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The Importance of Tacit Knowledge: Dynamic Inventor Activity in the Commercialization Phase

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Abstract

Inventors generally know more about their inventions than what is written down in patent applications. Because they possess this tacit knowledge, inventors may need to play an active role when patents are commercialized. We build on Arora (1995) and model firm-inventor cooperation in the commercialization of a given invention. Tacit knowledge warrants inventor activity. However, imperfect IPRs may reduce inventors' incentives to engage in the commercialization process. We analyze when first-best inventor activity is achieved in a two-stage contract. In the empirical part, we analyze when inventor activity is important for the successful commercialization of patents by using a detailed patent database. The database contains unique information on inventor activity, patent commercialization modes and the profitability of commercialization. In the empirical estimations, we find that inventor activity has a strong positive correlation with profitability when a patent is sold or licensed to another firm. When a patent is sold or licensed in the second phase, it is still inventor activity in the first phase that matters for profitability. Thus, our interpretation is that tacit knowledge and close cooperation between inventors and external firms are often crucial for the successful commercialization of patents.

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1. Introduction

The essence of *tacit knowledge* is "you know more than you can tell" (Polanyi, 1967, p. 4). Tacit knowledge is the part of knowledge that cannot be described or codified. The transfer of tacit knowledge often requires, at the very least, personal face-to-face contact. Giovanni Dosi (1988a, p. 1126) writes: "Tacitness refers to those elements of knowledge, insight and so on, that individuals have which are ill-defined, un-codified and unpublished, which they themselves cannot fully express and which differ from person to person, *but which may to some significant degree be shared by collaborators and colleagues who have common experience*".

Individuals who acquire knowledge often need additional learning—through explanations, demonstrations, and testing—to appropriate the tacit part of that knowledge. For innovation, tacit knowledge is crucial. The innovation process, in which an invention becomes a commercialized product, often requires adaption, modifications, adjustments and development before the invention can be exploited commercially. The presence of tacit knowledge therefore requires that the inventor actively engage in the commercialization process.

The main purpose of the present study is to empirically analyze when tacit knowledge is important for the commercialization of inventions/patents. Examining patents is a fruitful way to analyze tacit knowledge, since patents are related to both codified and tacit knowledge. In patent applications, inventors need to disclose only as much information (codified knowledge) as is necessary for patents to be granted. A part of the knowledge that is not disclosed is firmly bound to the inventors, who have often undertaken numerous experiments when creating the inventions. This tacit knowledge can be available to external agents only through direct interaction with the inventors – and sometimes not even then.

We build on Arora (1995) and model inventor activity in the commercialization process of an invention. Inventors have the intellectual property rights (IPRs) for their invention but also have private knowledge about the nature of the invention. Successful innovation requires the transfer of both formal property rights and tacit knowledge. Standard contracts may not ensure incentives for transferring tacit knowledge. An option contract in which the transfer of

IPRs occurs after the transfer of tacit knowledge may provide first-best incentives for inventor activity when IPRs are strong enough.

In our empirical estimations, we use a detailed database on individual patents owned by small firms and inventors. The uniqueness of this database is that it contains information on whether, when and how a patent is commercialized (for example, commercialization mode), whether the inventors are active during commercialization and how commercialization performs in profit terms. This makes it possible to empirically test under which conditions inventor activity (and tacit knowledge) is important for successful commercialization. To the best of our knowledge, the importance of tacit knowledge in the commercialization process of inventions/patents has not been analyzed in previous empirical studies.

Our empirical estimations show that inventor activity is positively related to successful commercialization. However, this relationship is even stronger when the patent is licensed or sold to an external firm. Our interpretation of the results is that tacit knowledge of the inventors and cooperation between the inventors and external firms are crucial for successful patent commercialization.

The paper is organized as follows. Theories and previous studies about tacit knowledge are discussed in section 2. In section 3 we present a model of transfer of tacit knowledge in the commercialization process of an invention. Section 4 presents the database and descriptive statistics. In section 5, econometric models and hypotheses are presented and explanatory variables are defined. Empirical estimations are performed in section 6, and the final section concludes the paper.

2. The importance and transfer of tacit knowledge

2.1 Background

Invention and innovation are different activities. This was underlined early by Schumpeter (1911, p. 88−89), who writes: “Economic leadership must be distinguished from “invention” As long as they are not carried into practice, inventions are economically irrelevant. …Although entrepreneurs *may* be inventors just as they may be capitalists, they are inventors not by nature of their function but by coincidence and vice versa. …The entrepreneurial kind of leadership (…) consists in fulfilling a very special task which only in rare cases appeals to the imagination of the public". Although it is possible for inventors to commercialize their own inventions (and also become entrepreneurs), research/inventing and commercialization require quite different skills. Firms may have financial and marketing resources that are crucial for commercialization, whereas inventors have technological knowledge.

In line with Schumpeter, there is a long tradition in economics (and other disciplines) in analyzing the market for technology (see, e.g., Shapiro, 1985, Kamien, 1992, Teece, 1988, Arora *et al.*, 2001, Reinganum, 1989, Arora and Gambardella, 2010 or Scotchmer, 2004, for excellent reviews). A large part of this literature focuses on strategic interactions between patent owners/licensors (inventors) and licensees (technology buyers). In general cases, this literature proposes that a fixed fee rather than royalties generates higher revenues for the licensor and a higher surplus for consumers. The reason is that royalties impose higher marginal costs on producers, which results in higher prices and lower output.

In markets for technology, however, there are many complications related to the general conclusions from the literature. First, knowledge has public-good characteristics. Knowledge is non-rival and only partially excludable. IPRs in the form of patents and copyright are institutional responses to the public-good characteristics of knowledge. Second, the market for knowledge is characterized by asymmetric information. Arrow (1962) describes the problem in markets for technology: "its value for the purchaser is not known until he has the information, but then he has in effect acquired it without cost". Uncertainty about the value of an invention is one reason why patent licensing may include both a fixed fee and (sub-optimal) royalties (see, e.g., Mendi, 2005). A fixed fee assigns all risk to the licensing firm, while royalties involve risk sharing between the inventor and the firm.

When inventor activity is required for successful commercialization of an invention, moral hazard problems may arise. With fixed fees, incentives for inventor activity are limited. With royalties, inventors have larger incentives to contribute to the commercialization process.

<u>Tacit and standard knowledge</u>

In this paper, we focus on tacit knowledge. We assume that an invention is valuable for a firm but that the full value can be acquired only if tacit knowledge is also transferred with the patent. The inventor controls the tacit knowledge and acquires it through learning, testing, observing and exercising. Therefore, tacit knowledge cannot easily be transferred to others through written texts or manuals. If it is possible at all, tacit knowledge transfer requires close interaction between the sender and the recipient − at the very least through personal face-to-face contact.

Pure tacit knowledge represents the opposite of knowledge spillovers. Tacit knowledge cannot flow costlessly to other agents even if the owner wants to transfer it. On the other hand, knowledge externalities, spillovers, denote the case when agents acquire knowledge from others when it is unintended.

The intermediate type of knowledge, which can be transferred if and only if the sender wants to transfer it, is denoted as *standard* knowledge. Standard knowledge can be sold and bought in markets. Perfect knowledge transfer implies that the recipient receives a perfect copy of the original knowledge. Once knowledge is transferred, the recipient has the same control over it as the submitter has because knowledge is non-rival. In markets for knowledge, the seller keeps what she sells. However, standard knowledge is excludable through IPRs. Without them, standard knowledge would be a textbook case of a public good: once provided, everybody can benefit from it. Since IPRs secure the ownership of (commercially exploitable) knowledge, licensing or selling of knowledge is facilitated. Spillovers from knowledge reflect deficient IPRs. Spillovers represent one main reason why markets for knowledge work imperfectly: Producers of knowledge must cover the full cost of the investment, but their benefit is less than the full social benefit. Therefore, they produce less knowledge than what is socially optimal.

