Publicly-Funded R&D Programs and Survival of Patents

Roger Svensson

► To cite this version:

Roger Svensson. Publicly-Funded R&D Programs and Survival of Patents. Applied Economics, 2011, 45 (10), pp.1343-1358. 10.1080/00036846.2011.617700 . hal-00762896

HAL Id: hal-00762896

<https://hal.science/hal-00762896>

Submitted on 9 Dec 2012

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Publicly-Funded R&D Programs and Survival of Patents

Journal:	<i>Applied Economics</i>
Manuscript ID:	APE-2010-0316.R1
Journal Selection:	Applied Economics
Date Submitted by the Author:	03-Apr-2011
Complete List of Authors:	Svensson, Roger; Research Institute of Industrial Economics (IFN)
JEL Code:	O34 - Intellectual Property Rights: National and International Issues < O3 - Technological Change Research and Development < O - Economic Development, Technological Change, and Growth, O38 - Government Policy < O3 - Technological Change Research and Development < O - Economic Development, Technological Change, and Growth, G30 - General < G3 - Corporate Finance and Governance < G - Financial Economics
Keywords:	patents, Government financing, contract terms, survival and renewal, R&D

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For Peer Review

Publicly-Funded R&D Programs and Survival of Patents

Roger Svensson *

April 2011

Key words: Patents, renewal, R&D, Government financing, contract terms, selection, survival model.

JEL Classification: O34, O38, G30

Abstract

I apply a survival model to a detailed data set of Swedish patents to estimate how different financing factors affect the likelihood of patent renewal. Since the owners know more about the patents than potential external financiers, there is a problem of asymmetric information. To overcome this, Sweden has for a long time relied on government support rather than private venture capital. In the empirical analysis, two kinds of government loans are unbundled. The empirical results show that patents which have received soft government loans in the R&D-phase have a higher probability of expiring than patents without such financing. But patents that have received more market-oriented government loans during the commercialization phase are renewed for as long as other commercialized patents. This finding suggests that rather than bad choices of projects, it is the nature of the contract terms that explains the low renewal of some patents with government financing.

* Research Institute of Industrial Economics (IFN), P.O. Box 55665, SE-10215 Stockholm, Sweden; E-mail: roger.svensson@ifn.se ; Tel: + 46 – 8 – 665 405 49; Fax: + 46 – 8 – 665 45 99.

The author would like to thank Per Botolf Maurseth, Ove Granstrand, Erik Mellander, Johan Almenberg and Magnus Henrekson and the seminar participants at the EEA annual conference in Milano, the EARIE annual conference in Toulouse and the SNEE conference in Mölle for constructive comments, as well as Jakob Eliasson for collection of and work with the data set. Financial support from the Torsten and Ragnar Söderberg's Foundation and the Jan Wallander and Tom Hedelius Foundation is gratefully acknowledged.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1. Introduction

The total return on R&D investments for the society as a whole (the social return) is greater than the private return, since firms cannot utilize the results of all their R&D and some of the new knowledge gained is transferred to other firms in the form of spillovers (for a literature survey, see e.g. Wieser, 2005). However, technological knowledge also has other characteristics. Technology is non-rivalry in the sense that the marginal costs for its use by an additional firm are negligible. It is partially non-excludable, since the returns to private R&D are partly private and partly public. It is difficult for a firm which has created new technology through R&D to exclude other firms from using it. But if some kind of protection exists (usually in the form of patents) the output (innovation) of R&D results in a temporary monopoly.

Due to spillovers and non-excludability, firms in a free market tend to invest less in R&D than the socially optimal level (Arrow, 1962; Teece, 1986). This motivates public R&D subsidies to private firms. The most logical approach for the Government is to fund R&D where the difference between private and social return is considerable, i.e. where spillovers are extensive, as it is this type of R&D that would otherwise not be carried out.

Another justification for public R&D subsidies is the presence of imperfect capital markets for high-risk R&D projects (Kaplan and Strömberg, 2001; Carpenter and Petersen, 2002). Compared to potential external financiers, inventors and owners have more knowledge about ongoing R&D-projects and the possible resulting inventions, creating problems related to adverse selection and moral hazard (asymmetric information). Consequently, for external financiers search and transaction costs incurred when seeking interesting projects and evaluating their commercial potential are large – especially in early phases when uncertainty is high (Lerner, 2009). Due to the lack of external financing, firms and inventors will disregard some valuable R&D-investments.

To overcome such market failures and to fill the chasm between inventors and external financiers, different countries have initiated different strategies (Bottazzi *et al.*, 2004). In the United States, the government has preferred private market solutions and facilitated the growth of private venture capital firms (Gompers and Lerner, 2001). In other countries, like Sweden, the Government has stepped in to offer financial assistance and loans to both inventors as well as small technology-based firms (Griliches, 1992; Braunerhjelm, 1999).

The purpose of the present study is to empirically investigate how different Swedish public R&D support programs influence the performance of individual patents. In the analysis the performance variable is the patent renewal pattern, the acknowledged standard measurement for private patent values (Schankerman, 1998). Previous studies have found external financing important for how frequently inventions are patented (e.g., Kortum and Lerner, 2000), but have not related it to the prospective survival of patents.

This study is unlike the previous literature, looking closely and in an extended way at two different Swedish public R&D support programs aimed at small technology-based firms and individual inventors. They are: 1) soft loans connected to specific projects in the R&D phase; and 2) more market-oriented loans connected to the firm in the commercialization phase. Both types of loan include a subsidized interest rate, but the former can easily be written off, if the borrower does not commercialize the invention or if the commercialization fails. What has been learnt can then be used in a new project. Such terms increase the moral hazard problems, because the borrowers have fewer incentives to continue with commercialization of the project. By estimating the performance of patents with different public loan terms, this study examines if these terms can explain differences in actual patterns of patent renewal.

The analysis uses a detailed data set on Swedish patents granted to individuals and small firms, containing information about individual patents (e.g. firm size), if and when the patents were commercialized, the renewal pattern, government and private financing and the number of patent forward citations. A survival model is employed to test empirically how these different explanatory factors affect the renewal decision. Such a survival analysis of the patent renewal pattern including explanatory variables has seldom been undertaken.

The present study also relates to the literature on the private value of patents. Patenting is one important method among many others (e.g. secrecy, first-mover advantage) to protect inventions created through R&D. The private value of patents is regarded as a measurement of the private economic returns to R&D (Schankerman, 1998). Several previous studies thus have estimated the private value of patents utilizing the renewal scheme of patents (Pakes, 1986; Schankerman and Pakes, 1986).¹ Patent

¹ Other groups of studies have estimated the private value of patents through: 1) asking the patent owners directly about the market values (see, e.g., Rossman and Sanders, 1957; Schmookler, 1966); or 2) relating the firms' profits or market values to patents or innovations (see, e.g., Griliches *et al.*, 1987; Hall, 1993).

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

holders must pay an annual fee to keep their patents in force. The fee increases over time and the maximum life span is 20 years. According to Griliches (1990), rational owners will only renew their patents if it is economically profitable to keep them in force. Schankerman and Pakes (1986) assume that more valuable patents survive for longer periods. They show most patents have a low value and depreciate fast, and only a few patents have a significant high value and are kept for the maximum period.²

There is an additional literature which examines factors effecting renewal decisions. Duguet and Iung (1997) relate patent renewal data on the firm level to factors such as R&D intensity and organization size. They find that the renewal decision has a positive correlation to the existence of product imitations. Harhoff *et al.* (1999) show that German and U.S. patents renewed for the whole statutory period receive more citations than do expired patents. They conclude by pointing to a positive correlation between patent value and the number of citations a patent receives. Lee and Lee (2008) find that long-lived patents are more focused, have more competitiveness and are more collaborative. Consequently, such patents are in fact a proxy for technology transfer. Maurseth (2005) uses a survival model to explain the renewal pattern, but draws a distinction between citations across and those within technology fields: patents receiving citations across fields survive longer, whereas patents with citations within the same field expire earlier. A possible interpretation is that citations across technology fields indicate a weighty scientific breakthrough, while citations within fields indicate many competing innovations.

