to do the diagnosis herself. We have here a clear example of a strategy of exclusion that leads to an effective monopoly position and to an increase of the price of the diagnosis of breast cancer. Furthermore, since Myriad does not grant exploitation licences, she can also build her own database, which in the long run may be even more profitable than to have a monopoly position on the diagnosis of breast cancer. Lastly, research in this field is impeded because the results of this research are likely to be covered by the patents owned by Myriad, which decreases the expected return of R&D and the incentives to do research. Therefore, not only does Myriad increase the price to diagnose breast cancer but she also contributes to slowing down research in the field.

The central question for those who wish to foster innovation in life sciences deals therefore with the possibility to implement mechanisms in order to encourage the necessary collaborations between the actors who are part of the innovation process and to counterbalance the negative effects linked to the application of strict strategies of exclusion (Campart and Pfister, 2002; Cassier, 2002). Whatever may be changed to the patent legislation in the life science domain, modifications will have to take into account the double nature of the patent system, which is at the same time a source of conflicts and confrontations and an instrument that can ease collaborations and coordination within the innovation process.

Conclusion of the chapter

This chapter focused on the role of patents as devices to openly disclose knowledge. First, in our theoretical discussion we insisted on the importance of the knowledge disclosure function of patents. We explained that it is the combination of the protection and disclosure functions of a patent that gives this instrument its strategic importance, by allowing it to play an essential role of coordination among the agents who are part of the innovation process.

Second, by focusing on biotechnologies this chapter confirmed the existence of strategies of signalling in reality and, among others, it confirmed the role of patents as signalling devices. Indeed our case study suggests that if the disclosure function of patents is not perceived to be as essential as the protection function, it is nevertheless considered as important by some firms. Furthermore, biotechnologies firms in our sample report to use the protection given by a patent in two different ways that seem equally important: To exclude rival firms and to improve bargaining power in negotiations. It also comes out that patents play a role at all stages of R&D collaborations between firms. Finally, we found that biotechnologies companies do use many methods to disclose knowledge and to signal their competences, including the patent system, which is nevertheless not perceived to be as important as the participation in conferences, the publications in scientific journals or the encouragement of informal relationships between employees.

By combining the recent theoretical economic developments on the patent system with the first elements of an empirical study in the field of biotechnologies, our work provided therefore some insights and raised interesting questions that will deserve more in depth explorations in future studies.

GENERAL CONCLUSION

This thesis focused on behaviours of open knowledge disclosure, which we defined as situations in which firms decide voluntarily to disclose some of their knowledge, without any explicit contractual agreements (i.e. without any direct remuneration) and without being able to control the population of recipients of the disclosed knowledge.

Conversely to conventional wisdom, we stressed that firms in diverse industries do often openly disclose part of their knowledge, although the benefits arising from this disclosure are not certain and although the disclosure may be costly. Firms usually openly disclose knowledge through conferences, publications in scientific journals and books, patents and through the Internet.

Specifically, we focused on the reasons that may encourage firms to adopt those behaviours. Indeed, to openly disclose knowledge may involve important costs for the disclosing firm (the most important cost being probably the one that stems from the communication of technical information to competitors) whereas, by definition, disclosing firms are not ensured of any remuneration. Therefore, at first sight, it is not straightforward why profit seeking firms should engage in such an activity of open knowledge disclosure. Yet, we showed that there exist several economic reasons that can induce firms to openly disclose knowledge.

We reviewed many indirect mechanisms that can make open knowledge disclosure very profitable for a firm. In particular, our central interest lied in the reputation triggered by open knowledge disclosure. We demonstrated that this reputation can help to break adverse selection problems regarding firms' competences and therefore can facilitate the formation of R&D collaborations among firms.

In other words, we argued in this thesis that there is no need to refer to concepts such as altruism, irrationality, intrinsic motivations or externalities to explain knowledge transfers. This finding stands out in sharp contrast with the traditional view, which tends to attribute knowledge flows to externalities meaning that, once produced by a firm, new knowledge instantly spills over from its creative source and feeds a public pool of knowledge from which other firms can draw freely. Following the classical definition of an externality, firms are viewed as completely exogenous in this process of knowledge transfer. They can control neither the absorption of external knowledge nor the diffusion of their knowledge, which implies that traditionally scholars have assimilated knowledge flows to undesirable leakage. They did not consider the fact that firms may wish to deliberately release part of the knowledge they hold.

By considering that knowledge may not spill over randomly from its source but may be voluntarily disclosed, we therefore questioned in depth the traditional vision of knowledge flows. In particular, we rethought the traditional vision regarding one central point, which is the status of knowledge as a public good, i.e. as a good that once produced leaks from its creative source and benefits other agents instantly. We argued that knowledge is not a pure public good because once produced it does not become automatically available to other agents. Rather, we considered knowledge as a collective good or a club good in the sense that knowledge flows only within specific structures, clubs or networks, and is available only to members of these structures.

To put it plainly, we considered that the innovation process is a collective process and that knowledge is a collective good, which is a view shared by many scholars in economics of innovation nowadays. This point, the fact that innovation is a collective process, led us to propose an original explanation for behaviours of open knowledge disclosure:

Since innovation is a collective process, we first argued that it is essential for firms who want to remain innovative to develop R&D collaborations. Specific emphasis was put on the importance of collaborations to access knowledge held by other firms and that would not be available without collaborating with its owner. Since knowledge is not a public good, firms who wish to access a given piece of knowledge must first collaborate with the owner(s) of this piece of knowledge, they must enter the club in which this knowledge is flowing. To develop R&D collaborations is hence an essential strategy for firms willing to increase their stock of knowledge.

However, we emphasised that a major challenge for firms involved in this collaborative process is to identify appropriate partners. Since the process of finding competent partners with whom to cooperate in R&D occurs in an environment of incomplete information (firms do not know exactly the competences of other firms and, in particular, of their potential partners), firms may not be able to identify the partners that fit them best. For instance, how can firms identify potential fruitful partnerships? How (i.e. on which criteria) can they distinguish between profitable R&D collaborations and less profitable ones?

These problems of adverse selection that impede the collective process of innovation may offer an explanation for behaviours of open knowledge disclosure. Indeed, we showed, with the help of a signalling game under incomplete information that, due to adverse selection problems, firms may be induced to disclose widely part of their knowledge in order to signal their competences to potential partners (who would wonder whether or not to cooperate with the disclosing firm), thus encouraging other firms and public institutions to collaborate in R&D with them. According to us disclosing firms are more likely to be proposed R&D partnerships since, by widely disclosing some of their knowledge, they decrease the uncertainty regarding their level of competences. Our work gives therefore some strength to the idea that the existence of adverse selection problems within the process of knowledge production can provide an explanation for behaviours of open knowledge disclosure.

