Publicly-Funded R&D Programs and Survival of Patents

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Abstract

I apply a survival model to a detailed dataset 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 indicates that it is the contract terms rather than bad choices of projects that explain the low renewal of some patents with government financing.

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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). Thus, firms in a free market will 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 not otherwise 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 resulting inventions, creating problems related to adverse selection and moral hazard (asymmetric information). Consequently, search and transaction costs incurred when seeking interesting projects and evaluating their commercial potential are large for external financiers.[1] Due to the lack of external financing, firms and inventors will disregard some valuable R&D-investments.

To overcome market failures and to fill in the gap between inventors and external financiers, different countries have applied 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 inventors as well as small technology-based firms (Griliches, 1992; Braunerhjelm, 1999).

The purpose of the present study is to empirically analyze how different Swedish public R&D support programs influence the performance of individual patents. The performance variable is the patent renewal scheme, since it is the standard measurement for private patent values (Schankerman, 1998). Previous studies have empirically shown that external financing is important for how frequently inventions are

[1] It is especially difficult to make this evaluation in the R&D-phase, when uncertainty about the project is very high.

patented (e.g., Kortum and Lerner, 2000), but they have not related external financing to the survival of patents.

Unlike the previous literature, this study includes 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 loans include a subsidized interest rate, but the former type of loans 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 patterns of the patent renewal.

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

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, which are created through R&D. Therefore, the private value of patents is regarded as a measurement of the private economic returns to R&D (Schankerman, 1998). Since there is not yet a well-developed market for patents, several previous studies have estimated the private value of patents utilizing the renewal scheme of patents (Pakes, 1986; Schankerman and Pakes, 1986).[2] Patent 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. Schankerman and Pakes (1986) assume that more valuable patents survive for longer periods, and show

[2] 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).

that 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.[3]

Another part of the literature examines factors effecting renewal decisions. Duguet and Iung (1997) relate patent renewal data on firm level to factors as R&D intensity and firm 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 expired patents. They conclude that there is a positive correlation between patent value and the number of citations a patent receives. Maurseth (2005) uses a survival model to explain the renewal pattern, but makes a distinction between citations across and within technology fields. He finds that 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 scientific breakthrough, while citations within fields indicate many competing innovations.

With regard to patent renewal studies, Maurseth (2005) is the most closely related paper to the study at hand, since both use survival model estimations, but they differ in several aspects. First, the dataset used in the Maurseth study is on Norwegian patents granted from the European Patent Office (EPO), this paper occupies itself with data on Swedish patents. Second, as well as the citation variables in the Maurseth study additional explanatory variables are examined here. Among them are financing and commercialization variables which suggest that the Maurseth study may suffer from potential omitted variable bias. And finally, the empirical model specification has been improved, taking into account that a granted patent cannot expire until it has been granted.

I have organized the paper as follows. Section 2 discusses the previous literature about public financing of innovations and the Swedish public R&D funding programs for small firms. Section 3 introduces the dataset 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.

[3] The social return is best measured by patent citations (Trajtenberg, 1990).

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, it appears that publicly-funded R&D performed by private firms affects productivity and growth positively, but that this effect is somewhat weaker than that of self-funded R&D (Griliches, 1986, 1992; Lichtenberg and Siegel, 1991; Guellec and van Pottelsberghe, 2004). There is also a risk of public R&D crowding-out private R&D by two reasons. First, the 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 – find that public R&D is complementary to private R&D (David *et al.*, 2000).

A branch of the literature compares subsidized firms or projects with non-subsidized ones on a micro level. 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 that 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) find no evidence that public support of private R&D increases innovative activities in German firms.