Within the research tradition concerned with the issue of patent renewal, Maurseth (2005) is the study most closely related the present inquiry, since both use survival model estimations. Yet they differ in several key respects. First, the data set used in the Maurseth study involves Norwegian patents granted from the European Patent Office (EPO), whereas data set under review here involves Swedish patents. Second, in addition to the citation variables in the Maurseth study, this study examines further explanatory variables. Among them are financing and commercialization variables which suggest the Maurseth study may well suffer from potential omitted variable bias. And finally, the empirical model specification has been improved (see section 4).

² The social return is best measured by patent citations (Trajtenberg, 1990).

I have organized the paper as follows. Section 2 discusses prior literature about public financing of innovations and some Swedish public R&D funding programs for small firms. Section 3 introduces the data set and descriptive statistics. The statistical model for the choice to renew patents is specified in section 4. Section 5 describes the explanatory variables. The empirical results are presented in section 6. The final section summarizes the conclusions of the study.

2. Government financing of innovations

2.1. Previous literature about R&D subsidies to firms

Governments in many countries have programs aimed at supporting R&D undertaken by private firms (see, e.g., Griliches, 1992). In general, publicly-funded R&D performed by private firms affects productivity and growth positively, but this effect is somewhat weaker than that of self-funded R&D (Griliches, 1986, 1992; Lichtenberg and Siegel, 1991; Guellec and van Pottelsberghe, 2004). However, there are exceptions. Johnson *et al.* (2007) find that in New Zealand privately funded R&D has had positive effects on both own-sector productivity and cross-sector spillovers, whereas publicly financed R&D has had none.

There is also a dual risk of public R&D funding crowding-out private R&D. First, public support may be given to R&D-projects that firms would otherwise undertake on their own. Second, additional public R&D-spending may raise the price of scarce R&D resources, which makes the firms' own R&D more costly. However, most studies – especially those on an aggregate level – claim that public R&D is complementary to private R&D (David *et al.*, 2000). This view is taken by Falk (2006) who demonstrates that both public university R&D and public direct R&D-subsidies are positively correlated to private R&D. Hoseo (2004) shows there exists a bidirectional causality between public and private R&D expenditures in Korea, i.e., finding that they reinforce each other.

A branch of the literature compares on a micro level subsidized firms or projects with non-subsidized ones. Here, the empirical literature is less developed. Maggioni *et al.* (1999) test the efficiency of a public R&D program supporting technology-based start-up firms in Italy. They conclude the program increased the number of high technology start-up firms, but that these firms were somewhat inefficient. Aided firms were associated with a higher financial risk and did not grow faster than non-aided ones.

Hujer and Radic (2005) looking at German firms find no evidence that public support of private R&D increases innovative activities.

Irwin and Klenow (1996) show that while companies that participated in a publicly-funded R&D consortium in the semi-conductor industry in the U.S. experienced a higher growth in sales than companies that did not take part, there was no difference in labor productivity. Czarnitzki *et al.* (2004) show that tax credits stimulate additional innovative output in Canadian firms. Czarnitzki *et al.* (2007) estimate the impact of innovation policies and R&D collaboration in Germany and Finland. In general, they find that collaboration positively affects R&D and patenting. Medda *et al.* (2006) analyze Italian companies and find that publicly-funded R&D is sought and used more for high-risk projects that could impact long term productivity and growth. Self-funded R&D relates to projects where a safe return is envisaged.

2.2 The Swedish public R&D programs

The Swedish Government offers loans with soft terms to inventors and small technology-based firms in the early R&D phase (i.e., before manufacturing has started).³ To give soft loans to a firm or an inventor, the government authorities have three main selection criteria: 1) the project should have a good chance of success both technically and commercially; 2) the project should be a high-tech project; and 3) the firm should not have more than 100 employees. The project borrows at a subsidized interest rate and begins to repay the loan only several years after the commercialization has started. If the borrower receives income during commercialization, the repayment of the loan is often linked to product turnover. However, if there is no commercialization or if commercialization is attempted but fails, it is highly probable the borrower will not need to pay back the loan at all. One requirement for debt forgiveness from the government agency is that the patent has to expire.

Government financing could cover up to 50-70 percent of the total R&D costs, depending on which government authority provided the loan; there is thus a requirement of co-financing by the borrower or somebody else. The idea behind the co-financing is two-fold: 1) it will give incentives to the borrower to make an effort; and 2) the co-financing works as a visible and cogent signal to the government fund which specific

³ Such loans were offered by SIC (Foundation Innovation Center) and NUTEK (Swedish Agency for Economic and Regional Growth) from the beginning of the 1990s through 2005. SIC and NUTEK had a yearly budget of ca. 60 to 80 MSEK. The loans for individual projects could range from 0.1 to 1.5 MSEK.

projects the market has determined are promising (Lerner 2009). However, this co-financing is allowed to take the form of unpaid labor incomes. The government fund cannot control the latter cost (raising moral hazard problems). In practice, the government loans can conceivably cover more than 80 percent of the project's total R&D costs. Consequently, neither the incentives for the borrower nor the signal will work. Last but not least, the loans are allocated to the project, not the inventor, which implies the borrower may close down the project, allowing the patent to expire and using what they have learnt in a new project.

Given this loose structure, potential moral hazard problems are likely to worsen. Inventors who have received soft loans from the government need not care about the commercialization of the patent. Rather than paying back a loan with accrued interest, it is often better to exit the project, receive debt forgiveness and move to a new project.⁴

The Swedish Government also provides loans during the commercialization phase, the terms usually similar to commercial loans. The loan is given to the firm, some actual co-financing (at least 50 percent) is required and repayment is not linked to the turnover of the project. Accordingly, repayment can only be avoided if the firm goes into bankruptcy. The interest rate for these loans is somewhat higher than that of banks.⁵ Unlike the R&D phase loans, the terms of these loans do not reduce the borrower's incentives to perform well in the market.

Financing during the R&D-phase can also be supplied by private venture capital (PVC) firms or individuals (so called "business angels"), in return for shares in the patent project. Repayment is then connected to whatever profit may arise when the patent is commercialized. Furthermore, government financing institutions typically do not seek to maximize their profit. Therefore, their administrators have few incentives to search for really good patent projects for which they should loan money.⁶ The employees do not invest their own private funds. The unintended consequence of this

⁴ SIC and NUTEK ceased operations in 2003 and 2005, respectively. The loan stocks were overtaken by the government fund Almi, which have offered similar soft loans since 2003. In 2005, Almi determined that only 15 percent of the SIC loans and 30 percent of the NUTEK loans would be repaid. Thus, the default rates on the soft loans were as high as 85 and 70 percent, respectively.

⁵ But since these projects are more risky than those financed by banks, the interest rate is subsidized.

⁶ On the other hand, PVC firms and business angels more consistently aim at profit-maximizing. They are more careful than government institutions about the patent projects where they choose to invest, and have a more active role during the R&D phase. PVC firms not only provide financial capital, but also networks and competence, e.g., knowledge about market conditions, marketing and legal assistance, etc. (Bottazzi *et al.*, 2004; Hellmann and Puri, 2002). An inventor or a firm that has received contacts and financing from a PVC firm or a business angel in the R&D phase should be in a advantageous position to more easily receive financing and advice during the commercialization phase.

arrangement is that bad performance of projects with government funding might well depend on government administrators not being able to select promising projects to fund.