Then, with the help of numerical simulations, we investigated the effect of strategies of open knowledge disclosure aiming at triggering R&D collaborations on firms' performances. For this purpose we built a theoretical model describing the formation of innovation networks by allocating a central role to behaviours of open knowledge disclosure. This model was concerned with the fact that a strategy of open knowledge disclosure constitutes not only a gift made by disclosing firms to other firms but also contributes to an increase in the reputation of disclosing firms, thus allowing them to increase their individual profitability. It was indeed argued that firms who widely disclose knowledge to other firms are more likely to enter innovation networks and to acquire a central position within these networks because the act of disclosing knowledge triggers the reputation, which constitutes the main criterion firms take into account when deciding whether or not to start a cooperation with another firm.

Some implications of our model were tested by using numerical simulations. Overall, we found that to openly disclose knowledge is not profitable in the short run and is even risky, since disclosing firms are more likely to go bankrupt. But openly disclosing knowledge may be profitable in the long run, provided that firms do not disclose too much knowledge. Furthermore, we found that adopting a strategy of high level of open knowledge disclosure allows firms who started with low endowments of specific knowledge to catch up with and to outperform (in terms of profitability) firms who started with higher endowments of specific knowledge and who adopted a strategy of low level of knowledge disclosure. This model provided therefore a rationale to behaviours of open knowledge disclosure by showing that such strategies, although risky in the short run, may pay in the long run by enabling firms to access external sources of knowledge more easily.

Finally, we explored empirically the role of patents as devices to openly disclose knowledge. First, we provided a theoretical discussion in which we insisted on the importance of the "open knowledge disclosure" function of patents. We explained that it is the combination of the protection and disclosure functions of a patent that gives this instrument its strategic importance, by allowing it to play an essential role of coordination among the agents who are part of the innovation process.

Then we focused on the field of biotechnologies, which enabled us to confirm the existence of strategies of signalling in reality and, among others, the important role of patents as signalling devices. In our case study we found that if the disclosure function of patents is not perceived to be as essential as the protection function, it is nevertheless considered to be important for some firms. We also found that patents seem to play a role at all stages of R&D collaborations between firms. Finally, we stressed that biotechnologies companies do use many methods to disclose knowledge and to signal their competences, including the patent system, which is nevertheless not perceived to be as important as participation in conferences, publications in scientific journals or the encouragement of informal relationships between employees. The fact that strategies of open knowledge disclosure are at work in biotechnologies tends to support the view that in many sectors firms frequently adopt such behaviours.

Indeed, the biotechnology industry is highly competitive, thus suggesting that disclosing knowledge must be a very costly strategy for biotechnologies firms. If they nevertheless adopt such behaviours, it must somehow be also the case of firms in other less competitive sectors.

To summarize, we proposed in this thesis that open knowledge disclosure can be a strategy adopted by firms willing to collaborate in R&D in order to signal their competences to other firms and to public institutions and therefore, in order to develop R&D partnerships more easily. We explored this hypothesis theoretically, by using a game theory model and numerical simulations, as well as empirically, with the help of a case study in the field of biotechnologies.

This work focused on the link between open knowledge disclosure, adverse selection problems and the formation of collaborations in R&D but it can be extended to many other situations than the one considered in this thesis. Similar mechanisms than those stressed here may be at work in the following cases: As a government decides to distribute grants to encourage innovation within particular industries, as private investors decide to invest in industrial projects, as graduate students choose their future employers, as a firm wants to take-over spin-offs or to enter new markets. In all these situations problems of adverse selection regarding the competences of firms may arise. It follows that in all these situations the most competent firms may be induced to reveal widely some of their knowledge in order to reduce the problems caused by incomplete information and, for instance, in order to be granted public contracts or subsidies, to hire promising young graduate students, to gather capital on financial markets or to dissuade potential competitors from entering a given market.

However, this work was only a first step in the exploration of behaviours of open knowledge disclosure and there is still a lot of work to do. This is essentially true from an empirical point of view. We seriously lack robust empirical studies focusing on behaviours of knowledge disclosure. The last chapter of this thesis was a first attempt to fill this gap but we must go further.

To embrace fully all the problems at work when dealing with open knowledge disclosure, we need to implement inquiries that focus specifically on these problems. The case study used in this thesis was focused on patents and thus, although it allowed us to gain interesting insights, it offered only limited coverage of the issues related to open knowledge disclosure. To go further it will be necessary to build a questionnaire dealing specifically with problems of open knowledge disclosure.

Furthermore, another path that would deserve to be explored in order to test empirically the hypothesis defended in this thesis is to use econometrics techniques to link data on firms' publications with data on firms' R&D collaborations. These kinds of datasets become more and more easily available nowadays (at least concerning firms' publications in scientific journals, patents and number of R&D collaborations) and this may give us the opportunity to test our signalling hypothesis. For instance, as a departure point one can merely regress firms' number of publications, patents or participations in conferences on the number of R&D collaborations firms' developed in the years that followed the publications. A positive link between the number of publications of firms at time t and the number of R&D collaborations they were involved in at time $t+n$ may suggest that publications indeed help firms to develop R&D collaborations. Conversely, no link or even a negative link would contradict our hypothesis that publications act as a signal and hence ease the formation of R&D collaborations.

On the theoretical side, some improvements can also be brought to our present work, especially regarding our signalling game under incomplete information. Specifically, it may be important to consider a game with more than two firms in order to obtain a better understanding of the effect of competition. It may also be of major interest to introduce the qualitative dimension of knowledge, such as its generality, its importance, etc. Thus, we could draw up propositions on which type of knowledge firms choose to disclose rather than how much knowledge they disclose. But above all, we believe that it may be particularly important to investigate in more depth the link between open and closed knowledge disclosure. We emphasised in this thesis that open knowledge disclosure is a prerequisite to closed knowledge disclosure. But in our modelling we did not really focus on the interactions between these two kinds of knowledge disclosure. Yet, to obtain a full understanding of the mechanisms at work when knowledge is openly disclosed, it will probably be necessary to consider more directly behaviours of knowledge trading. To endogenise behaviours of closed knowledge disclosure may be particularly important in order to explore how open knowledge disclosure affects knowledge trading and vice versa. We believe that the interaction between open and closed knowledge disclosure stands at the heart of the innovation process and that the investigation of this relationship may foster deeply the overall understanding of the innovation process.