Irwin and Klenow (1996) show that companies that participated in a publicly-funded R&D consortium in the semi-conductor industry in the USA experienced a higher growth in sales than companies that did not take part, but 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 affects R&D and patenting positively. Medda *et al.* (2006) analyze Italian companies and find that publicly-funded R&D is sought and used to a greater degree for high-risk projects that may have effects on productivity and growth in the long term. 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 (see the Appendix) to inventors and small technology-based firms in the early R&D phase (i.e. before manufacturing has started).[4] To give soft loans to a firm or an inventor in the R&D phase, the government authorities have two main selection criteria: 1) the project should have a good chance of success both technically and commercially; and 2) the project should be a high-tech project. The project borrows pays at a subsidized interest rate and begins to repay the loan several years after the commercialization has started. However, if there is no commercialization or if commercialization is attempted but fails, there is a high probability that 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.

If the borrower receives income during commercialization, the repayment of the loan is linked to product turnover. Projects with a low or medium expected profit level may chose not to commercialize at all, since the repayment of the loan may then eliminate the entire profit. However, this will not prevent commercialization if the expected profit level is high. Due to this 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 the loan with an interest, it is often better to exit the project, receive debt forgiveness and move to a new project. Last but not least, the loans are given to the project, not the inventor, which implies that the borrower can close down the project, let the patent expire and use what she/he has learnt in a new project.

The Swedish Government also provides loans during the commercialization phase. The terms on these loans are usually similar to commercial loans. The loan is given to the firm and repayment is not linked to the turnover of the project. Accordingly, the firm can only avoid repayment if it goes into bankruptcy. These loans have an interest rate somewhat lower than the one charged by banks. Unlike the R&D phase loans, the terms of these loans do not reduce the borrower's incentives to perform well in the market.

[4] Government financing could cover up to 50-70 percent of the total R&D costs depending on which government authority provided the loan. Thus, there is a requirement of co-financing by the borrower or somebody else, but this financing is allowed to take the form of unpaid labor incomes. The government authority cannot control the latter cost (raising moral hazard problems). In practice, the government loans could therefore cover more than 80 percent of the project's total R&D costs.

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. In contrast to government-financed projects, this means that even if the expected profit is mediocre, the inventors have incentives to undertake commercialization. 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 to which they loan money.[5] The employees do not invest their own private funds. Thus, bad performance of projects with government funding might 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 more attractive for inventors, and are higher in the pecking order, than equity financing from private venture capitalists.[6] The authors give three reasons why such soft loans are attractive for firms and inventors. First, the owners do not lose control of the project. Second, the repayment is a variable cost, not a fixed cost, and does not increase the financial risk of the firm. Third, debt usually requires collateral financing, whereas the soft government loans are backed by future incomes and therefore do not require any collateral. 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 compares both soft loans during R&D and

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[5] On the other hand, PVC firms and business angels aim more consistently at profit-maximizing. They are more careful than government institutions about the patent projects they choose to invest in, and have a more active role during the R&D phase. PVC firms not only provide financial capital, but also networks and competence in terms of knowledge about, for example, market conditions, marketing, legal assistance (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 more easily receive financing and advice during the commercialization phase.

[6] The authors call this kind of government financing "sales contingent claims" (SCC), which are almost identical to the soft loans provided by the Swedish government.

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 dataset on patents granted to small firms (less than 1000 employees) and individual inventors are employed in the empirical analysis.[7] Thus, patents owned by large firms are excluded.[8] The dataset is based on a survey of Swedish patents granted in 1998. In that year, 1082 patents were granted to Swedish small firms and individuals.[9] Information about inventors, applying firms and their addresses as well as application dates and renewal dates for each patent were acquired from the Swedish Patent and Registration Office (PRV). Using this information, a questionnaire was sent out to the inventors of the patents.[10]

In the questionnaire, inventors were asked about the work place 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, i.e., the response rate was 80 percent. The falling off was not systematic.[11] This response rate is satisfactorily high, taking into account that such a dataset has rarely been collected before and that