A common view is that the government selects among projects that have been turned down by private investors. Therefore, loans from the government would go to relatively less profitable or more risky projects. However, Kaivanto and Stoneman (2006) have shown that soft government loans, as described above, are in fact more attractive for inventors and higher in the pecking order than equity financing from private venture capitalists. They offer three reasons why such soft loans are more attractive for firms and inventors. First, the owners do not lose control of the project. Second, the repayment is a variable cost rather than a fixed cost, and does not increase the financial risk of the firm. Third, debt usually requires collateral financing, unlike the soft government loans do not require any collateral, being backed by *future* incomes. Thus, it is not necessarily the case that the government chooses among inferior projects that have been turned down by private investors.

In Svensson (2007), empirical estimations show that patent owners who receive soft government loans are less likely to commercialize their patents. However, since only one type of government loans is analyzed, there is no room to discriminate between bad contract terms and bad selection of projects as explanations for why patents perform badly. The present study goes well beyond this limitation, comparing both soft loans during R&D and market oriented loans during commercialization with the patent renewal option. Thus, the different Government loans are unbundled.

3. Dataset and descriptive statistics

Since the Swedish public R&D-programs are only aimed at small firms and inventors, a detailed data set on patents granted to small firms (less than 1000 employees) and individual inventors is employed in the empirical analysis. Thus, patents owned by large firms are excluded.⁷ The data set is based on a survey of Swedish patents granted in 1998. In that year, 1082 patents were granted to Swedish small firms and individuals.⁸ Information about inventors, applying firms (with their addresses) as well as application and renewal dates for each patent was acquired from the Swedish Patent and

⁷ The sample selection is not a problem, if the conclusions are drawn for small firms and individuals.

⁸ In 1998, 2760 patents were granted in Sweden: 776 were granted to foreign firms, 902 to large Swedish firms (>1000 employees), and 1082 to Swedish individuals or small firms (<1000 employees).

Registration Office (PRV). Using this information, a questionnaire was sent out to the inventors of the patents.

In the questionnaire, inventors were asked about the workplace where the invention was created and the financing of the invention during the R&D-phase. They were also asked if, how and when the invention had been commercialized, how the commercialization was financed, and whether the commercialization was profitable. 867 of the 1082 inventors filled in and returned the questionnaire. The falling off was not systematic.⁹ This 80 percent response rate is remarkably high, taking into account that inventors or applying firms usually consider information about inventions and patents to be secret, and because such a data set has rarely been collected before.

In Sweden, patent owners must pay an annual renewal fee to PRV to keep their patents in force. If the renewal fee is not paid in any single year, the patent expires. A patent expires annually based on its application date. In 1999, the size of renewal fees increasing annually – ranging from 200 SEK in the first year to 4,300 SEK in the last year, adding up to total of around 35,000 SEK over 20 years.¹⁰ The Swedish renewal fees are modest compared to those required by the EPO or United States Patent and Trademark Office (USPTO) (van Pottelsberghe and Francois (2009)).¹¹

The commercialization and renewal rates of the 867 patents by firm size are listed in Table 1.¹² 408 patents (47 percent of the sample) were granted to individuals, 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. The commercialization rate for the whole sample is 61 percent. This rate should be compared to the few available studies which have measured commercialization of patents in other contexts.¹³ The commercialization rate for patents held by firms ranges from 66 to 74 percent compared to the rate of 51 percent for

⁹ The falling off was due to 10% of the inventors having old addresses, 5% having correct addresses but where we did not get in touch with the inventors and 5% failing to reply. For IPC-class of the patent and the region of the inventors, there was no systematic difference between respondents and non-respondents.

¹⁰ In 1999, the annual fees for the 20 years in ascending order were: 200, 250, 350, 550, 700, 900, 1,100, 1,350, 1,600, 1,900, 2,250, 2,500, 2,700, 2,850, 3,050, 3,300, 3,550, 3,800, 4,050 and 4,300 SEK.

¹¹ According to van Pottelsberghe and Francois (2009), the total cost for a patent which is renewed for 20 years is € 120,000 (40,000) in 13 (3) EPO member states, € 14,500 in the U.S. and € 17,300 in Japan.

¹² The term commercialization means here that the patent was sold or licensed, or that a new product based on the patent was introduced in the market by the owner himself.

¹³ The commercialization rate is 47 percent for American patents reported by Morgan *et al.* (2001) and 55 percent in the American studies surveyed by Griliches (1990). These studies use a definition of commercialization that is similar to mine, i.e., 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.

individual patent holders. An unmistakable pattern is that the larger the firm, the higher the renewal rate. It increases from 44 percent for individuals to 76 percent for medium-sized firms.¹⁴

[Table 1]

The renewal rate is related to external financing in the R&D phase in Table 2. Patents with external financing in the R&D-phase have a significantly lower renewal rate than those without. When dividing the external financing on different sources, the renewal rate is significantly lower for patents supported by government funds. However, when the patents expired is not shown. A survival analysis of the data will be undertaken in section 6. It should also be noted that external financing – irrespective of source – is more common among individuals and micro companies. Of the 142 government-financed projects, 111 are for individuals and 25 micro companies. The risk should be higher in patent projects owned by individuals as compared to projects owned by companies. It would then be expected that the government finances projects with higher risk than the average patent project, and this might help explain the lower renewal rate among government-financed projects. In the group of 408 patents owned by individuals, the renewal rate is 30 percent for government-financed projects and 49 percent for projects without government financing (compared with 37 and 59 percent for all patents in the sample in Table 2).

[Table 2]

Table 3 compares commercialized patents and renewed patents. As expected, renewed patents (71 percent) are commercialized to a higher degree than expired ones (48 percent). The chi-square test reported at the bottom of Table 3 shows that we can clearly reject independence of commercialization and renewal. 35 percent of the patents have been commercialized, but have already expired. This is either due to the products having a short lifecycle or the commercialization having failed. 42 percent of the non-commercialized patents are still alive. Many of these patents might be defensive patents,

¹⁴ Contingent table tests indicate statistically significant differences in commercialization and renewal rates between firm size categories. The chi-square values are 30.6 (with 3 d.f.) and 46.7 (with 3 d.f.), significant at the one percent level.

with the purpose of defending other patents, which implies that the owner should have obtained similar patents. Among the commercialized patents in our data set, 46 percent of the owners have at least one patent similar to their current patent. Among the non-commercialized patents, the share is only 33 percent. If the patent had not been commercialized, the inventor was asked to specify the reason. Among the 341 non-commercialized patents, only 15 inventors listed shadow-patenting as one of the reasons for why the patent had not been commercialized.¹⁵ This indicates that keeping patents for strategic reasons, a practice frequently employed by large multinational firms (Cohen *et al.*, 2000), is uncommon among individuals and small firms.