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APPENDIXES

Appendix II.1: Summary of the variables used by Harhoff *et al.* (2003)

α $(0 \leq \alpha \leq 1)$	Reflects the degree of competition between user firms. The higher α, the sharper the competition and the more the profits of a user firm affect negatively the profits of the other user firm.
γ $(0 \leq \gamma \leq 1)$	Reflects the degree of generality of the revealed technology. If it is equal to 0, the technology is specific to the innovator and the disclosure does not profit the other user firm. Conversely, if it is equal to 1 the technology is generic, meaning that it yields similar benefits to both users and that the disclosure profits highly the other user firm.
δ	Reflects the benefits of the innovation for the innovator if he does not reveal his innovation. In other terms, it represents the value of the innovation (the increase of the present discounted profits).
μ	Reflects the extent to which the manufacturer firm improves the revealed innovation.
C	Reflects the costs for both user firms to adopt the products that have been improved by the manufacturer firm.

Appendix III. 1: Proof of proposition III.1

Under complete information firm *E* knows the type of firm *A* and therefore she chooses to cooperate with firm *A* only if the latter is of the competent type and, according to our hypotheses, firm *A* always accepts cooperation with firm *E*. The outcome of the game is hence $\left(\pi_E,\pi_{A2}\right)$ if firm *A* is of the type 2 and $\left(\pi_E^{A1},\pi_{A1}^{E}\right)$ if firm *A* is of the type 1.

Consider now a situation of incomplete information in which firm *E* does not know the type of firm *A* but only the probability that firm *A* is of a certain type. Assume further that firm *E* uses the criteria of the expected utility to decide whether or not to cooperate with firm *A* (she decides by maximizing her expected gain). It follows that firm *E* chooses to cooperate with firm *A* only and only if:

$$\frac{n}{n+m}\pi_E^{A1}+\frac{m}{n+m}\pi_E^{A2}\geq\pi_E$$

From this, it is straightforward to deduce the three results emphasized in proposition 1:

(1) Under incomplete information, there exist parameter values under the ones firm *E* may either choose to cooperate with firm *A* (if $\frac{n}{n+m}\pi_E^{A1}+\frac{m}{n+m}\pi_E^{A2}\geq\pi_E$) while the latter is of the less competent type or decide not to cooperate (if $\frac{n}{n+m}\pi_E^{A1}+\frac{m}{n+m}\pi_E^{A2}<\pi_E$) while firm *A* is of the competent type. Since, these situations can never happen under complete information it follows that firm *E* is in a better situation under complete information.

(2) Similarly, when firm *A* is of the competent type, under incomplete information there exist parameter values for which $\frac{n}{n+m}\pi_E^{A1}+\frac{m}{n+m}\pi_E^{A2}<\pi_E$ and hence for which firm *A* may be excluded of the cooperation although she is competent whereas this can never happen under complete information. Hence, firm *A* of the competent type can only suffer from the presence of incomplete information.

(3) Conversely, if firm A is of the less competent type, under incomplete information there exist parameter values under the ones she may be given a chance to cooperate with firm E (if $\frac{n}{n+m}\pi_E^{A1}+\frac{m}{n+m}\pi_E^{A2}\geq\pi_E$) whereas this can never happen under complete information. Hence, firm A of the less competent type can only be advantaged by incomplete information.

Appendix III.2: Proof of proposition III.2

Assume that firm *E* believes that if firm *A* is competent she plays *S*, i.e. if she does not play *S* she is believed to be of the less competent type. It follows from these beliefs that firm *E* decides to cooperate with firm *A* if and only if the latter plays *S*. Furthermore, in order to have a PBE these beliefs must be confirmed by the action chosen by firm *A*, i.e. firm *A* must play *S* if and only if she is of the competent type. According to our hypotheses, if firm *A* is not of the competent type she cannot play *S*. All that remains to prove is therefore that, given firm *E*'s beliefs, firm *A* plays *S* if she is of the competent type, which requires that:

$$\pi^E_{A1}(S) \geq \pi_{A1}$$

$$\Leftrightarrow \quad \delta_A k^E_{A1} - \alpha\left(\sum_{i \neq A} \delta_i \,(k_i + \beta_i\, k^S)\right) - c^E_{A1} \geq \delta_{A1} k_{A1} - \alpha\left(\sum_{i \neq A} \delta_i\, k_i\right)$$

$$\Leftrightarrow \quad \delta_A k^E_{A1} - \alpha\left(\sum_{i \neq A} \delta_i\, \beta_i\, k^S\right) - c^E_{A1} \geq \delta_A k_A$$

$$\Leftrightarrow \quad k^S \geq \frac{\delta_{A1}\left(k^E_{A1} - k_{A1}\right) - c^E_{A1}}{\alpha \sum_{i \neq A} \delta_i\, \beta_i} \qquad \textit{(condition III.1)}$$

Appendix III.3: Proof of proposition III.3

Assume again that firm *E* believes that if firm *A* is of the competent type she plays *S* and that if she is not of the competent type she does not play *S*. Then, we have a separating PBE if and only if the two following conditions hold: (1) Given firm *E*'s beliefs firm *A* plays *S* if she is of the competent type and; (2) Given firm *E*'s beliefs, firm *A* does not play *S* if she is of the less competent type.

The first requirement leads to *condition III.1.'*, which is identical to *condition III.1.* displayed above. The second requirement implies that:

$$\pi_{A2}^{E}(S) < \pi_{A2}$$

$$\Leftrightarrow \quad \delta_{A2} k_{A2}^{E} - \alpha\left(\sum_{i \neq A} \delta_i \left(k_i + \beta_i\, k_{A2}^{S}\right)\right) - c_{A2}^{E} - w < \delta_{A2} k_{A2} - \alpha\left(\sum_{i \neq A} \delta_i\, k_i\right)$$

$$\Leftrightarrow \quad k_{A2}^{S} > \frac{\delta_{A2}\left(k_{A2}^{E} - k_{A2}\right) - c_{A2}^{E} - w}{\alpha \sum_{i \neq A} \delta_i\, \beta_i} \qquad \textit{(condition III.2)}$$

Appendix III.4: Proof of proposition III.4

A situation for which firm *A* discloses her knowledge only and only if she is of the less competent type cannot be a PBE because if firm *E* expects that only firms of the less competent type disclose their knowledge, she will decide to cooperate only if firm *A* does not play *S*. And hence, as long as to disclose knowledge is assumed to be costly, firm *A* of the less competent type will always deviate and decide to not play *S*, i.e. firm *E*'s beliefs will not be confirmed by firm *A*'s decision.