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[7] All inventions do not result in patents. However, since an invention that does not result in a patent is not registered anywhere, there are two problems in empirically analyzing the invention rather than the patent. First, it is difficult to find these new ideas, products and developments among all firms and individuals. On the other hand, all patents are registered. Second, even if the inventions are found, it is difficult to judge whether they are sufficient improvements to qualify as inventions. Only the national and international patent offices make such judgements. Patent data has limitations, for example, some sectors do not apply for patents, but instead use secrecy and first-mover advantage. Therefore, patent data will not cover all inventions/innovations. When focusing on the renewal scheme of patents, patents is of course the best unit of observation. Åstebro and Dahlin (2005) examines why inventors patent their inventions. They find that only the technical feasibility to patent the invention determine whether the inventor applies for a patent or not. Inventions that are easier to legally protect, are also more often patented. Factors related to the opportunity to commercialize the invention do not affect the decision to apply for a patent.

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

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

[10] Each patent always has at least one inventor and often also an applying firm. The inventors or the applying firm can be the owner of the patent, but the inventors can also own the patent indirectly, via the applying firm. Sometimes, the inventors are only employed in the applying firm, which owns the patent. If the patent had more than one inventor, the questionnaire was sent to one inventor only.

[11] The falling off was due to 10% of the inventors having old addresses, 5% having correct addresses but we did not get in touch with the inventors and 5% refusing to reply. The only information we have about the non-respondents is the IPC-class of the patent and the region of the inventors. For these variables, there was no systematic difference between respondents and non-respondents.

inventors or applying firms usually consider information about inventions and patents to be secret.

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 can only expire at a fixed date every year, which coincides with the application date. In 1999, the size of the renewal fees was 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.[12] The Swedish renewal fees are modest in size compared to the fees for patents given by the EPO and United States Patent and Trade Office (USPTO) (van Pottelsberghe and Francois (2006).[13]

The commercialization and renewal rates of the 867 patents by firm size are listed in Table 1.[14] 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.[15] 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.[16] The commercialization rate for patents held by firms ranges from 66 to 74 percent compared to the rate of 51 percent for

[12] 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.

[13] According to Van Pottelsberghe and Francois (2006), 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. High costs include procedural costs (official costs up to the grant date) and external services that the inventor/firm needs when filing the patent. The high cost of an EPO patent is due to high translation costs. The granted patent must be translated and validated in each targeted national patent office. The other reason why EPO patents are more expensive is higher annual renewal fees (which vary with the duration of the protection). The authors show that renewal fees for 20 years in the EPO system are € 89,000 (22,000) in 13 (3) member states, whereas this cost is considerably lower in the U.S. and Japan. However, the renewal fees in a single European country like Sweden are of modest size.

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

[15] The group of individual inventors includes private persons, self-employed inventors as well as groups of two to four inventors, who are organized in trading companies or private firms without employees.

[16] 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, in Griliches (1990), it means that the patent is used commercially. The commercialization does not need to be profitable for the owner in either of these studies. The higher commercialization rate in the present study is most likely explained by the fact that only patents owned by small firms and individual inventors are included. Large (multinational) firms tend to have many more defensive patents. Griliches (1990) reports a commercialization rate of 71 percent for small firms and inventors, confirming this view.

individual patent holders.[17] The renewal rate is increasing in the firm size, rising from 44 percent for individuals to 76 percent for medium-sized firms. A contingent table test indicates a statistically significant difference between firm size categories. The chi-square value is 46.7 (with 3 d.f.), significant at the one percent level.

[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.[18] However, it is not shown when the patents expired. 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 can be found among individuals and 25 among 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. This might be an explanation for the lower renewal rate among government-financed projects. However, 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.

[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 statistic reported at the bottom of Table 3 shows that

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[17] A contingent-table test indicates a statistically significant difference between the commercialization rates of firms and individuals. The chi-square value is 30.6 (with 3 d.f.), significant at the one percent level.