Transaction costs

For tacit knowledge, transfer is limited even if the sender wants to transfer it. Pure tacit knowledge cannot be transferred at all. For this type of knowledge, there is no market (although there may well be a market for what the knowledge is used for). Generally, though, tacit knowledge introduces transaction costs for the transfer to happen, as underlined by Dosi (1988a) in the quote above (text in italics). The sender must take an active part in the transfer process for the transaction to succeed. Nelson and Winter (1982) write (p. 78): “It seems clear that the “tacitness” of a skill is a matter of degree”. They continue (p. 82): “Finally, it should be emphasised that costs matter. Whether a particular bit of knowledge is in principle articulable or necessarily tacit is not the relevant question in most behavioural situations.

Rather, the question is whether the costs associated with the obstacles to articulation are sufficiently high so that the knowledge *in fact* remains tacit”.

Tacit knowledge makes it costly to transfer knowledge from one agent to the other. Transaction costs are a main ingredient in Coase’s *Theory of the firm* (1937). Because of transaction costs, firms integrate tasks when doing so is more profitable than disaggregated micro-agents doing their individual tasks and selling them on a market.

Tacit knowledge may enhance IPRs since acquiring and using knowledge becomes costly and more difficult without the owner’s consent. Others’ use of an invention that also depends on tacit knowledge becomes difficult and costly. Therefore, elements of tacit knowledge in patented inventions may increase their owners’ market power. The invention becomes difficult to copy even when the codified part of the invention is made public through patenting.

Since tacit knowledge is exclusive knowledge, asymmetric information problems arise when it is transferred. The large body of literature on asymmetric information describes how such information is used strategically to the benefit of agents. When innovation occurs and inventions are commercialized, agents have engaged in principle-agent relationships. The work of Grossmann and Hart (1986) on incomplete contracts and vertical integration provides a framework for analyzing the integration of invention and entrepreneurship.

As Nelson and Winter (1982) point out, tacitness is a matter of degree. An important issue is whether it is also a matter of choice and therefore endogenous. Some inventions may be targeted for sale in a market. In that case, the inventor may wish to disclose as much as possible about her invention in patent documents and elsewhere to make the market price for the patent as high as possible. In other cases, the inventor may want to keep parts of the invention secret or tacit in order to be able to extract more value from it during and after the commercialization process.

2.2 Previous studies

Teece (1981) analyzes the role of tacitness in technology transfer. He underlines that because of tacitness, knowledge is transferred more easily between agents who share context and experience. He writes (p. 82): “Transmittal and receiving costs are lower the greater the similarities in the experience of the transmitting unit and the receiving unit”.

A related study is Block *et al.* (2013), who investigate the importance of entrepreneurs for different kinds of innovations. While new-to-the-market innovations require more entrepreneurial efforts, new-to-the-firm innovations seem to be less dependent on external entrepreneurs. This is confirmed by empirical studies based on the Community Innovation Survey (CIS) and a dataset on entrepreneurship (COMPENDIA). The number of new-to-the-market innovations depends more on the entrepreneurship rate in the population.

Mendi (2005) studies the impact of contract duration in determining scheduled payments in international transfers of technology. Mendi’s model analysis predicts a higher prevalence of royalty payments (in addition to fixed fees) when contracts cover more periods, which serves as insurance against contract termination. Mendi finds empirical support for his model in data on technology transfer among Spanish firms.

Marco-Stadler *et al.* (1996) analyze patent license contracts that involve knowledge transfer. Transfer of knowledge after licensing a patent creates a moral hazard problem, since it is not easy to monitor inventors’ behavior with respect to the transmission of know-how. The authors argue that this moral hazard problem can be attenuated by including royalties in contracts. They present evidence from technology contracting between Spanish and foreign firms.

Choi (2001) presents a theoretical model along the same lines. To reduce moral hazard in transferring non-contractible inputs in a licensing relationship, royalties in addition to a fixed fee could be used.

Arora *et al.* (2001) use the same model as outlined in the next section and analyze a dataset on technology transfers to Indian firms. They find that technology transfers are often accompanied by complementary supportive services from the sender. Even for India, with a weak patent regime during the period analyzed, patents play an important role in technology transfers. Arora *et al.* (2001) argue that stronger patent rights in the host country may facilitate technology transfers to developing countries. In a related study, Arora (1996) reaches the conclusions that (p. 252) “the provision of technical services is accompanied by the provision of complementary inputs" and that "patents are bundled with more technologically sophisticated know-how".

3. A model of inventor-firm cooperation

To frame our discussion about inventor-firm cooperation, we develop a model based on Arora (1995). Consider an inventor who has patented an invention. The invention has the potential to reduce marginal costs for a firm operating in a market. The inventor and the firm can therefore profitably cooperate. They may form a joint firm or make a license agreement. The cost reduction potential of the invented technology is assumed to depend on the transfer of accompanying tacit knowledge from the inventor to the firm. Transfer of tacit knowledge is assumed to be costly, and we assume that it is not possible to verify the transfer of tacit knowledge. Effective use of the technology by the firm also depends on accompanying activities (investments) performed by the firm. Neither these investments are assumed to be verifiable. These assumptions create complications for license agreements. If the firm pays the inventor upfront for the license, the inventor has small incentives for transfer of tacit knowledge. If the firm pays the inventor after transfer of tacit knowledge, the firm may benefit from the transfer of tacit knowledge only and refuse to pay for transfer of the formal license.

Arora (1995) demonstrated that a two-stage contract could induce the inventor with first best incentives for knowledge transfer. In the first stage, the firm pays the inventor an entry fee for acceptance of the contract. Thereafter the inventor transfers tacit knowledge. After the inventor has transferred knowledge, the firm pays a second fee to the inventor and receives the legal rights to exploit the patent. When the first and second stage fees are determined optimally, the inventor have first best incentives to transfer tacit knowledge given that intellectual property rights are strong enough. This result, however, requires that the firm is not able renegotiate the contract after the transfer of tacit knowledge. If the firm cannot commit to abstaining from renegotiation, incentives for the transfer of tacit knowledge are sub-optimal.

We show that when renegotiation is an option, incentives for knowledge transfer may depend on the firm's investment in the cost-reducing project. If firm activities and the transfer of the inventor's tacit knowledge are complements, the firm may increase the inventor's knowledge transfer through higher activity levels. If firm activities and tacit knowledge are substitutes, the firm may restrict its own activities in order to increase the inventor's transfer of knowledge. Subsequently, the firm may increase its activities or even sell the project with no further engagement from the inventor. Our model therefore adds a potential second stage in commercialization processes and predicts a lower need for inventor activity in this stage. An additional result from our model is that since knowledge transfer is a fixed cost, the profitability of the license agreement depends on the size of the firm's market.

3.1 The model

The firm faces a demand curve with constant demand elasticity:

$$q = ap^{-\sigma}$$

Above, q denotes quantity, p price, σ (>1) demand elasticity and a the size of the market.[1] An inventor has invented and patented a technology that potentially reduces marginal costs. The inventor considers licensing the technology to the firm. If the technology is licensed to the firm, the firm obtains legal access to the technology, t. Marginal costs also decrease with the transfer of tacit knowledge, k. t is a binary variable, while k is continuous. Costs also depend on the firm's activities, b. We assume that without access to the technology, the firm does not invest in b. However, with access to the inventor's technology, marginal costs decrease with b. Profit maximization gives the well-known pricing behavior (1) and the operating surplus (2) for the firm.