Appendix III.5: Proof of proposition III.5

Assume that firm *E* believes that firm *A*, whatever her type, plays *S*. In this case, firm *E* decides to cooperate with firm *A* only and only if the expected profit under collaboration is higher than the expected profit without collaboration. This condition is equivalent to condition *III.3.* below:

$$\frac{n}{n+m}\pi_E^{A1}+\frac{m}{n+m}\pi_E^{A2}\geq\pi_E \qquad \textit{(condition III.3)}$$

Given this condition, firm *E* beliefs are true only and only if, knowing firm *E* strategy, firm *A* decides to disclose her knowledge whatever her type. Assume therefore that if firm *A* does not disclose firm *E* decides not to cooperate with *A*. Hence, firm *A* will decide to disclose whatever her type only if the two conditions below hold:

$$k_{A1}^S\leq\frac{\delta_{A1}\left(k_{A1}^E-k_{A1}\right)-c_{A1}^E}{\alpha\sum_{i\neq A}\delta_i\,\beta_i} \qquad \textit{(condition III.1')}$$

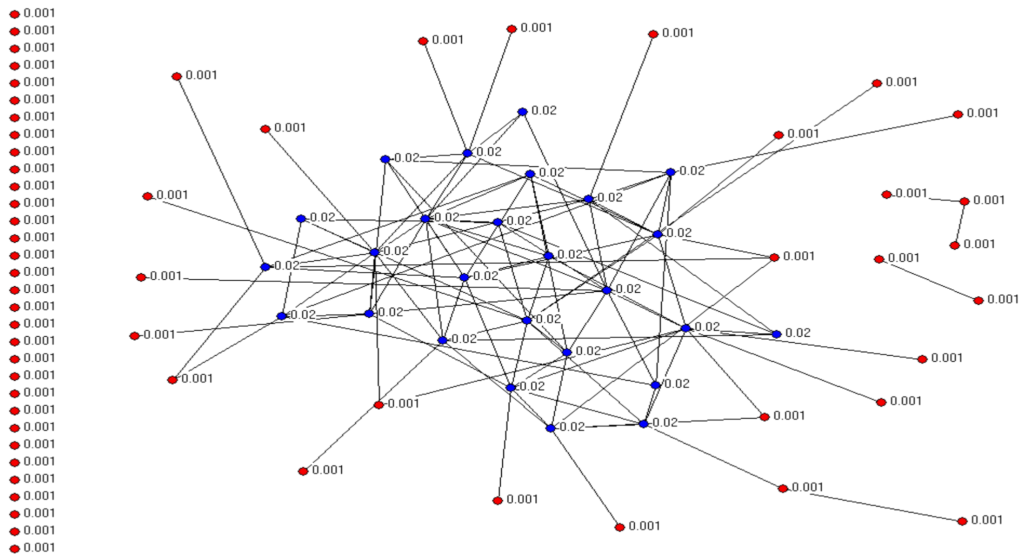
$$k_{A2}^S\leq\frac{\delta_{A2}\left(k_{A2}^E-k_{A2}\right)-c_{A2}^E-w}{\alpha\sum_{i\neq A}\delta_i\,\beta_i} \qquad \textit{(condition III.2')}$$

Condition *III.3* ensures that firm *E*, given her beliefs, chooses to cooperate with firm *A* if the latter discloses her knowledge. Conditions *III.1'* and *III.2'* ensure that firm *A* plays *S* whatever her type, given that firm *E* cooperates if firm *A* plays *S* and does not cooperate if firm *A* does not play *S*. Therefore, under these three conditions firm *E*'s beliefs are true and we have a pooling PBE.

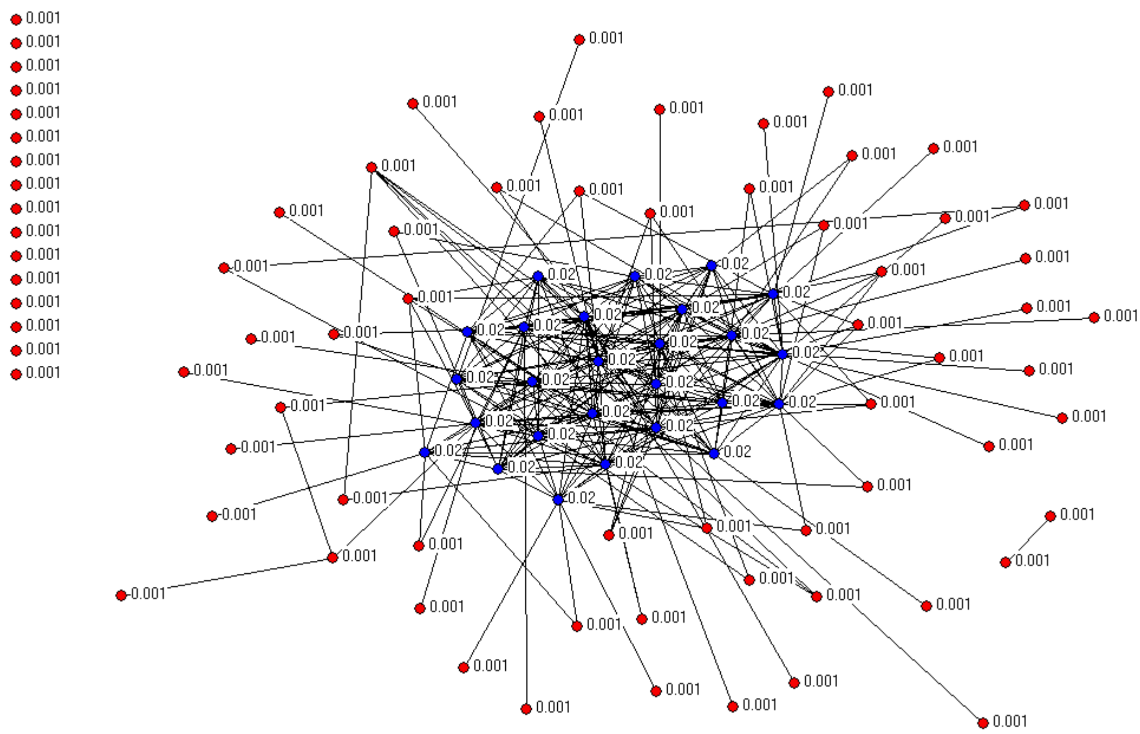
Appendix IV.I: Network of R&D relationships: An example