[Table 3]

4. Statistical model

The statistical analysis is based on the assumption that more valuable patents are renewed for longer periods. This assumption is widely accepted in the literature (see e.g., Griliches 1990). Since the analysis in the present study focuses on an event to occur (expiration of patents), survival (duration) analysis is used in the statistical estimations. The event in question is the decision to let the patent expire. I begin by estimating a survival distribution function and a hazard function. The survival function, $S(t)$ in equation 1, shows how large a share of the patents survive beyond a time point, t , and equals one minus the probability cumulative distribution function, $F(t)$. The hazard function, $h(t)$ in equation 2, shows the conditional probability of a patent expiring in a specific time period Δt , given that it has been renewed until time point t . The hazard can also be expressed as a function of the probability density function, $f(t)$, and the survival function:

¹⁵ This is a self-reported answer. To be sure some patent owners may not truthfully tell us that they keep the patents for defensive purposes. However, we have no better measurement on defensive behavior of patents. The most frequent reasons for why the patent was not commercialized were: 1) problems with financing (115 patents); 2) problems with marketing (75 patents); 3) problems in finding a manufacturing firm/licensor (74 patents); and 4) product not yet ready for commercialization (62 patents). Note that inventors may have mentioned more than one reason for why the patent was not commercialized.

$$S(t) = \Pr(T > t) = 1 - F(t) \quad , \quad (1)$$

$$h(t) = \frac{f(t)}{S(t)} = \lim_{\Delta t \rightarrow 0} \frac{\Pr(t \leq T < t + \Delta t | t \leq T)}{\Delta t} \quad . \quad (2)$$

In the main empirical analysis, I estimate how different explanatory factors affect the decision to let the patents expire. The dependent variable, t_i , is a random variable showing how many years it takes until patent i expires, measured from the time point of patent application.¹⁶ In the sample of 867 patents, those that had not yet expired at the end point of observation (in 2004) – are “right-censored” (480 observations). The remaining 387 patents expired in 2004 at the latest. Given this, the appropriate statistical model is the Cox (1972) proportional hazard model:

$$\log h_i(t) = \log \lambda_0(t) + x_{i1}\beta + x_{i2}(t)\gamma \quad , \quad (3)$$

where $\log \lambda_0(t)$ is a baseline hazard function, β and γ are vectors of parameters to be estimated, $\mathbf{x}_1$ is a vector of time independent explanatory variables, and $\mathbf{x}_2(t)$ is a vector of time dependent explanatory variables. The measurement of number of years is an exact measure, an integer, since the owner must pay a renewal fee by the same date every year when the specific patent application was filed. Therefore, I use a discrete approximation of the Cox model in order to account for the fact that two or more events may occur at the same point in time (Allison, 2010).

A patent cannot expire until it has been granted, and is therefore not in the risk set before this time point. If the owner had not paid the renewal fee for a patent application before the patent was granted, the invention would neither have been granted a patent nor have been included in the data set. Therefore, I remove the patent from the risk set between the origin (application date) and the time point for granting patents (Allison, 2010).¹⁷ This is a fruitful methodological extension, going beyond previous studies (Maurseth, 2005).

The major advantage of the Cox model over the alternative statistical model (the accelerated failure time model) is that time-dependent explanatory variables can be

¹⁶ The application year is utilized as the standard starting time. Information on the application year is directly available from the Swedish National Patent Office (PRV).

¹⁷ This procedure is called left truncation. It is accomplished by excluding the observation when the patent is not in the risk set. In practice, this means that patents are excluded between the application and granting dates.

effectively introduced in the estimations (Allison, 2010). A further advantage of the Cox model is that it eliminates the need to choose between different residual distributions, meaning that the baseline hazard function, $\log \lambda_0(t)$, can be left unspecified. Finally, the Cox model makes it possible to interpret the quantitative effects in terms of how an increase in the explanatory variable affects the hazard.

5. Explanatory variables

The explanatory variables are those factors expected to affect or be correlated with the probability patents will be renewed or expire – with a specific focus on those associated with Government financing. Table 4 reports basic statistics for these factors. Since the explanatory variables have not been derived from a theoretical model, and this study is elaborative, hypotheses are only set up when the expected impact is obvious. For example, patents that are commercialized or used for defensive purposes are expected to survive for longer periods.¹⁸ A positive (negative) expected parameter estimate means that the hazard rate of letting the patent expire increases (decreases), when the explanatory variable attains a higher value.

[Table 4]

5.1 Financing variables

As discussed in Section 2.2, Swedish government agencies offer soft loans to patent projects in the R&D phase. These loans have a rather particular design. The borrower often receives debt forgiveness if the patent is not commercialized, or if the project fails. Furthermore, the co-financing can take the form of unpaid labor income. The result is that it is likely such government financing generates moral hazard problems, which in turn suggests that patents with such loans will expire with a higher probability. The dummy variable *GOVRD* equals 1 if part of the R&D-phase was financed through government soft loans, and 0 otherwise. A positive influence on the hazard is expected, based on the discussion in section 2.2 and the statistical measures in Table 2.

The government routinely offers loans to projects owned by individual inventors. Such projects should have a higher risk than projects run by companies. To take account of the higher risk associated with patents owned by individuals, an

¹⁸ Commercialization and defensive purposes are the two main reasons why inventors choose to patent their inventions (Griliches, 1990).

interaction dummy, D , taking the value of 1 if the patent is owned by a firm, and 0 otherwise, is used for $GOVRD$.¹⁹ In practice, the parameter of $GOVRD$, β_{GF} , is divided into two parts:

$$\beta_{GF} = \beta_{Ind} + \beta_D D \quad . \quad (4)$$

β_{Ind} shows the parameter value of $GOVRD$ for the group of individuals, $\beta_{Ind} + \beta_D$ is the parameter value for the firm groups and β_D shows whether there is a significant difference for the parameter of $GOVRD$ between firms and individuals.

In a similar way, the dummy variable $PRIVRD$ equals 1 if the R&D-costs were financed (even if partially) through external private venture capital and 0 otherwise. There is a third kind of external R&D-financing captured by the dummy variable $OTHERFIN$ that takes on the value of 1 if a project was financed through universities or research foundations (during the R&D phase) and 0 otherwise. All financing dummies are here relative to self-financed R&D.

Financing from the government or private venture capital firms during the commercialization can only be given to commercialized patents. Therefore, interaction dummies must be created. The dummy GOV takes on the value of 1 if the project received government financing during the commercialization, and PVC equals 1 if the project received private venture capital during the commercialization phase and 0 otherwise. These dummies are then multiplied by COM , creating the variables $GOVCOM$ and $PVCCOM$. The parameter of $GOVCOM$ will then show whether the patents which have received government financing during the commercialization survive longer than do other *commercialized* patents. The impact of $GOVCOM$ and $PVCCOM$ on the hazard is unsettled,

Based on the terms of government financing and the length of patent renewal, two possible outcomes are considered:

Outcome A: If patents with soft government loans expire faster than patents without such loans, but projects with market-oriented government loans do not expire faster than

¹⁹ Preferably, three different interaction dummies would be included – one for each firm group. However, there are only three patents with government financing in groups of medium-sized and small firms. When estimating the model with three interaction dummies, the small variation with respect to government financing in these two groups causes extremely high values of the standard errors of two of the interaction dummy parameters. Therefore, the three firm groups must be pooled into one group.

other *commercialized* patents, then the failure should depend on bad contract terms rather than on the source of financing.

Outcome B: If patents with government financing – irrespective of the contract terms – expire faster than those in their control groups, then the failure is caused by the government choosing bad projects. Thus, the source of financing would be the reason for the failure.

Other outcomes may occur as well. For example, patents with market-oriented government loans may fail, but those with soft terms do not. If such an outcome occurs, then it is difficult to draw any conclusions about the public R&D programs.

5.2 Commercialization and defensive purposes

The most obvious explanatory variable is whether the patent is commercialized or not. The additive dummy *COM* takes the value of 1 if the patent is commercialized, and 0 otherwise. The expected impact on the hazard is negative, i.e., commercialized patents should survive longer than non-commercialized ones.

Keeping a patent for defensive purposes is the second main explanatory factor for the renewal decision, besides commercialization. If the patent is not commercialized but kept as a defensive patent to protect other closely related patents or deter competitors from using the invention, the additive dummy *DEF* equals 1 and 0 otherwise. The expected impact on the hazard is negative. The fact that only non-commercialized patents can take on the value of 1 for *DEF* is important for the interpretation of the parameter estimates for this variable, as well as *COM*. The parameter estimate for *DEF* will show the difference as compared to other non-commercialized patents, since a patent cannot take on the value of 1 for both *DEF* and *COM*. For the same reason, *COM* shows the difference as compared to non-commercialized non-defensive patents. Patents that are neither commercialized nor defensive are here regarded as patents, where either the owner has postponed the commercialization or the project has failed prior to commercialization.