[18] In the group with other external financing (universities, research foundations), the financing might be from a government agency or a private source, but the intention with this kind of financing is not to finance a patent application/project, but rather research in general. Here, inventors often use the resources for the patent without the financers' (mostly a university) knowledge. Therefore, this kind of financing is regarded as passive. In contrast, the government and private groups represent active financing, where the financier supports, or invests in, a specific patent.

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, with the purpose of defending other patents, which implies that the owner should have obtained similar patents. Among the commercialized patents in our dataset, 46 percent of the owners have at least one similar patent 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.[19] 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, for a survey). 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:

[19] This is a self-reported answer, and 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.

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

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

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.[20] There are 867 patents included in the estimations. Patents that have not yet expired at the end point of observation (in 2004) – are "right-censored" (480 observations). The other 387 patents have expired in 2004 at the latest. Given this, the appropriate statistical model is the Cox (1972) proportional hazard model:

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

where log $\lambda_0(t)$ is a baseline hazard function, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ 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, since the owner must pay a renewal fee the same date every year as the patent was applied for. Therefore, I use a discrete approximation of the Cox model, to account for the fact that two or more events may occur at the same point in time (Allison, 1995).

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 an applied patent before the patent was granted, the invention would neither have been granted a patent nor have been included in the dataset. Therefore, I remove the patent from the risk set between the origin (application date) and the time point for granting patents (Allison, 1995).[21] This is an important methodological extension beyond previous studies (Maurseth, 2005).[22]

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[20] 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).

[21] This procedure is called left truncation. It is accomplished by defining a time-dependent covariate whose values are missing at times when the patent is not in the risk set. In practice, this means that patents, which have a grant date before the renewal (application) date in 1998, will get a starting year of 1997 (the first possible year of expiration is then 1998). If the renewal date occurs before the grant date in 1998, the starting year is 1998 (the first possible year of expiration is then 1999). Using the grant year as

The largest advantage of the Cox model compared to the alternative statistical model (the accelerated failure time model), is that time-dependent explanatory variables can be included in the estimations (Allison, 1995). In the present study, the time point of commercialization of the patent will be included. Another advantage of the Cox model is that there is no need to choose between different residual distributions. Thus, 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 consist of factors that are expected to affect, or to be correlated with, the probability that the patent will be renewed or expire – with a specific focus on variables associated with Government financing. Table 4 reports basic statistics for the explanatory factors. Since the explanatory variables have not been derived from a theoretical model and the 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.[23] A positive (negative) expected parameter estimate means that the hazard rate of letting the patent expire increases (decreases), when the explanatory variable obtains 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.

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the starting year in the model is not appropriate, since the time-dependent explanatory variable associated with the commercialization decision may change value between the application and the grant dates.

[22] Maurseth (2005) also estimates a log-likelihood model to test how the explanatory variables influence the expected survival time (see equations 12-13 and Table V in Maurseth, 2005). He estimates the decay rate, as well as the mean and the standard deviation of patent returns, R_{aj} in order to estimate the distribution of patent values. This is similar to previous studies in this area (see, e.g. Schankerman, 1998). The estimated parameters are then used to estimate how explanatory variables influence the time it takes until patents expire. This type of parametric model is not able, however, to handle time-dependent explanatory variables. Since time-dependent variables are essential in the present model, the model used in Maurseth (2005) cannot be utilized. It is beyond the scope of the present paper to estimate a distribution of patent values, along the same lines as e.g. Schankerman (1998).

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

Therefore, it is likely that the government financing during the R&D phase 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.[24] A positive influence on the hazard is expected, based on the discussion in section 2.2 and the statistics in Table 2.

The government especially 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 interaction dummy, *D*, taking the value of 1 if the patent is owned by a firm, and 0 otherwise, is used for *GOVRD*.[25] In practice, the parameter of *GOVRD*, α_{GF}, is divided into two parts:

$$\alpha_{GF} = \alpha_{Ind} + \alpha_D D \quad . \tag{4}$$

α_{Ind} shows the parameter value of *GOVRD* for the group of individual s, $\alpha_{Ind} + \alpha_D$ is the parameter value for the firm groups and α_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 also 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

[24] Patent application costs are included in the R&D costs.
[25] 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 each. 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.