(HD firms (frequency of disclosure of 2%) represent 26% of the total number of firms in this particular simulation. LD firms (frequency of disclosure of 0.1%) represent 74% of the total number of firms)

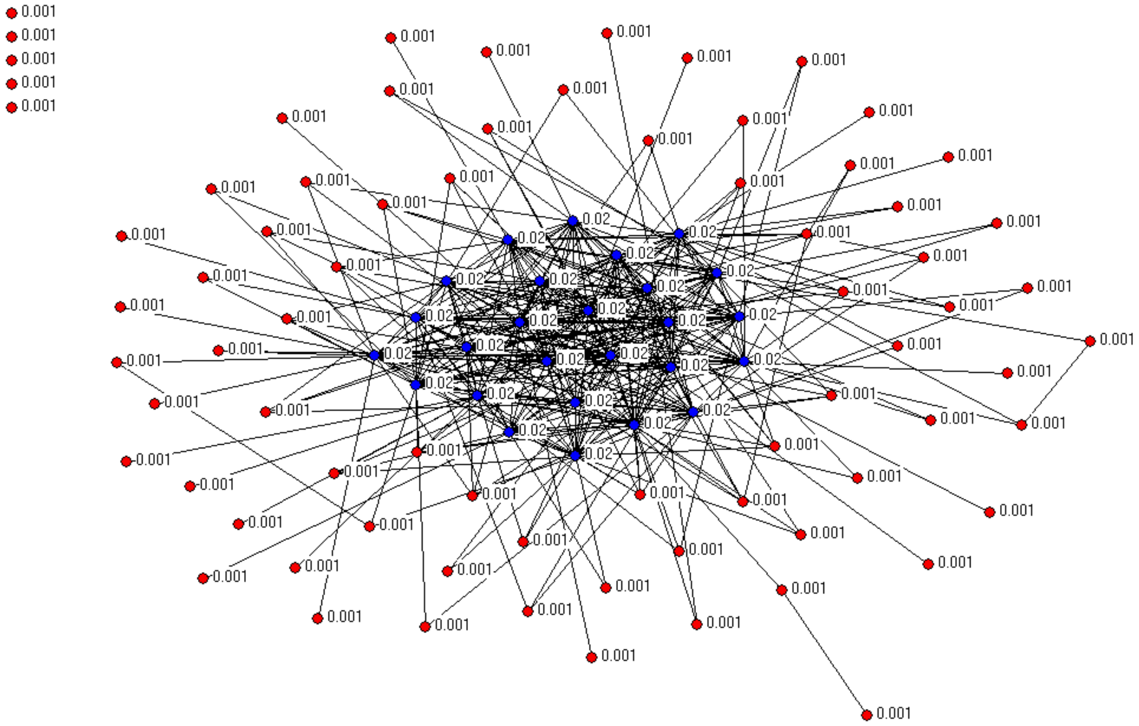
after 4000 periods:



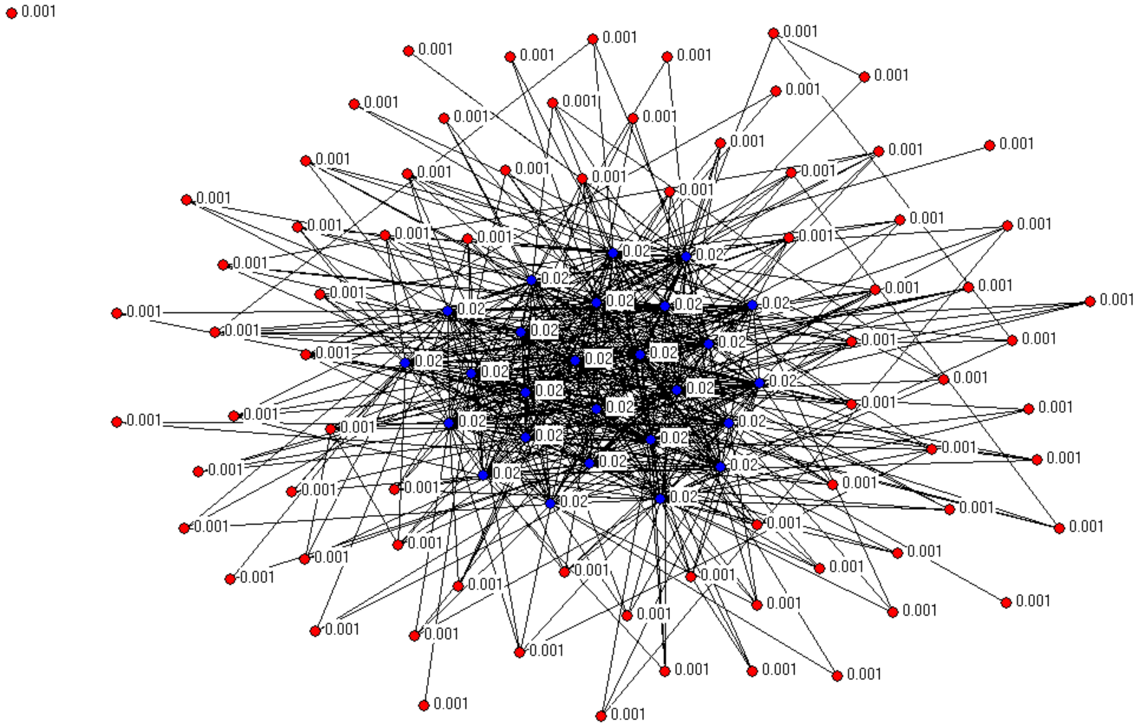
after 12000 periods:



after 20000 periods:



after 4000 periods:



Appendix V.1: The English version of the questionnaire BETA-BioValley

Questionnaire BETA-BioValley :
The role of patent in biotechnology companies

This questionnaire is addressed either to the CEO, the R&D director or the intellectual property director of the company. If you are not concerned, could you be kind enough to pass it on to the relevant person.

Answering this questionnaire should not exceed 20'. It includes three parts:

- Identification of the company
- Patenting strategies
- Role of patents in research collaborations

Answers must be filled directly on the e-file, as shown in the two following examples:

Example 1: Question: Did your company already apply for a patent in the past? *(please underline the right answer)*

- ❑ Yes
- ❑ No

If your company already applied for a patent, please underline yes as above.

Example 2: Question: Why does your company apply for patents? *(please, mark each item from 0 to 4 : 0=not important - 4= very important).*

To prevent competitors to imitate the innovation	4
To improve your bargaining power in negotiations with other firms	2
To collect royalties	0
Others	0

Please, answer as above if your company applies for patents mainly in order to prevent imitation, at a lesser degree in order to improve bargaining power and not at all to receive royalties.