1) $$p = \frac{\sigma}{\sigma - 1} c$$

2) $$\pi = \frac{1}{\sigma} qp = \frac{1}{\sigma} a \left(\frac{\sigma}{\sigma - 1} \right)^{1-\sigma} c^{1-\sigma}$$

We assume that

$$c(t,0,0) > c(t,k,b)$$
$$\frac{dc(t,k,b)}{dk} < 0, \ \frac{dc(t,k,b)}{db} < 0,$$
$$\frac{dc(0,k,b)}{dk} < 0, \frac{dc(0,0,b)}{db} = 0$$

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[1] [1]As is well known, the above demand function could represent a monopolistic competitive market in which consumers have love-of-variety preferences. Note that with the presumed demand function, there is no issue regarding whether the innovation is drastic. Firms with the above demand function always face positive demand, regardless of what the price or costs are.

We assume that use of the technology without legal access to the patent reduces surplus. Therefore,

$$\pi(0,k,b) = p\pi(t,k,b), \quad \forall k,b$$

Above, p denotes the inverse of the strength of IPRs. If IPRs are perfect, $p=0$. If they are absent, $p=1$. One interpretation of this is that illegal use of the inventor's technology implies a risk that all profits are confiscated. Another is that 'inventing around' the patent yields lower profits than legally using the invention. This means that obtaining legal access to technology increases profits for any level of knowledge transfer and firm activity. Knowledge transfers also reduce marginal costs both when the firm has legal access to the technology and when it does not.

We assume that there are costs associated with k and b. These costs are $R=R(k)$, $R_k>0$, $R_{kk}>0$ and $H=H(b)$, $H_b>0$, $H_{bb}>0$.

An *integrated firm* faces the following maximization problem:

$$\max_{k,b}\left\{\pi(t,k,b)-R(k)-H(b)\right\}=\frac{1}{\sigma}a\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}c(t,k,b)^{1-\sigma}-R(k)-H(b)$$

First-order conditions are

$$-a\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}c_k = R_k$$

$$-a\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}c_b = H_b$$

We denote these resulting first-best levels of k, b and profits as k^*, b^* and π^*. In an integrated firm, incentives for inventor activity are therefore first best. Note that $dk^*/da>0$ and $db^*/da>0$ (see Appendix A).

Bargaining

A *bargained solution* between the inventor and the firm gives the firm a *share*, λ, of profits and leaves the inventor with the residual $(1-\lambda)$. These shares result from the firm's and the inventor's bargaining power. As a result, both the transfer of tacit knowledge and the firm's activities are lower than in the first-best solution:

$$(1-\lambda)\pi_k = R_k$$
$$\lambda\pi_b = H_b$$

Additionally, any joint ownership in the project leads to underinvestment by the firm and the inventor. This is a well-known result and is similar to the finding of Grossman and Hart (1986).[2] As described in the introduction to this sub-section, a contract requiring the inventor to transfer the IPR to the firm for a fixed fee upfront gives no incentives for the inventor to transfer tacit knowledge. However, since the firm is a residual claimant, incentives are first best for the firm. This corresponds to $\lambda=1$ above.

3.2 A first-best contract

Arora (1995) proposed a contract in which the firm first pays the inventor an entry fee, T_1. Thereafter, the inventor transfers tacit knowledge. After tacit knowledge has been transferred, the firm pays the second-period fee, T_2, and the formal IPR is transferred. It is assumed that the contract is formulated under full information (also about $R(k)$ and $H(b)$) but that the levels of k and b are not verifiable and therefore not contractible. Arora demonstrates that if the parties can commit to not renegotiating, optimally determined T_1 and T_2 provide first-best incentives for the transfer of tacit knowledge given that IPRs are strong enough.

In the last period, the maximum T_2 the firm is willing to pay is

$$T_2 = (1-p)\pi(t,k,b)$$

If $p=1$, IPRs are absent. If $p=0$, IPRs are perfect, and it is not possible to make use of the technology even after the transfer of tacit knowledge. For the inventor to be willing to transfer tacit knowledge, we require that

$$T_2 \geq R(k)$$

The firm's participation constraint is

$$T_1 + T_2 = \pi(t,k,b) - H(b) - \pi(0,0,0)$$

[2] Also see the discussion in Salanié (2005).

Inserting for T_2 from above, gives

$$T_1 + (1-p)\pi(t,k,b) = \pi(t,k,b) - H(b) - \pi(0,0,0)$$

Therefore,

$$T_1 = p\pi(t,k,b) - H(b) - \pi(0,0,0)$$

The inventor's problem is a constrained maximization problem:

$$\max_k (T_1 + T_2) = \underbrace{p\pi(t,k,b) - H(b) - \pi(0,0,0)}_{T_1} + \underbrace{(1-p)\pi(t,k,b)}_{T_2} - R(k)$$
$$= \pi(t,k,b) - \pi(0,0,0) - H(b) - R(k)$$
$$s.t$$
$$(1-p)\pi(t,k,b) \geq R(k)$$

The solution to the problem gives $\pi_k=R_k$ and therefore $k=k^*$ given that the constraint does not bind. Furthermore, by optimally determining T_1 and T_2, the inventor also ensures that the firm invests b^*, i.e.,

$$T_1 + T_2 = \pi(t,k^*,b^*) - H(b^*) - \pi(0,0,0)$$

The constraint is less likely to be binding the smaller p is. With perfect IPRs, the constraint never binds if the first-best solution implies $k^*>0$. Also note that since π increases in a, the constraint is less likely to bind the larger the market is. When the constraint does not bind, the inventor expropriates all surplus.

3.3 Renegotiation

Now assume that the firm requires renegotiation of the contract after tacit knowledge has been transferred. As above, λ denotes the firm's bargaining power. The firm's reservation point is what it can obtain without agreement. This is $p\pi(t, k, b)$. The inventor's reservation point is 0 (T_1 is already paid). A bargained solution thus gives

$$T_2 = \pi(t,k,b)(1-\lambda)(1-p)$$

The firm's net profits after the transfer of T_2 is

$$\pi(t,k,b) - T_2 = \pi(t,k,b)(\lambda - (1-\lambda)p)$$

Anticipating the bargaining after investments, both the inventor and the firm underinvest:

$$R_k = \pi_k(1-\lambda)(1-p)$$
$$H_b = \pi_b(\lambda-(1-\lambda)p)$$

Denote the resulting *k* and *b*, *k'* and *b'*. Note that the constraint $T_2>R(k)$ is more likely to be binding in this case. If it binds, the inventor underinvests more than *k*-k'*. In the first stage of the game, the firm's participation constraint becomes

$$T_1 + T_2 = \pi(t,k',b') - H(b') - \pi(0,0,0)$$

Thus, T_1 becomes

$$T_1 = \pi(t,k',b')(\lambda+(1-\lambda)p) - H(b') - \pi(0,0,0)$$

As in the game without renegotiation, the inventor adjusts the total fees to expropriate all the surplus. This surplus is lower with renegotiation than without.

With renegotiation, there is the possibility that one of the parties becomes the Stackelberg leader. In this case, the Stackelberg leader takes into account how the follower reacts to the leader's investments. The first-order conditions for the inventor and the firm given that either of them has a Stackelberg position are

$$R_k = \left(\pi_k + \pi_b \frac{db}{dk}\right)(1-\lambda)(1-p)$$
$$H_b = \left(\pi_b + \pi_k \frac{dk}{db}\right)(\lambda-(1-\lambda)p)$$

Given that the other party is the Stackelberg follower, we obtain the following for the inventor and the firm, respectively, by differentiating the first-order conditions:

$$\frac{db}{dk} = -\frac{\pi_{kb}(1-\lambda)(1-p)}{\pi_{kk}(1-\lambda)(1-p) - R_{kk}}$$
$$\frac{dk}{db} = -\frac{\pi_{bk}(\lambda-(1-\lambda)p)}{\pi_{bb}(\lambda-(1-\lambda)p) - H_{bb}}$$

The denominators are negative given that the second-order conditions for the maximization problems are fulfilled. The sign of the nominators depends on whether *k* and *b* are complements or substitutes. If they are complements, higher *k* induces higher *b* and higher *b* induces higher *k*. If they are substitutes, it is the other way around.