GOVCOM and *PVCCOM*. The parameter of *GOVCOM* will then show whether the patents which have received government financing during the commercialization survive longer than other *commercialized* patents. The impacts of *GOVCOM* and *PVCCOM* on the hazard are 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 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 to 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. This factor should be included as a time-dependent covariate.[26] The commercialization decision is represented by an additive time-dependent dummy, *COM*, which takes on the value of 1 when the commercialization starts and onwards, and 0 otherwise. The expected impact on the hazard is negative.

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 shadow patent to protect other closely related patents, the additive dummy *DEF* equals 1 and 0 otherwise. The expected impact on the hazard is negative. The fact

[26] 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.

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*. By the same reason, *COM* shows the difference as compared to non-commercialized patents, which are not shadow-patents.

Patents that are neither commercialized nor defensive are here regarded as patents, where the owner has postponed the commercialization or where the project has failed before 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 is the spillover effect and hence the social value of the cited patent. In the literature, forward citations have frequently been used as a measure of patent value, even though it is often discussed whether forward citations really measure patent value and / or spillover effects (Hall *et al*., 2006). 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. A patent which has a late application date will, on average, be cited fewer times than a patent with an early application date. Therefore, the citations in the present study are weighted by the number of days from the application date until October 2007. To get an easier interpretation, the citation variables are then multiplied by 1826 (the number of days in a 5 year period). The citation variables will measure how many 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.[27] Self-citations are excluded. In the literature, this kind of forward citation variable has been regarded as an indicator of the social value of patents and is expected to have a negative relationship to the hazard. The citation variables are divided into intra-industry and inter-industry citations according to Maurseth (2005): *INTRA* shows the number of intra-industry forward citations, whereas *INTER* measures the number of inter-industry citations, based on the ISIC technology

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

classes of the patents.[28] According to Maurseth, 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 that the patent expires. On the other hand, a high value of *INTER* indicates that the patent is a scientific breakthrough. Thus, a negative relationship is expected to the hazard.

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 themselves are 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 cite more frequently than patents from EPO and PCT (Patent Cooperation Treaty). This suggests that U.S. citations are less valuable than citations from EPO and PCT. For this reason, forward citations from primarily EPO- and PCT-patents are used to measure citations in the empirical analysis.

5.4 Other control variables

The included control variables might be correlated with the renewal scheme, 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 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

[28] The ISIC technology field classification is built on the eight digit level. In Espacenet, from where the classification has been collected, the classification is mostly only shown on a six digit level. In line with Maurseth (2005), the citation is *within* the same technology class, if the cited and the citing patents have the same classification on the five digit level. If they have not the same five digit classification, then the citation is regarded as *between* technology classes. This division of citations on within and between classes can also be done on the four digit level, but the results of the estimations are similar.

inventors of the patent. Some characteristics of the inventors are also included in the model. *SEX* measures the share of inventors (for each patent) who are female. *ETH* measures the share of inventors who belong to ethnic minorities, i.e. immigrants from other countries than Western Europe. *OWNER* measures how large a share (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 conditional probability of a patent expiring. Patents are divided into 30 technology categories according to Breschi *et al.* (2004). These groups are based on the patents' main IPC-Class.[29] 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, 1995). The grant date is set to 0, since patents are not at risk of expiring until they have been granted.[30] Year 1 is the first possible year when the patent can expire. The survival functions are declining from the outset and decline more steeply for each year. The corresponding hazard functions have an increasing trend.[31] Considering patents with and without government R&D-financing, the survival functions suggest that the gap in the hazard rates of these two categories increases over time. The hazard is significantly higher for patents with government financing, suggesting that patents with soft public loans are less valuable or fail more frequently

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[29] All technology categories are not represented in the dataset and some categories do not have enough observations. Therefore, only 26 categories and 25 additive dummies are used in the present study The technology classes without enough observations are instead merged with other closely related classes (Breschi *et al.*, 2004).