Answers can be e-mailed or faxed to the following address :
By e-mail : penin@cournot.u-strasbg.fr
by fax : (00.33) (0)3.90.24.20.71

If you have any question or doubt concerning this questionnaire please contact :

PENIN Julien
BETA, Université Louis Pasteur,
61 avenue de la Forêt Noire,
67085 Strasbourg Cedex, France
tel : (00.33) (0)3.90.24.21.81

penin@cournot.u-strasbg.fr

Thank you for your cooperation.
Best regards,
the BETA team.

PART I : General information about the company

Name of company:

Postal address:

Describe in a few words your main activity:

Year of creation of your company:

Type of company *(please underline the right answer)***:**

- ❑ Independent start-up
- ❑ Start-up subsidiary of a group
- ❑ Big pharmaceutical company
- ❑ Other

If other, please specify :

In which country is the headquarter of your company located? *(please underline the right answer)*

- ❑ Switzerland
- ❑ Germany
- ❑ France
- ❑ USA
- ❑ Japan
- ❑ Other

If other, please specify :

Activity of your company *(several answers are possible ; please underline the right answer(s))* :

- ❑ Agro-biotechnology
- ❑ Bio-informatics
- ❑ Drug manufacturing
- ❑ Clinical trials
- ❑ Production and management of databases
- ❑ Search for new compounds
- ❑ Other

If other, please specify :

Total number of employees :

Total number of employees with a PhD:

Total number of employees working in secretariat, management or finance :

Function of respondent:

PART II : Patenting strategy

How many patents does your company hold ?

How many patents has your company applied for during the last three years ?

Does your company have a department specialised in intellectual property, either within the company or within the group owning the company ? *(please, underline the right answer)*

- ❑ Yes
- ❑ No

How does your company achieve technological and scientific intelligence? (*please, mark each item from 0 to 4 : 0=you do not use this method - 4= you use it frequently*)

Scanning patent databases	
Scanning scientific publications	
Attending conferences regularly	
Reverse engineering new products	
Others	

If others, please specify :

Why does your company apply for patents? *(please, mark each item from 0 to 4 : 0= not an important reason - 4= very important. Only companies who already applied for patents are expected to answer this question)*

To protect the know-how	
To signal scientific and industrial competences to potential partners	
To attract funds (risk-capital, banks, etc.)	
To exploit innovation in a monopoly situation	
To improve bargaining power in negotiations with other firms	
To collect royalties	
Others :	

If others, please specify :

According to you, what are the main deficiencies of the patent system ? *(please, mark each item from 0 to 4 : 0= total disagreement with the proposed item - 4= total agreement. Even companies who never applied for patents are expected to answer this question)*

Patent fees (application and maintenance) are too high	
Patents are too difficult to defend on front of a court	
Patents do not prevent competitors from imitating the innovation	
Patents disclose too much information to competitors about your research	
Others	

If others, please specify :

How does your company prevent rival firms from imitating your innovations? *(please, mark each item from 0 to 4 : 0= I use this method but I do not consider it as efficient - 4= I use it and it is very efficient. If the company does not use one of the proposed methods, please do not indicate anything in the corresponding box. Even companies who never applied for patents are expected to answer this question)*

Patenting	
Commercial trademark	
Secrecy	
Complementarity with unique assets held by your company	
Lead time	
Others	

If others, please specify:

How does your company signal competences to industrial and academic worlds ? *(please, mark each item from 0 to 4 : 0= I use this method but I do not consider it as efficient - 4= I use it an it is very efficient. If the company does not use the proposed method, please do not indicate anything in the corresponding box. Even companies who never applied for patents are expected to answer this question)*

Patenting	
Allow researchers to publish in scientific reviews	
Allow researchers to participate in conferences	
Encourage informal relationships with other researchers	
Participation in public research programs (either national or European)	
Disclosure of information via Internet (on the firm's web site for instance)	
Others	

If others, please specify:

Among the following items that describe possible consequences of being granted a patent, which one did your company really experience? *(please, mark each item from 0 to 4 : 0= not an important reason - 4= very important. Only companies who already applied for patents are expected to answer this question)*

Integration within new networks	
Proposal of buyout or merger	
Significant growth of your turnover	
Access to new funds for your researches	
Access to new markets or niches	
Competitors were quickly able to imitate your technology	
Others	

If others, please specify:

PART III : Role of patent in research collaborations

Did your company collaborate in R&D with other organisations over the last three years ? *(please, underline the right answer*)

- ❑ No collaboration
- ❑ Only one collaboration
- ❑ Among two and five collaborations
- ❑ More than five collaborations

If the answer to the previous question is no collaboration, please go directly to the last question of the questionnaire.

Does a patent play any role in one of this (these) collaboration(s) ? *(please, underline the right answer)*

- ❑ Yes
- ❑ No

If yes, at which step of the collaboration(s) ? *(please, mark each item from 0 to 4 : 0= not an important reason - 4= very important)*

Prior to the collaboration: It was a patent that enabled my company to identify the partner (or the partner to identify my company)	
When defining the modalities of the collaboration: Patent provides its owner with a bargaining power	
After the collaboration: A joint patent application enables the partners to share the benefits of the collaborative research	
At another step	

If other, please specify:

Within which institutional framework(s) did the collaboration(s) take place ? ***(several answers are possible ; please underline all the right answer(s))***

- ❑ Informal relationships (no formal contract)
- ❑ Sub-contracting
- ❑ Patent cross-licensing
- ❑ Government sponsored R&D collaboration (including European programs)
- ❑ Joint R&D contract (excluding government sponsored programs)
- ❑ Creation of a joint venture
- ❑ Other types of collaboration

If others, which ones:

Which type of partner(s) was (were) concerned by this (those) collaboration(s)? ***(several answers are possible ; please underline the right answer(s))***

- ❑ Independent start-up
- ❑ Start-up part of a group
- ❑ Big pharmaceutical company
- ❑ Public R&D laboratory
- ❑ Private R&D laboratory
- ❑ Other type of partners

If other, which ones:

Was any of the partners a member of the BioValley network? *(please, underline the right answer)*

- ❑ Yes
- ❑ No

Does the collaboration include any of the following modalities? ***(several answers are possible ; please, underline the right answer(s))***

- ❑ **Hiring young researchers**
- ❑ PhD student working and preparing their PhD in the company
- ❑ Co-publication in scientific reviews
- ❑ Co-patenting
- ❑ Others

If others, which ones:

Thank you for your attention. Would you agree to participate in a more in depth oral interview regarding your company strategies on patenting and R&D collaborations? *(please, underline the right answer)*

- ❑ Yes
- ❑ No

Appendix V.2: The French version of the questionnaire BETA-BioValley

Questionnaire BETA-BioValley : le rôle de la propriété intellectuelle dans les biotechnologies

Ce questionnaire est destiné, soit au CEO, soit au directeur scientifique, soit au responsable de la propriété intellectuelle de votre entreprise. En cas d'erreur d'adressage nous vous serions reconnaissant de le transmettre à la personne concernée.