Presume that the firm is the Stackelberg leader and that *k* and *b* are complements. In this case, the firm induces the inventor to invest more than *k'* by increasing its own investments in *b*.

For this to be a credible solution, however, the firm must commit to overinvesting in *b* relative to *b'*. This is well known for Stackelberg leadership: The leader must commit to deviating from its ex post optimal strategy. One possibility in our context is that the firm has an agreement to sell the technology after the investments have been made.

Presume that the firm is the Stackelberg leader and that *k* and *b* are substitutes. In this case, the firm may *underinvest* in *b* in order to increase investment by the inventor. This approach may well be credible. After T_2 is paid and formal ownership to the technology is transferred, the firm has fulfilled its obligations vis-à-vis the inventor. Thereafter, the firm may increase *b* without any further involvement by the inventor.

3.4 Conclusions and theoretical predictions

We have analyzed inventor-firm cooperation in the commercialization phase of an invention. We have assumed that successful commercialization requires the transfer of formal IPRs in addition to tacit knowledge from the inventor as well as investments from the firm. Due to incomplete contracts (neither *k* nor *b* are contactable), outcomes are dependent on the implicit incentives in the contract between the inventor and the firm.

For an integrated firm, incentives are assumed to be first best. When the firm is not integrated with the inventor, incentives to invest in *k* and *b* are insufficient if the firm and the inventor engage in profit sharing. A contract design proposed by Arora (1995) provides first-best incentives for investment in *k* and *b*. This contract design involves a sequence of steps. In the first step, the firm pays the inventor an entry fee. Thereafter, the inventor transfers *k* and the firm invests in *b*. The last step involves payment of the last fee and transfer of the formal property right to the invention. The first-best incentives are obtained by optimally determining the payments from the firm to the inventor. These incentives are the result of a constrained maximization problem, however. If the constraint binds, the inventor transfers less *k* than what is optimal. The constraint is less likely to bind if IPR protection is high and there is a larger market for the final product.

The first-best solution depends on the parties being able to commit to not renegotiating the contract. With renegotiations, the firm may abstain from the last payment and insist on a negotiated payment. Anticipating the bargained solution, the inventor and the firm underinvest in *k* and *b*.

Finally, the firm may have a Stackelberg leader position in the last round of negotiations. In that case, the firm may overinvest/underinvest in *b* to influence the inventor's transfer of *k*. Such a strategy involves fewer commitment problems when *k* and *b* are substitutes. In that case, the firm underinvests in *b* but is free to increase its investments after the contract with the inventor is completed. In a second round of commercialization, the need for the inventor's continued involvement is smaller.

In sections 4–6, we investigate whether implications from the model are supported by data. The most important implications are as follows:

- Inventor activity is more frequent when the invention is commercialized within the firm with which the inventor is affiliated.
- Successful commercialization depends on inventor activity in the first stage of commercialization.
- If there is a second stage of commercialization, the model predicts higher inventor activity in the first stage than in the second stage.

4. Database and descriptive statistics

When studying tacit knowledge, using patent data is fruitful because patents are related to both codified and tacit knowledge. When applying for a patent, the inventors must disclose important information about the function of the invention. This information is codified by patent examiners at patent offices so that the information will be available worldwide when the patent application is published.[3] However, inventors must disclose only as much information (codified knowledge) in the application as is necessary for the patent to be granted. A part of the knowledge that is not disclosed is firmly bound to the inventors, who have often undertaken numerous experiments when creating the invention. This tacit knowledge can be available for external agents only through direct interaction with the inventors – and sometimes not even then.

To test under which circumstances inventor activity is important, we use a detailed database on patents granted to small and medium-sized firms (fewer than 1 000 employees) and individual inventors. The data set is based on a survey conducted in 2003−04 on Swedish patents granted in 1998. In that year, 1 082 patents were granted to Swedish small firms and

[3] Publication occurs 18 months after patent filing, irrespective of whether a patent is granted.

individuals.[4] Information about the inventors, the applying firms and their addresses as well as the filing dates for each patent was collected from the Swedish Patent and Registration Office (PRV). Thereafter, a questionnaire was sent out to the inventors of the patents, and 867 (out of 1 082) inventors completed and returned the questionnaire; i.e., the response rate was 80 percent. The attrition is not systematic with respect to International Patent Classification (IPC classes) or geographical regions.[5]

The questionnaire asked the inventors about the type of workplace where the invention was created; whether, when, and how the invention had been commercialized; the profitability of the commercialization; the activity of the inventors during commercialization; and miscellaneous information about characteristics of the inventors. The data set was later complemented with data on patent renewal, patent equivalents, forward citations and filing routes from the Espacenet (2014) website. Thus, the database contains information on several traditional patent value indicators. The database has earlier been used to analyze the efficiency of government support programs (Svensson 2007, 2013). Other articles have analyzed the correlations between different measurements of patent quality (Svensson 2012, Maurseth and Svensson 2014).

The database includes some key factors that make it possible to empirically analyze the efficiency of inventor activity and identify under which circumstances tacit knowledge is transferred:

- Activity of the inventors during commercialization;
- Performance of commercialization in profit terms;
- Commercialization mode of the patent: new firm, existing firm (with the innovator as owner or non-owner), licensing or selling.

[4] In 1998, 2 760 patents were granted in Sweden. Of these patents, 776 were granted to foreign firms, 902 to large Swedish firms with more than 1 000 employees, and 1 082 to Swedish individuals or firms with fewer than 1 000 employees. A pilot survey carried out in 2002 revealed that large Swedish firms refused to provide information on individual patents. Furthermore, it proved very difficult to persuade foreign firms to answer questionnaires about patents. Foreign firms are almost always large multinationals. However, the sample selection in our data is not a problem insofar as the conclusions are drawn for small firms and individual inventors located in Sweden.

[5] Of the 20 percent of inventors who did not respond, 10 percentage points of the inventors had outdated addresses, 5 percentage points had correct addresses but did not respond, and the remaining 5 percentage points declined to participate. The only information we have about the non-respondents is the IPC classes of their patents and their region. For these variables, there was no systematic difference between respondents and non-respondents.

The definition of commercialization in the present study is that an innovation, based on its patent, has been introduced in the market by the inventor, the inventing firm or an external firm that has licensed or acquired the patent. The 867 patents and the commercialization rate are described across firm groups in Table 1. As many as 408 patents (47 percent) were granted to individual inventors, and 116, 201, and 142 patents were granted to medium-sized firms (101–1000 employees), small firms (11–100 employees) and micro-companies (2–10 employees), respectively.[6] The commercialization rate for the whole sample is 61 percent.[7] In Table 1, the commercialization rate for firm groups is between 66 and 74 percent, but for individuals, it is no higher than 51 percent.[8]

Table 1. Commercialization of patents across firm sizes, number of patents and percent.

Kind of firm where the invention was created	Commercialization		Total	Percent commercialized
	Yes	No		
Medium-sized firms (101−1000 employees)	77	39	116	66 %
Small firms (11−100 employees)	137	64	201	68 %
Micro-companies (2−10 employees)	105	37	142	74 %
Inventors (1−4 inventors)	207	201	408	51 %
Total	526	341	867	61 %

When the database was collected (2003−04), the inventors were asked to estimate whether the commercialized invention would yield profit, attain break-even or result in a loss. If they did not know, their reply was registered as a missing value (uncertain outcome).[9] In Table 2, discrete values of the outcomes in profit terms are described across firm groups. It would have been desirable to measure the outcomes in money terms. However, such information was

[6] The group of individual inventors includes private persons, self-employed inventors and groups of two-three inventors who are organized in trading companies or private firms without employees.