5.3 Patent citations

Trajtenberg (1990) shows that forward citations indicate the social value of patents. The more frequently a patent is cited by later patents, the higher the spillover effect and

hence the social value of the cited patent. A patent can be cited any time after the application date, even after it has expired. The data on patent citations are right censored if the end point of observation is fixed. On average a patent which has a late application date will be cited fewer times than one with an early application date. Therefore, the citation variables here will take into account and measure the volume of citations the patents receive during a five year period.

CIT measures the total number of citations *a patent and its patent equivalents* have received during a five year period.²⁰ Self-citations are excluded. Forward citations from primarily EPO- and PCT-patents are used to measure citations in the empirical analysis.²¹ *CIT* is expected to have a negative relationship to the hazard, and is also divided into intra-industry and inter-industry citations: *INTRA* shows the number of intra-industry forward citations, whereas *INTER* measures the number of inter-industry citations, based on the ISIC technology classes of the patents.²² According to Maurseth (2005), a high value of *INTRA* shows that the patent faces hard competition from later patents. Therefore, *INTRA* should have a positive relationship to the hazard of patent expiration. On the other hand, a high value of *INTER* indicates that the patent is a scientific breakthrough. Thus, a negative relationship to the hazard is expected.

5.4 Other control variables

The included control variables might well be correlated with the renewal pattern, and they also help to avoid problems with omitted variables. Firms and individuals have different resources for renewing their patents, so additive dummies for different firm sizes are included. *MEDIUM* is a dummy that equals 1 for medium-sized firms with 101-1000 employees and 0 otherwise. *SMALL* equals 1 for small firms with 11-100 employees and 0 otherwise. Finally, *MICRO* is a third dummy variable taking the value

²⁰ A patent equivalent is the same patent granted at a different patent office, e.g., EPO, USPTO.

²¹ According to Hall *et al.* (2005), there are different procedures when patents are cited. At EPO, the patent examiners add references to previous patents, meaning that the citations should be consistent. At USPTO, the inventors / applicants are themselves required to add references to prior patents. Thereafter, the patent examiners decide which patents should be cited. According to Michel and Bettels (2001) and Ejermo and Kander (2007), U.S patents have a higher requirement for citing other patents, implying that they more frequently cite than do patents from EPO and PCT (Patent Cooperation Treaty). This suggests that U.S. citations are less valuable than citations from EPO and PCT.

²² In line with Maurseth (2005), the citation is *within* the same ISIC technology class, if the cited and the citing patents have the same classification to the five digit level. If they do not have the same five digit classification, then the citation is regarded as *between* technology classes. This can also be done at the four digit level, but the results of the estimations are similar.

of 1 for micro companies with 2-10 employees and 0 otherwise. The firm group dummies relate to the reference group of the individual inventors.

The additive dummy *UNIV* equals 1 for university patents and 0 otherwise. *MOREPAT* is an additive dummy, which equals 1 if the inventors or the applying firm have other competitive patents in the same technology area and 0 otherwise. The dummy *COMPL* takes on the value of 1 if complementary patents are needed for commercialization and 0 otherwise. The variable *INVNMBR* measures the number of inventors of the patent. Several attributes of the inventors are included in the model. *SEX* measures the percentage of inventors (for each patent) who are female. *ETH* measures the percentage of inventors who belong to ethnic minorities, i.e., immigrants from countries other than Western Europe. *OWNER* measures how large a portion (in percent) of the patent the inventors own directly or indirectly.

Different technologies are likely to be associated with different risks. Consequently, the type of technology can affect the hazard of a patent expiring. Patents are divided into 30 discrete technology categories, following Breschi *et al.* (2004). These groups are based on the patents' main IPC-Class.²³ The data is divided into six different kinds of regions according to NUTEK (1998): Large-city regions, university regions, regions with important primary city centers, regions with secondary city centers, small regions with private employment, and small regions with government employment. Five additive dummies are included in the estimations for these six groups. Additive dummies are also included for different application years, to control for economic shocks that may affect all patents in a given year. The data has nine application years (1990-98), and eight additive dummies are assigned for these years.

6. Empirical estimations

6.1 Survival and hazard functions

Figure 1 shows the survival and hazard functions for the whole sample of patents, as well as for those patents with and without government R&D-financing, as estimated by the Life-table method (Allison, 2010). The grant date is set to 0, since patents are not at risk of expiring until they have been granted. Year 1 is the first possible year when the patent can expire. The survival functions decline from the outset, and more steeply for

²³ All technology categories are not represented in the data set, and some categories have insufficient observations. Therefore, only 26 categories and 25 additive dummies are used in the present study. The technology classes with insufficient observations are instead merged with other closely related classes (Breschi *et al.*, 2004).

each successive year. The corresponding hazard functions have an increasing trend.²⁴ Considering both patents with and without government R&D-financing, the survival functions suggest the gap in the hazard rates of these two categories increases over time. The hazard is significantly higher for patents with government financing, suggesting patents with soft public loans are less valuable or fail more frequently than the control group of patents.²⁵

[Figure 1]

6.2 Cox proportional hazard estimations

The results of the Cox estimations are shown in Tables 5 and 6. A number of different model specifications are included to test for robustness. Model I is the main model. It includes all financing variables and forward citations from PCT and EPO. Three versions of Model I are estimated, including (a) region dummies, (b) technology dummies and (c) region and technology dummies. Models II-V are similar to Model Ic and include both region and technology dummies. Model II distinguishes between intra- and inter-technology citations. To test for robustness and multicollinearity, Model III excludes the citation variables, Model IV omits some control variables and Model V excludes the financing variables.

[Table 5]

Government soft loans in the R&D-phase, *GOVRD*, have a significant and positive impact on the hazard that patents expire. The hazard for patents with government financing in the R&D-phase is 44 percent higher than patents without such financing (Model Ic). The parameter of *GOVRD* is stable across all the models. This result is in line with the theoretical argument that government financing with soft terms offers patent owners fewer incentives to commercialize or keep them in force. One objection might be that this impact is different across a large range of firm sizes. When including an interaction dummy for firms, *GOVRD*D* in Model Ic, the positive impact on the hazard is valid only for patents owned by individuals. The hazard is then around

²⁴ The survival and hazard functions are markedly less for the seventh year, because patents renewed in 2004 are right-censored.

²⁵ This difference is significant at the 1%-level for both the Log-rank test and the Wilcoxon test. The chi-square statistics are 23.19 and 20.89, respectively, for 1 d.f.

57 percent higher for individuals with government R&D-financing than for those without such financing. The parameter estimate for firms ($GOVRD + GOVRD*D$) is insignificant, close to zero.²⁶ The other two financing variables, *PRIVRD* and *OTHRD*, have no significant impact on the renewal decision.

[Table 6]

Neither market-oriented government loans (*GOVCOM*) nor private venture capital (*PRIVCOM*) have a statistically significant effect. There is no indication patents receiving these kinds of financing in the commercialization phase differ, with respect to the renewal pattern, from other *commercialized* patents.

In sum, only patents with soft government loans given in the R&D-phase perform worse than the average, whereas patents with more market-oriented government loans perform in the normal range. This clear pattern suggests it is the contract terms that lead to the poor performance of government financed projects, and not the government choosing to lend money to bad projects. In brief, Outcome A dominates Outcome B (see Section 5.1).

One of the main variables in the model is the commercialization variable, *COM*. As expected, the parameter is negative and highly significant. For commercialized patents, the hazard is 52 percent lower than for non-commercialized non-defensive patents (Model Ic).²⁷ Equally in line with expectation, patents used for pure defensive purposes, *DEF*, likewise have a significantly negative impact. The hazard decreases by 78 percent for shadow patents, as compared to other non-commercialized patents (Model Ic). It is important to bear in mind, however, that many more patents are commercialized than used as shadow patents in this data set of patents owned by small firms and individuals.