Le remplissage de ce questionnaire ne prendra pas plus de 20mn. Le questionnaire comprend trois parties :
- identification de l'entreprise
- pratiques liées au brevet
- liens entre le brevet et les coopérations en R&D.

Les réponses sont à formuler directement sur ce fichier, conformément aux deux exemples suivants :

Exemple 1: Question : Votre entreprise a-t-elle déjà déposé un brevet par le passé?

- ❑ Oui
- ❑ Non

Si votre entreprise a déjà déposé des brevets soulignez la réponse oui comme ci-dessus

Exemple 2 : Question : Pour quelles raisons votre entreprise dépose-t-elle des brevets? *(notez chacune de ces propositions de 0 à 4 : 0 = pas du tout importante - 4= très importante.)*

Pour empêcher l'imitation de l'innovation	4
Pour améliorer votre position stratégique lors de négociations avec d'autres firmes	2
Pour toucher des royalties	0
Autres :	0

Répondez comme dans l'exemple ci-dessus si votre entreprise dépose des brevets essentiellement dans le but d'empêcher l'imitation mais pas du tout pour toucher des royalties et très peu pour améliorer votre position stratégique lors de négociations.

Les réponses sont à retourner à votre convenance :
Soit par mail à : penin@cournot.u-strasbg.fr
Soit par fax au : 03.90.24.20.71

En cas de problème concernant la compréhension d'une question n'hésitez pas à nous contacter :

PENIN Julien
BETA, Université Louis Pasteur,
61 avenue de la Forêt Noire,
67085 Strasbourg Cedex, France
tel : 03.90.24.21.81

En vous remerciant par avance de votre coopération, veuillez agréer Madame, Monsieur, l'expression de nos salutations respectueuses.

PARTIE I : Identification de l’entreprise

Nom de l’entreprise :

Adresse de l’entreprise :

Code NAF :

Décrivez en une ligne votre activité principale :

Année de création :

Type d’entreprise (*soulignez la réponse adéquate)***:**

- ❑ Start-up indépendante
- ❑ Start-up filiale d'un grand groupe
- ❑ Grande entreprise pharmaceutique
- ❑ Autre

Si autre, lequel :

Nationalité de votre entreprise *(indiquez la nationalité du siège de votre établissement dans le cas d’une filiale d’un grand groupe ; soulignez la réponse adéquate)*

- ❑ Suisse
- ❑ Allemande
- ❑ Française
- ❑ Américaine
- ❑ Japonaise
- ❑ Autre

Si autre, laquelle :

Secteur d’activité de votre entreprise (*plusieurs réponses possibles ; soulignez les réponses adéquates)* :

- ❑ Agro-biotechnologie
- ❑ Bio puces
- ❑ Fabrication de médicaments
- ❑ Tests cliniques
- ❑ Production et gestion de bases de données
- ❑ Recherche de nouvelles molécules actives
- ❑ Autre

Si autre, lequel:

Nombre total d’employés (à la date du 01/01/2003):

Nombre de docteurs (à la date du 01/01/2003): :

Nombre de personnes travaillant dans l’administration, la finance ou la gestion (à la date du 01/01/2003):

Quelle est votre fonction dans cette entreprise :

Nous allons maintenant chercher à connaître les activités de dépôt de brevet de votre entreprise, ainsi que votre perception du système de brevet.

PARTIE II : Pratiques liées au brevet et évaluation du système de brevet

Combien votre entreprise détient-elle de brevets?

Combien votre entreprise a-t-elle déposé de brevets durant les trois dernières années ?

Pour le dépôt et la gestion de vos brevets, disposez-vous d'un service de propriété industrielle, soit propre à votre firme, soit appartenant au groupe dont vous faites partie ? *(soulignez la réponse adéquate)*

- ❑ Oui
- ❑ Non

Parmi les activités de veille technologique suivantes, lesquelles sont pratiquées régulièrement par votre entreprise? (*Notez chacune de ces propositions de 0 à 4 : 0=vous n'utilisez pas cette méthode - 4= vous l'utilisez souvent.*)

Etude des bases de données de brevet	
Etude des publications scientifiques	
Participation régulière à des conférences et colloques	
Reverse engineering de nouveaux produits	
Autres	

Si autres, lesquelles :

Pour quelles raisons votre entreprise dépose-t-elle des brevets? *(notez chacune de ces propositions de 0 à 4 : 0 = pas importante - 4= très importante. Seules les entreprises qui ont déjà déposé des brevets par le passé doivent répondre à cette question)*

Pour protéger votre savoir-faire	
Pour faire connaître vos compétences scientifiques et technologiques	
Pour lever des fonds (capital-risque, banques, etc.)	
Pour exploiter l'innovation en situation de monopole	
Pour améliorer votre position stratégique lors de négociations avec d'autres firmes	
Pour toucher des royalties	
Autres :	

Si autres, lesquelles :

Quelles sont selon vous les déficiences du système de brevet? *(Notez chacune de ces propositions de 0 à 4 : 0 = pas du tout d'accord - 4= tout à fait d'accord. Même les entreprises qui n'ont jamais déposé de brevet doivent répondre à cette question)*

Un brevet est trop coûteux à déposer et à entretenir	
Un brevet est trop coûteux à défendre devant les tribunaux	
Un brevet n'empêche pas vos concurrents de vous imiter	
Un brevet divulgue trop d'informations à vos concurrents sur votre recherche	
Autres	

Si autres, lesquelles :

Quelles méthodes utilisez-vous pour empêcher l'imitation de vos innovations ? *(Notez chacune de ces propositions de 0 à 4 : 0=pas efficace - 4= très efficace. Si vous n'utilisez pas une de ces méthodes : ne rien indiquer dans la case correspondante. Même les entreprises qui n'ont jamais déposé de brevet doivent répondre à cette question)*

Le brevet	
La marque commerciale	
Le secret	
La complémentarité avec d'autres actifs que ne possèdent pas les imitateurs	
L'avance technologique	
Autres	

Si autres, lesquelles :