[7] This rate should be compared to rates in the few available studies that have measured commercialization of patents. These figures include 47 percent for American patents found by Morgan *et al.* (2001) and 55 percent in the studies surveyed by Griliches (1990). The higher commercialization rate in the present study is explained by the fact that only patents owned by small firms and individual inventors are included; large (multinational) firms have many more defensive patents. Griliches (1990) confirms this view and reports that the commercialization rate is as high as 71 percent for small firms and inventors. These other studies use a definition of commercialization similar to the one used here; i.e., commercialization means that the patent has been used commercially. In Morgan *et al.* (2001), commercialization means a commercialized product or process or a licensing contract, and in Griliches (1990), it means that the patent is used commercially. In neither of these studies does commercialization need to be profitable for the owner.

[8] A contingency-table test suggests a significant difference in the commercialization rate between firms and individuals. The chi-square value is 30.55 (with 3 d.f.), significant at the one-percent level.

[9] For the vast majority of the patents, commercialization had reached such a stage that there was no uncertainty at all about performance. In 2009, the information on the profitability of commercialization was updated through phone calls to inventors who had previously announced an uncertain outcome.

impossible to collect.[10] As described in the table, the outcomes are quite different across firm groups, where the group of individual inventors has the least favorable outcomes.

Table 2. Performance of commercialization across firm groups, number of patents.

Kind of firm where the invention was created	Performance				Total
	Profit	Break-even	Loss	Missing value	
Medium-sized firms	55	18	3	1	77
Small firms	97	24	15	1	137
Micro-companies	60	17	27	1	105
Inventors	69	47	87	4	207
Total	281	106	132	7	526

Inventor activity during commercialization is defined only for commercialized patents. As shown in Table 3, 87 percent of the inventors had an active role during commercialization. Inventor activity is the lowest in medium-sized firms. The difference is statistically significant compared to the other groups.[11]

Table 3. Inventor activity across firm sizes, number of patents and percent.

Kind of firm where the invention was created	Inventor activity		Total	Percent active
	Yes	No		
Medium-sized firms	51	26	77	66 %
Small firms	125	12	137	91 %
Micro-companies	97	8	105	92 %
Inventors	185	22	207	89 %
Total	458	68	526	87 %

The commercialization mode and activity among inventors are shown in Table 4. Among the 526 commercialized patents, 19 were sold, 46 were licensed, 158 were commercialized in the original firm where the inventors were employed (non-owners), 232 were commercialized in the original firm (partly or wholly) owned by the inventors, and 71 were commercialized in a new firm. It is also possible for a patent to be commercialized in a second phase; i.e., the commercialization mode may change. A patent that was commercialized in an existing firm or a new firm can later be licensed or sold. Among the 50 patents that were commercialized in the second phase, 37 were sold, 9 were licensed, and 4 were commercialized in a new firm.

[10] It is very complicated to estimate profit flows of individual patents because most firms have many products in their statement of account, and many individual inventors do not have any statement of account at all.
[11] A contingency-table test suggests a significant difference in activity between firms of different sizes. The chi-square value is 35.45 (with 3 d.f.), significant at the one-percent level.

While 87 percent of the inventors were active in the first commercialization phase, only 36 percent were active in the second phase. A higher inventor activity in the first phase was predicted by the model (see section 3.4) It is also obvious that inventor activity differs considerably across commercialization modes. When the patent is commercialized in a new firm or the original (existing) firm and the inventors are owners, activity is considerably higher. Activity is the lowest when the patent is sold to an external agent.

Table 4. Inventor activity across commercialization mode, number of patents and percent.

Commercialization mode (phase 1)	Inventor activity		Total	Percent active
	Yes	No		
Sold	9	10	19	47 %
Licensed	31	15	46	67 %
Existing firm, employed	120	38	158	76 %
Existing firm, owner	228	4	232	98 %
New firm, owner	70	1	71	99 %
Total	458	68	526	87 %
Commercialization mode (phase 2)				
Sold	8	29	37	22 %
Licensed	6	3	9	67 %
New firm, owner	4	0	4	100 %
Total	18	32	50	36 %

Table 5. Inventor activity across commercialization performance, number of patents and percent.

Performance of commercialization	Inventor activity (phase 1)		Total	Percent active
	Yes	No		
Profit	253	28	281	90 %
Break-even	88	18	106	83 %
Loss	111	21	132	84 %
Uncertain	6	1	7	86 %
Total	458	68	526	87 %

In Table 5, inventor activity (phase 1) is cross-tabulated with commercialization performance. When commercialization is profitable, activity is somewhat higher than the other outcomes.[12] However, cross-tabulation does not control for other variables. Inventor activity differs to a

[12] A contingency-table test suggests a small difference in performance between patents with active and non-active inventors. The chi-square value is 4.79 (with 2 d.f.), which is significant at the ten-percent level and based on the three outcomes: profit, break-even and loss.

high extent across both firm size (Table 3) and commercialization mode (Table 4). It is necessary to relate inventor activity with commercialization performance and simultaneously controlling for firm size and commercialization mode. This will be undertaken in the econometric part (section 5) of the study.

5. Econometric method and explanatory variables

5.1 Econometric method

Our purpose is here to test how inventor activity affects commercialization performance. The dependent variable, *SUCCESS*, in the empirical estimations measures patent commercialization performance in terms of profit. It can take on three different discrete values denoted by index *k*:

- Profit, *k*=2;
- Break-even, *k*=1;
- Loss, *k*=0.

Since it is possible to order the three alternatives, an ordered probit model is applied.[13] A multinomial logit model fails to take the ranking of the outcomes into account. On the other hand, an ordinary regression would treat outcomes 0, 1 and 2 as realizations of a continuous variable. This would be an error, since the discrete outcomes are only ranked. The ordered probit model can be described as follows (Greene 1997):

$$y_i^* = \mathbf{X_i}\,\boldsymbol{\alpha} + \varepsilon_i \quad , \qquad (6)$$

where $\mathbf{X_i}$ is a vector of patent characteristics and technology dummies. The vector of coefficients, $\boldsymbol{\alpha}$, shows the influence of the independent variables on the profit level. The residual ε_i represents the combined effects of unobserved random variables and random disturbances. The residuals are assumed to have a normal distribution, and the mean and variance are normalized to 0 and 1. The latent variable, y_i^*, is unobserved. The model is based

[13] The database included seven observations in which the owner could not specify the expected profit level of commercialization. These missing values could also be treated as a fourth, uncertain, outcome of *SUCCESS*. A multinomial logit model that included all four alternatives was estimated. Then, a test for the independence of irrelevant alternatives was performed (Hausmann and McFadden 1984). When the uncertain alternative in the multinomial logit model was excluded, this test could not be rejected. Thus, the parameter estimates between the other outcome alternatives were almost unaffected if the uncertain alternative was excluded. There was therefore no problem in excluding patents with unknown profit levels from the estimations.

on the cumulative normal distribution function, $F(X\alpha)$**,** and is estimated via maximum likelihood procedures. The difference with the two-response probit model is here that a parameter (threshold value), ω, is estimated by **α**. The probabilities $P_i(y=k)$ for the three outcomes are as follows:

$$P_i(0) = F(-\mathbf{X\alpha}) \quad ,$$

$$P_i(1) = F(\omega - \mathbf{X\alpha}) - F(-\mathbf{X\alpha}) \quad , \qquad (7)$$

$$P_i(2) = 1 - F(\varpi - \mathbf{X\alpha}) \quad ,$$

$$where \sum_{k=0}^{2} P_i(k) = 1 \quad .$$

The threshold value, ω, must be larger than 0 for all probabilities to be positive.