²⁶ Measuring the financial variables as percentages of the R&D-costs instead of as dummies gives similar results. If the government financing increases by 1 percent as a share of the R&D-costs, the hazard that the patent expires increases by 0.7 percent. In this case as well, this relationship only holds for individuals and not for firms.

²⁷ The commercialization variable could also be included as a time-dependent dummy variable, where it takes on the value of 1 when the commercialization starts and onwards, and 0 otherwise. Let us assume that a new product that is based on a patent has a lifetime of 5 years. Thereafter the owner lets the patent expire. The starting point of the commercialization will then determine how long the patent will be renewed. However, it is not possible to include left-truncation, time-dependent explanatory variables and heteroscedasticity robust standard errors in the same estimation. Estimations were also undertaken without robust standard errors, but with commercialization as a time-dependent dummy. Such estimations gave approximately the same results as in Tables 5 and 6.

Looking at patent citations, *CIT* is mostly significant in Models Ia-Ic, IV and V. This supports the view that forward citations indicate the social value of patents. However, when dividing the forward citations on intra-technology (*INTRA*) and inter-technology (*INTER*) citations in Model II, only *INTRA* is significant at the 10 percent level. Dropping the citation variables does not affect the results for the financing variables (Model III).

Among the other explanatory variables, the firm size dummies (*MEDIUM*, *SMALL* and *MICRO*) have negative and significant parameter estimates. If the patent is owned by a medium-sized, small or micro firm as compared to an individual, the hazard that the patent expires decreases by about 74, 48 and 33 percent, respectively (Model Ic). Patents owned by firms have a lower probability to expire than those owned by individuals. Finally, ownership, *OWNER*, decreases the hazard that the patent expires.

One possible serious objection that might be raised against the model specification is that the decisions of renewal and commercialization as well as the decision to use the patent for defensive purposes are taken by the owner. Thus, the decision of commercialization or using the patent for defensive purposes would be endogenously determined by other factors in the model. However, in point of fact there is not a simultaneous relationship between commercialization and renewal decisions. Commercialization clearly precedes and determines the renewal decision – the former decision is made before the latter. The primary and essential reason inventors patent their inventions at all is to protect their product in the market or deter competitors from using the invention (Griliches, 1990). Thus there should be a causal relationship. Svensson (2007) shows, however, that the commercialization decision is correlated with other explanatory factors in the model, for example, variables such as the financing and firm size, and whether the owner has other similar patents (*MOREPAT*). But these relationships are correlations, not causal. It seems unlikely that the firm size is the reason why a patent was commercialized or not. In this case, there might be multicollinearity between the explanatory variables.

I test for multicollinearity by alternatively excluding variables: citation variables in Model III, some control variables in Model IV, and the financing variables in Model V. The parameter estimates of the remaining variables are hardly affected by these exclusions. Therefore, multicollinearity itself is not a cause for concern for the results.

7. Concluding remarks

7.1 Summary of results

This study has empirically estimated how government R&D financing influences the renewal of patents by individual inventors and small firms. The model assumes more valuable patents are routinely kept for longer periods. What sets this study apart from previous work is that the analysis includes two different kinds of government loans which are unbundled: (1) soft government loans offered in the R&D phase; and (2) more market-oriented government loans in the commercialization phase. This broader perspective makes it possible to evaluate how the specific contract terms of the government loans are related to patent renewal.

By using survival models, it is shown that patents with soft government loans in the R&D-phase have a significantly higher probability of expiring than patents without such financing. The effect on the probability is marked; soft government loans increase the hazard by 44 percent. By estimating separate effects for individual inventors and firms, the different risk level of the types of projects is taken into account. It turns out that the positive effect of soft government R&D-loans on patent expiration is significant only for individual inventors. On the other hand, projects with more market-oriented government loans granted in the commercialization phase have the same performance as commercialized patents without such financing.

These two types of public loans are not directly comparable to each other, since market-oriented loans can only be given in the commercialization phase. However, the analysis in this study enables us to relate each loan to comparable control groups of patents. The results suggest that the poor performance of some projects financed by the government in the R&D-phase is caused by bad contract terms, rather than bad choices of projects. Thus, it is the contract terms rather than the source of financing that is the important factor.

7.2 Policy implications

A policy implication of the empirical estimations is that government funds should change the contract terms of the loans in the R&D-phase. Three main changes are needed:

- First, loans in the early phase should be granted to the firm, and not to the project. In this case, the borrower can then only avoid repayment if the firm goes

into bankruptcy. Hence, there are no incentives for borrowers to close down the project and use acquired knowledge in an alternative new project.²⁸

- Second, there should be a requirement that the borrower himself actually invests in the project. This will incentivize the borrower to make an effort during commercialization. The investment will also work as a signal informing the government fund which projects the markets find promising. But co-financing can today take the form of unpaid labor income, which cannot be controlled by the fund. Hence the two mechanisms (incentives and signal) are undermined and will not work. Such kind of co-financing should therefore not be allowed.
- Finally, loans should be repaid to the government, even if the project fails or the patent is never commercialized. This would deter opportunists with bad inventions from applying for government loans.

Still, the government should continue to focus on supplying financial support in the early phases, since it is here where problems related to asymmetric information are the largest and help needed. As a consequence, the lack of private funding is most serious here (Lerner 2009). This also indicates that the risk of crowding out private funding is low.

One retort to the aforementioned results would be that it is natural that publicly funded projects perform worse than those financed by private investors, since government agencies frequently choose among projects that have been turned down by private investors. As a consequence, the sample of patents with soft government loans would inherently not be comparable with the control group. However, recent economic research documents how soft government loans are generally more attractive for inventors and small firms than financing from private venture capitalists and business angels (Kaivanto and Stoneman, 2006). It is thus unlikely that government chooses among inferior projects that have been turned down by private investors. Furthermore, as mentioned in Section 2.2, there is the official requirement the project should have a good chance of success both technically and commercially in order to receive soft loans.

References

Allison, P.D. (2010) *Survival Analysis Using SAS – A Practical Guide*, 2nd edition, SAS Institute Inc., Cary, NC.

²⁸ This change will not be valid if the firm is a one-project firm.

- Arrow, K. (1962) The Economic Implications of Learning by Doing, *Review of Economic Studies*, 29(2), 155-73.
- Bottazzi, L., Da Rin, M. and Hellmann, T. (2004) The Changing Face of the European Venture Capital Industry: Facts and Analysis, *Journal of Private Equity*, 8(1).
- Braunerhjelm, P. (1999) Venture capital, mångfald och tillväxt, *Ekonomisk Debatt*, 27(4), 213-22.
- Breschi, S., Lissoni, F. and Malerba, F. (2004) The Empirical Assessment of Firms' Technological Coherence: Data and Methodology, in Cantwell, J., Gambardella, A. and Granstrand, O. (eds.), *The Economics and Management of Technological Diversification*, Routledge, London.
- Carpenter, R.E. and Petersen, B.C. (2002) Capital Market Imperfections, High-Tech Investment and New Equity Financing, *Economic Journal*, 112(477), pp. F54-F72.
- Cohen, W.M., Nelson, R.R. and Walsh, J.P. (2000) Protecting their Intellectual Assets: Appropriability Conditions and why U.S. Manufacturing Firms Patent (or not), NBER Working Paper No. 7552, NBER, Cambridge, MA.
- Cox, D.R. (1972) Regression Models and Life Tables, *Journal of Royal Statistical Society*, B 34(2), 187-220.
- Czarnitzki, D., Hanel, P. and Rosa, J.M. (2004) Evaluating the Impact of R&D Tax Credits on Innovation. A Microeconomic Study on Canadian Firms, ZEW Discussion paper No. 04-77, Mannheim.
- Czarnitzki, D., Ebersberger, B. and Fier, A. (2007) The Relationship between R&D Collaboration, Subsidies and R&D Performance: Empirical Evidence from Finland and Germany, *Journal of Applied Econometrics*, 22(7), 1347-66.
- David, A., Hall, B.H. and Toole, A. (2000) Is Public R&D a Complement or Substitute for Private R&D? A Review of Econometric Evidence?, *Research Policy*, 29(4-5), 497-529.
- Duguet, E. and Iung, N. (1997) R&D Investment, Patent Life and Patent Value, Working paper No. G 9705, Institut National de la Statistique et des Études Economiques, Malakoff Cedex.
- Ejermo, O., and Kander, A. (2007) Swedish Business Research Productivity – Improvements against International Trends, CIRCLE Working paper No. 2007/7, CIRCLE, Lund
- Falk, M. (2006) What Drives Business R&D Intensity across OECD Countries?, *Applied Economics*, 38(5), 533-47.
- Gompers, P., and Lerner, J. (2001) The Venture Capital Revolution, *Journal of Economic Perspective*, 15(2), 145-168.