Quelles méthodes utilisez-vous pour signaler vos compétences au monde industriel ou académique ? *(Notez chacune de ces propositions de 0 à 4 : 0=pas efficace - 4= très efficace. Si vous n'utilisez pas une de ces méthodes : ne rien indiquer dans la case correspondante. Même les entreprises qui n'ont jamais déposé de brevet doivent répondre à cette question)*

Le brevet	
Autoriser les chercheurs à publier dans des revues académiques	
Autoriser les chercheurs à participer à des colloques et conférences	
Encourager les relations informelles avec d'autres chercheurs	
Participer à des programmes publics de recherches nationaux ou Européens	
Divulgation d'informations via Internet	
Autres	

Si autres, lesquelles :

Les propositions suivantes décrivent certaines retombées pouvant résulter d'un dépôt de brevet. Quelles sont celles que votre entreprise a pu observer ? *(Notez chacune de ces propositions de 0 à 4 : 0 = pas importante - 4= très importante. Seules les entreprises qui ont déjà déposé des brevets par le passé doivent répondre à cette question)*

Une intégration dans de nouveaux réseaux	
Une proposition de rachat ou de fusion	
Une croissance significative de votre chiffre d'affaires	
Un accès à de nouveaux moyens de financement pour vos recherches	
Un accès à de nouveaux marchés ou de nouvelles niches	
Vos concurrents ont pu vous imiter ou améliorer leur technologie	
Autres	

Si autres, lesquelles :

PARTIE III : Rôle du brevet dans les collaborations en R&D

Avez-vous (eu) des collaborations en R&D avec d'autres organisations durant les 3 dernières années ? *(soulignez la réponse adéquate)*

- ❑ Aucune collaboration
- ❑ Une seule collaboration
- ❑ Entre 2 et 5 collaborations
- ❑ Plus de 5 collaborations

Si vous répondez aucune collaboration à la question précédente vous pouvez directement passer à la dernière question de ce questionnaire

Le brevet a-t-il joué un rôle important pour l'une ou l'autre de ces collaborations ? *(soulignez la réponse adéquate*)

- ❑ Oui
- ❑ Non

Si oui, à quelle(s) étape(s) de cette (ces) collaboration(s) ? *(Notez chacune de ces propositions de 0 à 4 : 0 = pas importante - 4= très importante)*

En amont : le brevet permet d'identifier - ou d'être identifié par -votre partenaire	
Lors de la définition des modalités de la collaboration : le brevet confère un pouvoir de négociation à son détenteur	
Suite à la collaboration : un dépôt conjoint de brevet permet de partager les résultats de recherche issus de la coopération	
Lors d'une autre étape	

Si autre, laquelle:

Dans quel(s) type(s) de cadre(s) institutionnel(s) s'inscrivait cette (ces) collaboration(s) ? ***(Plusieurs réponses possibles ; soulignez les réponses adéquates)***

- ❑ Relations informelles (pas de contrat formel)
- ❑ Contrat de sous–traitance
- ❑ Cession croisée de licence
- ❑ Contrat dans le cadre d'un programme public de R&D (y compris les programmes européens)
- ❑ Contrat de recherche conjointe hors programme public
- ❑ Création d'une société conjointe
- ❑ Autre type de collaboration

Si autre, laquelle :

Cette (ces) collaboration(s) concernai(en)t quel(s) type(s) de partenaires ? ***(Plusieurs réponses possibles ; soulignez les réponses adéquates)***

- ❑ Start-up indépendante
- ❑ Start-up filiale d'un grand groupe
- ❑ Grande entreprise pharmaceutique
- ❑ Laboratoire public de recherche
- ❑ Laboratoire privé de recherche (CRO)
- ❑ Autre type de partenaire

Si autre, lequel :

L'un de ces partenaires était-il membre du réseau Biovalley ? *(soulignez la réponse adéquate)*

- ❑ Oui
- ❑ Non

La collaboration a-t-elle inclu l'une des modalités suivantes ? *(plusieurs réponses possibles ; soulignez les réponses adéquates)*

- ❑ Embauche de jeunes chercheurs
- ❑ Doctorat en entreprise (CIFRE)
- ❑ Publications scientifiques communes
- ❑ Co-dépôt d'un ou plusieurs brevets
- ❑ Autre

Si autre, laquelle :

Merci de votre attention. Seriez-vous prêt à répondre à un entretien plus approfondi sur les stratégies de votre entreprise concernant le brevet et les collaborations? *(soulignez la réponse adéquate)*

- ❑ Oui
- ❑ Non

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The topic of this thesis deals with behaviours of open knowledge disclosure. In particular, we investigate the economic motives that encourage firms to adopt such behaviours. What are the reasons that lead rational profit-seeking firms to let their researchers publish their work in scientific journals or present their researches in conferences? We put a specific emphasis on reputation effects that are triggered by open knowledge disclosure and that can facilitate, for instance, the formation of cooperative links among agents who are part of the innovation process.

We start this thesis by a reminder of the classical theory of knowledge externalities. We show that the economic work on knowledge disclosure finds its source within the theory of knowledge externalities. It is by endogenising knowledge externalities that economic scholars came to deal with behaviours of open knowledge disclosure.

Then we give a definition of open knowledge disclosure, which we consider as a particular kind of knowledge disclosure, and we provide empirical evidence of such behaviours of open knowledge disclosure. We also review the different economic reasons that have been investigated in the economic literature and that can explain why firms openly disclose their knowledge.

In the third chapter we explore in more depth one of these reasons, namely open knowledge disclosure as a signal of competences aiming at breaking adverse selection problems that arise when firms try to cooperate in R&D. We show with the help of a simple model that, due to problems of adverse selection, firms willing to collaborate in R&D may wish to disclose knowledge in order to increase their reputation, which in turn may facilitate the establishment of links with other agents. In other words, we explain open knowledge disclosure by combining two different parts of the economic literature: Economics of innovation and economics of incomplete information.

The fourth chapter aims at exploring the link between open knowledge disclosure, R&D collaborations and the presence of incomplete information within the innovation process by using numerical simulations. For this purpose, we develop a theoretical model describing the formation of R&D collaborations among firms, with specific emphasis put on the role played by open knowledge disclosure during this process. The model is then tested with numerical simulations.

In the last chapter, we focus on the role of patents as devices to openly disclose knowledge. By combining a theoretical discussion on patents with the first elements of a case study in the field of biotechnologies we show that firms may sometimes value the function “disclosure of the knowledge underlying a given innovation” of patents as much as the function “protection of a given innovation”.