An objection against the sample and the chosen statistical model would be that the patents, which are commercialized, are not a random sample of patents but have specific characteristics that led to them be commercialized in the first place. This could result in misleading parameter estimates. An appropriate statistical model is therefore an ordered probit model with sample selectivity (Greene 2002). In the first step, a probit model estimates how different factors influence the decision to commercialize the patent:

$$d_i^* = \mathbf{X_i}\boldsymbol{\theta} + u_i \quad , \qquad (8)$$
$$d_i = 1 \;\; if \;\; d_i^* > 0 \;\; and \;\; 0 \;\; otherwise,$$

where d_i* is a latent index and d_i is the selection variable indicating whether the patent is commercialized. $\mathbf{X_i}$ is a vector of explanatory variables that influence the probability that the patent is commercialized, and **θ** is a vector of parameters to be estimated. $\mathbf{u_i}$ is a vector of normally distributed residuals with zero mean and a variance equal to 1.

From the probit estimates, the selection variable d_i is then used to estimate a full information maximum likelihood model of the ordered probit model (Greene 2002).[14] At the same time,

[14] Note that this is not a two-step Heckman model. No lambda is computed and used in the second step.

the first step probit model is re-estimated. The residuals [ε, u] are assumed to have a bivariate standard normal distribution and correlation ρ. There is selectivity if ρ is not equal to zero.

5.2 Explanatory variables and hypotheses

Definitions and descriptive statistics of the dependent and explanatory variables are shown in Appendix B, Table B1. Key variables among the explanatory variables are whether the inventors were active during the first and second commercialization phases, *ACTIVE1* and *ACTIVE2*. We hypothesize that inventor involvement in the commercialization process is important due to tacit knowledge. We therefore expect that the degree to which a commercialization process succeeds depends on whether the inventor takes part in the commercialization process.

We distinguish between situations where inventors are responsible for the commercialization themselves and when somebody else is responsible for it. Key variables are here the commercialization mode in the first and second phases. The additive dummy *EXT1* shows whether the patent was sold or licensed in the first phase. Similarly, the additive dummy *EMP1* measures whether inventors were employed (non-owners) when the patent was commercialized in the existing firm in the first phase. The reference group in the first phase is here that inventors themselves were responsible for the commercialization (owners). If the commercialization mode was changed and the patent was licensed or sold in a second phase, then the additive dummy *EXT2* equals 1. The additive dummy *EXT3* equals 1 if the patent was sold or licensed in the first or second phase and 0 otherwise. Patents that are commercialized externally (sold or licensed) should have better opportunities to become profitable, since inventing and commercialization require different skills.

The activity and commercialization variables are also multiplied by each other to test whether there are any interactive effects. For example, one would expect inventor activity to be particularly important when the patent is commercialized by an external firm due to tacit knowledge.

Some characteristics of the inventors and the inventing firm that might be related to the probability of commercialization and successful commercialization are included as control variables. The additive dummy *MOREPAT* equals 1 if the inventors have more similar patents and 0 otherwise. The size of the inventing firm is measured by the three additive dummies *MEDIUM*, *SMALL* and *MICRO*. The reference group is then that the patent is owned by individual inventors without employees. *SEX* and *ETHNICAL* measure the shares of female and non-European inventors.

Since patenting and innovations are known to vary considerably between industries and technology classes (Levin *et al.* 1987), we also include additive dummies for 25 different industry classes designated by Breschi *et al.* (2004).[15] These are based on the IPC technology class system. A patent may belong to several different IPC classes. However, it is not possible to determine the main IPC class, since the classes are listed in alphabetic order for each patent in Espacenet (2014). Therefore, a patent in our database may belong to as many as four different industry classes. Consequently, the 25 industry dummies are not mutually exclusive.

In the first selection equation (probit model), we also include the number of patent equivalents (family size worldwide) of the patent, *EQUIV*, as an indicator that the patent is commercialized (Svensson 2012, 2015). The advantage of using family size as a value indicator over using forward citations or patent renewal is that the filing of foreign patents must be done within the priority year and mostly occurs before commercialization. This is not the case with patent renewals and forward citations.

6. Results of the estimations

The results of the ordered probit estimations with sample selectivity are shown in Table 6. Parameter ρ is significant at the 1-percent level in all estimations. This indicates that selectivity is present and that the two-step procedure should be used. Furthermore, the likelihood ratio tests show that the explanatory power of the models improves significantly when selectivity is used. In the selection equation (not shown), the firm size dummies and particularly the number of patent equivalents have a significant relationship with the probability of commercialization.

In Models A1 and A2, both inventor activity, *ACTIVE1*, and external commercialization, *EXT1*, are associated with a higher probability of successful commercialization. However, commercialization in an existing firm when the inventor is employed, *EMP1*, is unrelated to

[15] Originally, there are 30 industry classes in Breschi *et al.* (2004). However, we have to reduce the number of industry classes to 25 due to the limited number of observations in some classes.

profitability (Model A2). The reference situation is here that the patent is commercialized by the inventors themselves.

Table 6. Results of the ordered probit estimations. 1st commercialization mode.

Statistical model: Ordered probit model with sample selection						
Dependent variable: *SUCCESS*						
Explanatory variables	A1	A2	B1	B2	C1	C2
ACTIVE1	0.610***	0.638***	0.416***	0.350***		
	(0.155)	(0.162)	(0.143)	(0.151)		
EXT1	0.413***	0.435***			-0.186	-0.196
	(0.145)	(0.149)			(0.191)	(0.206)
EMP1		0.145				-0.454**
		(0.164)				(0.213)
*EXT1*ACT1*			0.413**	0.426**	0.611***	0.630**
			(0.168)	(0.167)	(0.239)	(0.253)
*EMP1*ACT1*				0.188		0.613***
				(0.170)		(0.217)
MEDIUM	1.04***	0.915***	0.945***	0.814***	0.743***	0.877***
	(0.260)	(0.285)	(0.254)	(0.266)	(0.213)	(0.282)
SMALL	0.708***	0.638***	0.679***	0.594***	0.604***	0.615***
	(0.185)	(0.195)	(0.185)	(0.194)	(0.162)	(0.194)
MICRO	0.292*	0.273	0.274	0.250	0.211	0.252
	(0.171)	(0.171)	(0.172)	(0.171)	(0.153)	(0.167)
MOREPAT	0.112	0.112	0.119	0.115	0.101	0.111
	(0.114)	(0.114)	(0.115)	(0.114)	(0.108)	(0.114)
SEX	0.039	0.052	0.028	0.044	0.035	0.044
	(0.310)	(0.310)	(0.311)	(0.311)	(0.305)	(0.311)
ETHNICAL	0.239	0.235	0.221	0.231	0.204	0.247
	(0.382)	(0.383)	(0.379)	(0.379)	(0.355)	(0.379)
Intercept	0.167	0.135	0.378	0.439	0.830	0.789
Ω (threshold value)	0.548	0.548	0.551	0.549	0.517	0.543
Industry class dummies	Yes	Yes	Yes	Yes	Yes	Yes
ρ	-0.80***	-0.81***	-0.79***	-0.80***	-0.88***	-0.82***
Log likelihood	-985.67	-985.27	-986.71	-986.00	-990.63	-986.30
Test vs. restricted model	7.89***	7.92***	7.70***	7.87***	8.77***	8.11***

Note: n=858. Standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

In Models B1 and B2, inventor activity once again has a strong positive relationship with profitability. The positive relationship is even stronger if the patent was sold or licensed, as indicated by the significant parameter of the interactive variable *EXT1*ACT1*. Activity has no higher impact on profitability when the inventor is employed (the parameter of *EMP1*ACT1* is insignificant).

In Models C1 and C2, external commercialization has no relationship with *SUCCESS*. The estimated parameter of *EXT1* is negative and insignificant. However, if the inventor is active during external commercialization, the correlation with profitability increases significantly (*EXT1*ACT1*). Model C2 shows that profitability is significantly lower if employed inventors are non-active (*EMP1*). However, when employed inventors are active during the commercialization process, profitability is significantly higher (*EMP1*ACT1*).