- Griliches, Z. (1986) Productivity, R&D and Basic Research at the Firm-Level in the 1970s, *American Economic Review*, 76(1), 141-54.
- Griliches, Z. (1990) Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature*, 28(4), 1661-1707.
- Griliches, Z. (1992) The Search for R&D Spillovers, *Scandinavian Journal of Economics*, 94, S29-S48.
- Griliches, Z., Hall, B.H. and Pakes, A. (1987) The Value of Patents as Indicators of Inventive Activity, in Dasgupta, P. and Stoneman, P. (eds.), *Economic Policy and Technological Performance*, Cambridge University Press, Cambridge.
- Guellec, D. and van Pottelsberghe, B. (2004) From R&D to productivity growth: do the institutional settings and the source of funds of R&D matter?, *Oxford Bulletin of Economics and Statistics*, 66(3), 353-378.
- Hall, B.H. (1993) The Stock Market's Valuation of R&D Investment During the 1980s, *American Economic Review*, 83(2), 259-64.
- Hall, B.H., Jaffe, A. and Trajtenberg, M. (2005) Market Value and Patent Citations, *RAND Journal of Economics*, 36(1), 16-38.
- Harhoff, D., Narin, F., Scherer, F.M. and Vopel, K. (1999) Citation Frequency and the Value of Patented Inventions, *Review of Economics and Statistics*, 81(3), 511-15.
- Hellmann, T. and Puri, M. (2002) Venture Capital and the Professionalization of Start-Up Firms: Empirical Evidence, *Journal of Finance*, 57(1), 169-97.
- Hoseo, U. (2004) Public R&D Expenditure and Private R&D Expenditure: A Causality Analysis, *Applied Economics Letters*, 11(11), 711-14.
- Hujer, R. and Radic, D. (2005) Evaluating the Impacts of Subsidies on Innovation Activities in Germany, *Scottish Journal of Political Economy*, 52(4), 565-86.
- Irwin, D.A. and Klenow, P.J. (1996) High-Tech R&D Subsidies: Estimating the Effects of SEMATECH, *Journal of International Economics*, 40(3-4), 323-44.
- Johnson, R., Razzak, W.A. and Stillman, S. (2007) Has New Zealand Benefited from Its Investments in Research and Development?, *Applied Economics*, 39(19-21), 2425-40.
- Kaivanto, K. and Stoneman, P. (2006) Public provision of Sales Contingent Claims backed finance on SMEs: A Policy Alternative, *Research Policy*, 36(5), 637-51.
- Kaplan S.N. and Strömberg, P. (2001) Venture Capitals as Principals: Contracting, Screening, and Monitoring, *American Economic Review*, 91(2), 426-30.
- Kortum, S. and Lerner, J. (2000) Assessing the Contribution of Venture Capital to Innovation, *RAND Journal of Economics*, 31(4), 674-92.

- Lee, Y.J. and Lee, J.D. (2008) Technology Strategy for Enhancing the Public-to-Private Technology Transfer: Evidence from the Duration of Patent, *Applied Economics*, 40(1-3), 229-40.
- Lerner, J. (2009) *Boulevard of Broken Dreams. When Public Efforts to Boost Entrepreneurship and Venture Capital have Failed – and What to Do about It*, Princeton University Press, Princeton, NJ.
- Lichtenberg, F.R. and Siegel, D. (1991) The Impact of R&D Investment on Productivity – New Evidence Using Linked R&D-LRD Data, *Economic Inquiry*, 19(2), 535-51.
- Lin, D.Y. and Wei, L.J. (1989) The Robust Inference for the Proportional Hazards Model, *Journal of the American Statistical Association*, 84(408), 1074-78.
- Maggioni, V., Sorrentino, M. and Williams, M. (1999) Mixed consequences of government aid for new venture creation: evidence from Italy, *Journal of Management and Governance*, 3(3), 287-305.
- Maurseth, P.B. (2005) Lovely but Dangerous: The Impact of Patent Citations on Patent Renewal, *Economics of Innovation and New Technology*, 14(5), 351-74.
- Medda, G, Piga, C. and Siegel, D. (2006) Assessing the Returns to Collaborative Research: Firm-Level Evidence from Italy, *Economics of Innovation and New Technology*, 15(1-2), 37-50.
- Michels, J. and Bettels, B. (2001) Patent Citation Analysis. A Closer Look at the Basic Input Data from Patent Search Reports, *Scientometrics*, 51(1), 185-201.
- 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), 173-183.
- NUTEK (1998) *Småföretag och regioner i Sverige 1998 – Med ett tillväxtperspektiv för hela landet*, B1998:10, NUTEK, Stockholm.
- Pakes, A. (1986) Patents as Options: Some Estimates of the Value of Holding European Patent Stocks, *Econometrica*, 54(4), 755-84.
- Rossman, J. and Sanders, B.S. (1957) The Patent Utilization Study, *Patent, Trademark and Copyright Journal of Research and Education*, 1, 74-111.
- Schankerman, M. (1998) How Valuable is Patent Protection? Estimates by Technology Field, *RAND Journal of Economics*, 29(1), 77-107.
- Schankerman, M. and Pakes, A. (1986) Estimates of the Value of Patent Rights in European Countries during the Post-1950 Period, *Economic Journal*, 96(384), 1052-76.
- Schmookler, J. (1966) *Invention and Economic Growth*, Harvard University Press, Cambridge.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Svensson, R. (2007) Commercialization of Patents and External Financing during the R&D-Phase, *Research Policy*, 36(7), 1052-69.

Teece, D. (1986) Profit from Technological Innovation, *Research Policy*, 15(6), 286-305.

Trajtenberg, M. (1990) A Penny for Your Quotes, Patent Citations and the Value of Innovations, *RAND Journal of Economics*, 21(1), 172-187.

Van Pottelsberghe, B. and Francois, D. (2009) The Cost Factor in Patent Systems, *Journal of Industry, Competition and Trade*, 9(4), 329-55.

Wieser, R. (2005) Research and Development, Productivity and Spillovers: Empirical Evidence at the Firm Level, *Journal of Economic Surveys*, 19(4), 587-621.

Figure 1. Survival and Hazard functions for the renewal of patents across financing alternatives

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

Kind of firm where invention was created	Total number of patents	Percent commercialized latest 2003	Percent renewed in 2004
Medium-sized firms (101-1000 employees)	116	66 %	76 %
Small firms (11-100 employees)	201	68 %	63 %
Micro companies (2-10 employees)	142	74 %	61 %
Individuals (1-4 inventors)	408	51 %	44 %
Total	867	61 %	56 %

Table 2. External financing during the R&D-phase and renewal of patents, number of patents and percent renewed.

Any external financing		Total	Percent
External financing during the R&D-phase	Renewal in 2004		
	Yes	No	
No	390	270	660
Yes	92	115	207
Total	482	385	867
Chi-square = 13.64 ***			
Government external financing		Total	Percent
	Renewal in 2004		
	Yes	No	
No	429	296	725
Yes	53	89	142
Total	482	385	867
Chi-square = 22.96 ***			
Private venture capital		Total	Percent
	Renewal in 2004		
	Yes	No	
No	459	360	819
Yes	23	25	48
Total	482	385	867
Chi-square = 1.21			
Other external financing (e.g., universities, research foundations)			
Other external financing	Renewal in 2004	Total	Percent
	Yes	No	
No	459	372	831
Yes	23	13	36
Total	482	385	867
Chi-square = 1.05			

Note: 207 patents have external financing, but some patents have external financing from more than one source.

Table 3. Commercialized patents and patents still alive 2004, number of patents and percent.

Patents still alive 2004	Commercialized patents latest in 2003			Percent Commercialized
	Yes	No	Total	
Yes	340	142	482	71 %
No	186	199	385	48 %
Total	526	341	867	61 %
Percent still alive	65 %	42 %	56 %	

Note: Chi-square-value is 44.32, significant at the 1 percent level for 1 d.f.

Table 4. Descriptive statistics and hypotheses for the explanatory variables.

Denotation	Description	Mean	St.dev	Expected impact on hazard
<i>GOVRD</i>	Dummy that equals 1 if part of R&D was financed by government and 0 otherwise.	0.16	0.37	+
<i>PRIVRD</i>	Dummy that equals 1 if part of R&D was financed by private venture capital and 0 otherwise.	0.06	0.23	?
<i>OTHRD</i>	Dummy that equals 1 if part of R&D was financed by universities/research foundations	0.04	0.20	?
<i>GOVCOM</i>	Interactive dummy taking the value of 1 if commercialization was partly financed by government and 0 otherwise.	0.05	0.21	?
<i>PRIVCOM</i>	Interactive dummy taking the value of 1 if commercialization was partly financed by private venture capital and 0 otherwise.	0.05	0.22	?
<i>COM</i>	Dummy that equals 1 if the patent is commercialized and 0 otherwise.	0.61	0.49	-
<i>DEF</i>	Dummy that equals 1 if the patent is a pure shadow patent and 0 otherwise.	0.02	0.13	-
<i>CIT</i>	No. of forward citations during a five-year period	0.35	0.77	-
<i>INTRA</i>	No. of forward citations within technologies during a five-year period	0.30	0.70	+
<i>INTER</i>	No. of forward citations between technologies during a five-year period	0.05	0.16	-
<i>MEDIUM</i>	Dummy taking the value of 1 for medium-sized firms (101-1000 employees) and 0 otherwise.	0.13	0.34	
<i>SMALL</i>	Dummy taking the value of 1 for small firms (11-100 employees) and 0 otherwise.	0.23	0.42	
<i>MICRO</i>	Dummy taking the value of 1 for micro companies (2-10 employees) and 0 otherwise.	0.16	0.37	
<i>UNIV</i>	Dummy that equals 1 if the patent was created at a university and 0 otherwise.	0.04	0.19	
<i>MOREPAT</i>	Dummy taking the value of 1 if the inventors have more similar (competitive) patents.	0.41	0.49	
<i>COMPL</i>	Dummy that equals 1 if complementary patents are needed to create a product and 0 otherwise.	0.23	0.42	
<i>INVNMBR</i>	Number of inventors of the patent.	1.34	0.66	
<i>OWNER</i>	Percent of the patent that is directly or indirectly owned by the inventors.	65.2	45.2	
<i>SEX</i>	Share of inventors who are females	0.02	0.14	
<i>ETH</i>	Share of inventors with an ethnic background other than Western European or North American	0.03	0.16	

Table 5. Empirical estimations of the Cox model.

Dependent variable: $\log h(t)$		Statistical model: Cox hazard model with left-truncation		
Explanatory variables	Model Ia	Model Ib	Model Ic	Model II
<i>GOVRD</i>	1.37**	1.47**	1.44**	1.44**
<i>PRIVRD</i>	1.37	1.58	1.46	1.47
<i>OTHRD</i>	0.58	0.65	0.64	0.64
<i>GOVCOM</i>	0.96	1.06	0.96	0.96
<i>PRIVCOM</i>	0.70	0.69	0.70	0.69
<i>COM</i>	0.51***	0.49***	0.48***	0.48***
<i>DEF</i>	0.24**	0.23**	0.22**	0.22**
<i>CIT</i>	0.76**	0.83*	0.81**	-----
<i>INTRA</i>	-----	-----	-----	0.82*
<i>INTER</i>	-----	-----	-----	0.75
<i>MEDIUM</i> (dummy)	0.26***	0.28***	0.26***	0.26***
<i>SMALL</i> (dummy)	0.52***	0.54***	0.52***	0.52***
<i>MICRO</i> (dummy)	0.65**	0.67**	0.67**	0.67**
<i>UNIV</i> (dummy)	1.21	1.27	1.21	1.21
<i>MOREPAT</i> (dummy)	0.82	0.87	0.88	0.87
<i>COMPL</i> (dummy)	0.84	0.87	0.86	0.86
<i>INVNMBR</i>	0.94	0.99	1.00	1.00
<i>OWNER</i>	0.99**	0.99**	0.99**	0.99**
<i>SEX</i>	0.63	0.53	0.52	0.52
<i>ETH</i>	1.08	1.14	1.19	1.19
Region dummies	Yes	No	Yes	Yes
Technology dummies	No	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Log-likelihood	-1235.1	-1220.0	-1214.2	-1214.2
Likelihood-ratio test	149.6***	178.9***	191.5***	191.6***

Note: The total number of observations equals 867, of which 482 are right-censored. The estimated figures are hazard ratios. Standard errors (not shown) are heteroscedasticity robust according to Lin and Wei (1989). ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. Region, technology and year dummies are not shown, but available from the author upon request.

Table 6. Robustness tests of the Cox model.

Dependent variable: $\log h(t)$		Statistical model: Cox hazard model with left-truncation		
Explanatory variables	Model III	Model IV	Model V	
<i>GOVRD</i>	1.42**	1.43**	-----	
<i>PRIVRD</i>	1.48	1.71	-----	
<i>OTHRD</i>	0.66	0.70	-----	
<i>GOVCOM</i>	0.97	0.96	-----	
<i>PRIVCOM</i>	0.68	0.60	-----	
<i>COM</i>	0.47***	0.47***	0.46***	
<i>DEF</i>	0.22**	0.22**	0.22**	
<i>CIT</i>	-----	0.80**	0.82*	
<i>MEDIUM</i> (dummy)	0.25***	0.40***	0.23***	
<i>SMALL</i> (dummy)	0.50***	0.69**	0.47***	
<i>MICRO</i> (dummy)	0.65**	0.77	0.65**	
<i>UNIV</i> (dummy)	1.14	-----	1.04	
<i>MOREPAT</i> (dummy)	0.86	-----	0.86	
<i>COMPL</i> (dummy)	0.86	-----	0.85	
<i>INVNMBR</i>	0.98	-----	0.99	
<i>OWNER</i>	0.99**	-----	0.99**	
<i>SEX</i>	0.54	-----	0.53	
<i>ETH</i>	1.22	-----	1.23	
Region dummies	Yes	Yes	Yes	
Technology dummies	Yes	Yes	Yes	
Year dummies	Yes	Yes	Yes	
Log-likelihood	-1216.6	-1219.5	-1218.3	
Likelihood-ratio test	186.6***	180.8***	183.3***	

Note: The total number of observations equals 867, of which 482 are right-censored. The estimated figures are hazard ratios. Standard errors (not shown) are heteroscedasticity robust according to Lin and Wei (1989). ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. Region, technology and year dummies are not shown, but available from the author upon request.