Thus, from Table 6, we can make an important conclusion. For profitability to be as least as high as when the patent is commercialized by the inventors themselves (owners), inventor activity is necessary both when the patent is sold/licensed to another firm and when the inventors are employed (non-owners).

In Table 7, commercialization modes in both the first and the second phases are considered. If the inventor is not active, profitability is not higher than other commercialization modes for sold/licensed patents in the first phase (*EXT1*). However, when inventors are active during external commercialization, profitability increases significantly (*EXT1*ACT1*). This is the same result as in Models C1 and C2. Another interesting result is that patents that are sold or licensed in the second phase have a higher profitability even if the inventor is not active in this phase (*EXT2*). One reason for this result may be that it is primarily patents with successful commercialization in the first phase that are sold/licensed in the second phase. By entering the market with an invention, owners can signal to potential buyers that the product is successful. Activity in the second phase then does not matter at all (*EXT2*ACT2*). The last result is also very important because it shows that inventor activity is most important in the first commercialization phase, as predicted by the model. The result for employed inventors (*EMP1* and *EMP1*ACT1*) is similar between Models D2, E2 and F2 and Model C2.

Models E1 and E2 are similar to D1 and D2, but here, we also check whether activity in the first phase is important if the patent is sold/licensed in the second phase (*EXT2*ACT1*). The answer to that question is no.

In Models F1 and F2, we include *EXT3*, measuring external commercialization in the first or second phase, instead of *EXT1* and *EXT2*. The parameter of *EXT3* is not significant, indicating that external commercialization does not increase profitability when inventors are inactive. However, the estimations show that it is inventor activity in the first phase (*EXT3*ACT1*) rather than that in the second phase (*EXT3*ACT2*) that is important for successful external commercialization.

Table 7. Results of the ordered probit estimations. 1st and 2nd commercialization modes.

Statistical model: Ordered probit model with sample selection						
Dependent variable: *SUCCESS*						
Explanatory variables	D1	D2	E1	E2	F1	F2
EXT1	-0.210	-0.218	-0.275	-0.297		
	(0.213)	(0.225)	(0.229)	(0.244)		
EXT2	0.413**	0.453**	0.954*	1.08**		
	(0.211)	(0.218)	(0.533)	(0.544)		
EXT3					-0.112	-0.086
					(0.203)	(0.210)
EMP1		-0.453**		-0.483**		-0.419*
		(0.219)		(0.218)		(0.214)
*EXT1*ACT1*	0.657**	0.679**	0.713***	0.751***		
	(0.259)	(0.271)	(0.268)	(0.285)		
*EXT2*ACT1*			-0.634	-0.731		
			(0.572)	(0.583)		
*EXT2*ACT2*	0.072	0.038	0.153	0.137		
	(0.446)	(0.454)	(0.453)	(0.465)		
*EXT3*ACT1*					0.511**	0.500**
					(0.230)	(0.237)
*EXT3*ACT2*					-0.040	-0.057
					(0.332)	(0.338)
*EMP1*ACT1*		0.636***		0.651***		0.609***
		(0.223)		(0.222)		(0.219)
MEDIUM	0.814***	0.940***	0.778***	0.931***	0.810***	0.910***
	(0.227)	(0.298)	(0.218)	(0.294)	(0.227)	(0.291)
SMALL	0.654***	0.658***	0.635***	0.659***	0.639***	0.628***
	(0.171)	(0.203)	(0.164)	(0.201)	(0.171)	(0.198)
MICRO	0.233	0.272	0.213	0.261	0.230	0.260
	(0.162)	(0.177)	(0.155)	(0.173)	(0.163)	(0.175)
MOREPAT	0.103	0.111	0.094	0.104	0.114	0.121
	(0.110)	(0.116)	(0.108)	(0.115)	(0.111)	(0.115)
SEX	0.101	0.116	0.090	0.105	0.092	0.105
	(0.306)	(0.311)	(0.303)	(0.310)	(0.307)	(0.311)
ETHNICAL	0.167	0.207	0.155	0.187	0.249	0.293
	(0.372)	(0.401)	(0.368)	(0.402)	(0.357)	(0.378)
Intercept	0.774	0.726	0.802	0.747	0.769	0.729
Ω (threshold value)	0.532	0.558	0.167	0.555	0.529	0.551
Industry class dummies	Yes	Yes	Yes	Yes	Yes	Yes
ρ	-0.85***	-0.79***	-0.88***	-0.81***	-0.85***	-0.80***
Log likelihood	-986.83	-982.28	-986.16	-981.43	-989.40	-985.14
Test vs. restricted model	7.82**	7.26***	8.10***	7.42***	8.58***	8.01***

Note: n=858. Standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

7. Concluding remarks

In this study, we analyzed the importance of tacit knowledge, i.e., knowledge that cannot be written down or codified, when patents/inventions are commercialized.

We modelled inventor-firm interaction and analyzed the role of tacit knowledge in inventors' engagement in the commercialization process of an invention. First-best inventor engagement is achievable under some circumstances with a two-stage contract between the inventor and the firm. The first-best solution is more likely when IPR is stronger, when the market for the patented invention is larger and when demand elasticity is greater.

In the empirical analysis, we distinguished between situations in which the inventors themselves are responsible for the commercialization (owners) and when somebody else commercializes the patent. The latter situation occurs when patents are sold/licensed or when patents are commercialized in the existing firms and the inventors are only employed (non-owners). To the best of our knowledge, the importance of tacit knowledge in the commercialization process of inventions/patents has not been analyzed in previous empirical studies.

The empirical estimations show that inventor activity is positively related to the successful commercialization of patents. This positive relationship is even stronger when the patent is licensed or sold to an external firm. Inventor activity also has a strong positive correlation with profitability when the patent is commercialized in the existing firm and the inventor is only employed. Although a patent can be commercialized in several phases, it is inventor activity in the first commercialization phase that matters for successful commercialization. This finding was also predicted by the theoretical model. Our interpretation of the results is that the tacit knowledge of inventors and the cooperation between inventors and external firms are crucial for profitability when somebody other than the inventor is responsible for commercialization.

References

Arora, A., 1995, 'Licencing tacit knowledge: Intellectual property rights and the market for know-how', *Economics of Innovation and New Technology*, 4(1), pp. 41–59.

Arora, A., 1996, 'Contracting for tacit knowledge: the provision of technical services in technology licencing contracts', *Journal of Development Economics*, 50(2), pp. 233–56.

Arora, A., Fosfuri, A. and Gambardella, A., 2001, *Markets for Technology – The Economics of Innovation and Corporate Strategy*. MIT Press, Cambridge, Ma.

Arora, A. and Gambardella, A., 2010, 'The Market for Technology', in B.H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation Vol I*. Elsevier, Amsterdam, pp. 641–78.

Arora, A. and Merges, R.P., 2004, 'Specialized supply firms, property rights and firm boundaries', *Industrial and Corporate Change*, 13(3), pp. 451–75.

Arrow, K., 1962, 'Economic Welfare and the Allocation of Resources for Invention', in *The Rate and Direction of Inventive Activity: Economic and Social Factors*. NBER Special conference No. 13. Princeton University Press, Princeton, NJ, pp. 609–26.

Block, J.H., Thurik, R. and Zhou, H., 2013, 'What Turns Knowledge into Innovative Products? The Role of Entrepreneurship and Knowledge Spillovers', *Journal of Evolutionary Economics*, 23(4), pp. 693–718.

Breschi, S., Lissoni, F. and Malerba, F., 2004, 'The Empirical Assessment of Firms. Technological Coherence: Data and Methodology', in A. Cantwell, A. Gambardella and O. Granstrand (eds.), *The Economics and Management of Technological Diversification*. Routledge, London, pp. 69–98.

Choi, J.P., 2001, 'Technology transfer with moral hazard', *International Journal of Industrial Organization*, 19(1–2), pp. 249–66.

Coase, R.H., 1937, 'The Nature of the Firm', *Economica*, 4(16), pp. 386–405.

Dosi, G., 1988a, 'Sources, Procedures and Microeconomic Effects of Innovation', *Journal of Economic Literature,* 26(3), pp. 1120–71.

Dosi, G., 1988b, 'The Nature of the Innovation Process', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds.), *Technical Change and Economic Theory*. Pinter Publishers, London, pp. 221–38.

Espacenet, 2014, *Espacenet patent database*. Assessed at:
http://www.epo.org/searching/free/espacenet.html (January 2014).

Griliches, Z., 1990, 'Patent Statistics as Economic Indicators: A Survey', *Journal of Economic Literature,* 28(4), pp. 1661–1707.

Grossman, S.J. and Hart, O.D., 1986, 'The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration', *Journal of Political Economy,* 94(4), pp. 691–719.

Hausmann J. and McFadden, D., 1984, 'A Specification Test for the Multinomial Logit Model', *Econometrica,* 52(5), pp. 1219–40.

Kamien, M.I., 1992, 'Patent Licensing', in R.J. Auman and S. Hart (eds.), *Handbook of Game Theory Vol I*. Elsevier, Amsterdam, pp. 332–54.

Levin, R.C., Klevorick, A.K., Nelson, R.R. and Winter, S.G., 1987, 'Appropriating the Returns from Industrial Research and Development', *Brookings Papers on Economic Activity*, 1987(3), pp. 783–831.

Macho-Stadler, I., Martinez-Giralt, X. and Pérez-Castrillo, J.D., 1996, 'The role of information in licensing contract design', *Research Policy*, 25(1), pp. 43–57.

Maurseth, P.B. and Svensson, R., 2014, 'Micro Evidence on International Patenting', *Economics of Innovation and New Technology*, Vol. 23(4), pp. 398–422. https://doi.org/10.1080/10438599.2013.871166

Mendi, P. 2005, 'The Structure of Payments in Technology Transfer Contracts: Evidence from Spain' *Journal of Economics and Management Strategy*, 14 (2), pp. 403–29.

Morgan, R.P., Kruytbosch, C. and Kannankutty, N., 2001, 'Patenting and Invention Activity of U.S. Scientists and Engineers in the Academic Sector: Comparisons with Industry', *Journal of Technology Transfer*, 26(1–2), pp. 173–83.

Nelson, R.R. and Winter, S.G., 1982, *An Evolutionary Theory of Economic Change*. Belknap Harvard, Cambridge, Ma.

Polanyi, M., 1967, *The Tacit Dimension*. Doubleday Anchor, New York, NJ.

Reinganum, J.F., 1989, 'The Timing of Innovation: Research, Development, and Diffusion, in R. Schmalensee and R.D. Willig (eds.), *Handbook of Industrial Organization Vol. I*. North-Holland, Amsterdam, pp. 849–908.

Salanié, B. (2005) *The Economics of Contracts – A Primer*, 2nd ed. MIT Press, Cambridge Ma.

Schotchmer, S., 2004, *Innovation and Incentives*. MIT Press, Cambridge. Ma.

Schumpeter, J.A., 1911, *The Theory of Economic Development*. Transaction Publishers, New Brunswick.

Shapiro, C., 1985, 'Patent Licensing and R&D Rivalry', *American Economic Review*, 75(2), pp. 25–30.

Svensson, R., 2007, 'Commercialization of Patents and External Financing during the R&D-Phase', *Research Policy*, Vol. 36(7), pp. 1052–69. https://doi.org/10.1016/j.respol.2007.04.004

Svensson, R., 2012, 'Commercialization, Renewal and Quality of Patents', *Economics of Innovation and New Technology*, 21(1–2), pp. 175–201. https://doi.org/10.1080/10438599.2011.561996

Svensson, R., 2013, 'Publicly-Funded R&D-Programs and Survival of Patents', *Applied Economics*, Vol. 54(10–12), pp. 1343–58. https://doi.org/10.1080/00036846.2011.617700

Svensson, R., 2015, 'Measuring Innovation Using Patent Data', IFN Working paper 1067. http://dx.doi.org/10.2139/ssrn.3632376

Teece, D.J., 1981, ‘The Market for Know-How and Efficient International Transfer of Technology’, *Annals of the American Academy of Political and Social Science*, 458, pp. 81–95.

Teece, D.J., 1988, ‘Technological Change and the Nature of the Firm’, in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. and Soete (eds.), *Technical Change and Economic Theory*. Pinter Publishers, London, pp. 256–81.

Appendix A

Proof that first-best solution for *k* and *b* increases with *a*:

Differentiating the first-order conditions for *k* and *b* with respect to *k* and *a* (resp. *b* and *a*) gives

$$\left(\sigma a\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} c^{-\sigma-1}(c_k)^2 - a\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} c^{-\sigma}c_{kk} - R_{kk}\right)dk - \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} c^{-\sigma}c_k da$$

$$\frac{dk}{da} = \frac{\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} c^{-\sigma}c_k}{\left(\sigma a\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} c^{-\sigma-1}(c_k)^2 - a\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} c^{-\sigma}c_{kk} - R_{kk}\right)}$$

The above is positive given that the second-order condition for the maximization problem is fulfilled. A similar expression results for *db/db*.

Appendix B

Table B1. Descriptive statistics of dependent and explanatory variables.

Dependent variables	Definition	All observations (858 observations)		*COM* = 1 (519 observations)	
		Mean	Std. dev.	Mean	Std. dev.
COM	Dummy that equals 1 if the patent was commercialized and 0 otherwise	0.60	0.49	-----	-----
SUCCESS	Profitability of commercialization, 2 = profit, 1 = break-even, 0 = loss	-----	-----	1.29	0.84
Explanatory variables					
ACTIVE1	Dummy that equals 1 if inventors were active during the first commercialization phase and 0 otherwise	-----	-----	0.87	0.34
ACTIVE2	Dummy that equals 1 if inventors were active during the second commercialization phase and 0 otherwise	-----	-----	0.36 [a]	0.48 [a]
EXT1	Dummy that equals 1 if the patent was sold or licensed in the first commercialization phase and 0 otherwise	-----	-----	0.12	0.33
EXT2	Dummy that equals 1 if the patent was sold or licensed in the second commercialization phase and 0 otherwise	-----	-----	0.089	0.28
EXT3	Dummy that equals 1 if the patent was sold or licensed in the first *or* second commercialization phase and 0 otherwise	-----	-----	0.20	0.40
NEW1	Dummy that equals 1 if the patent was commercialized in a new firm and 0 otherwise	-----	-----	0.30	0.46
MEDIUM	Dummy that equals 1 if the invention was created in a medium-sized firm (101−1000 employees) and 0 otherwise	0.13	0.34	0.15	0.35
SMALL	Dummy that equals 1 if the invention was created in a small firm (11−100 employees) and 0 otherwise	0.23	0.42	0.26	0.44
MICRO	Dummy that equals 1 if the invention was created in a micro-company (2−10 employees) and 0 otherwise	0.16	0.37	0.20	0.40
MOREPAT	Dummy that equals 1 if inventors have more similar patents and 0 otherwise	0.41	0.49	0.46	0.50
SEX	Share of female inventors	0.024	0.14	0.023	0.14
ETHNICAL	Share of non-European inventors	0.030	0.16	0.024	0.15
EQUIV	The number of worldwide patent equivalents			-----	-----

[a] Based on that, the patent was sold or licensed in the second commercialization phase, i.e., *EXT2* = 1 (46 observations).