[30] Left-truncation is not possible when using the Life-table method and all patents were granted in 1998.

[31] The survival and hazard functions are not so reliable for the seventh year, because patents renewed in 2004 are right-censored.

than the control group of patents.[32] It would have been interesting to estimate survival and hazard functions with respect to commercialization. Since this is a time-dependent variable, it is instead included in the Cox estimations.

[Figure 1]

6.2 Cox proportional hazard estimations

The results of the Cox estimations are shown in Tables 5 and 6. In order to test for robustness, a number of different model specifications are included. 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, some control variables are omitted in Model IV, and Model V excludes the financing variables.

[Table 5]

Government soft loans in the R&D-phase, *GOVRD*, have a strongly significant and positive impact on the hazard that patents expire. The hazard is 47 percent higher for patents with government financing in the R&D-phase, compared to 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 gives the owners fewer incentives to commercialize or keep their patents in force. One objection might be that this impact is different across firm sizes. When including an interaction dummy for firms, *GOVRD*D* in Model Ic, the positive impact on the hazard is only valid for patents owned by individuals. The hazard is then around 59 percent higher for individuals with government R&D-financing than for individuals without such financing. The parameter estimate for firms (*GOVRD* + *GOVRD*D*) is

[32] 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.

insignificant and close to zero.[33] 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 that patents receiving these kinds of financing in the commercialization phase differ from other *commercialized* patents with respect to the renewal pattern.

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 on the average. This result suggests that it is the contract terms that lead to the poor performance of government financed projects rather than the government choosing to lend money to bad projects. In other words, Outcome A dominates Outcome B (see Section 5.1).

One of the main variables in the model is the time-dependent commercialization variable, *COM*. As expected, the parameter is negative and highly significant. When commercialization starts, the hazard decreases by 45 percent (Model Ic). Also in line with the expectation, patents used for pure defensive purposes, *DEF*, also have a significantly negative impact. The hazard decreases by 76 percent for shadow patents as compared to other non-commercialized patents (Model Ic).[34] It should be kept in mind, however, that many more patents are commercialized than used as shadow patents in this dataset of patents owned by small firms and individuals.

Looking at patent citations, *CIT* is significant in Models Ia-Ic when only citations from EPO- and PCT-patents are used as well as in Model III when citations from all kinds of patents are used. This supports the view that forward citations indicate the social value of patents. But when dividing the forward citations on intra-technology (*INTRA*) and inter-technology (*INTER*) citations in Model II, only *INTRA* is significant

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[33] 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. Also in this case, this relationship only holds for individuals and not for firms.

[34] *DEF* does not have a significant impact on the hazard in Model I, but here the parameter estimate shows the difference as compared to all other patents. In Models II-V, the parameter estimate shows difference as compared to other non-commercialized patents, since a patent cannot both be a shadow-patent and commercialized.

at the 10 percent level. Dropping the citation variables does not affect the results for the financing variables.

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 around 73, 49 and 34 percent, respectively (Model Ic). Firm size appears to be negatively correlated with the probability that a patent expires. However, only medium-sized firms (*MEDIUM*) and micro firms (*MICRO*) are significantly different from each other. Finally, ownership, *OWNER*, decreases the hazard that the patent expires.

An objection against the model specification would be that the decisions of renewal, commercialization as well as n 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, 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, and the main reason why 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 is a causal relationship. Svensson (2007) shows, however, that the commercialization decision is correlated with other explanatory factors in the model, for example, the financing variables, the firm size variables and whether the owner has other similar patents (*MOREPAT*). But these relationships are correlations, rather than causations. It seems unlikely that the firm size is the reason why the 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 is not a cause for concern for the results.[35]

[35] An alternative statistical procedure would be to estimate instruments for the commercialization variables using a survival function, and then insert these instruments in the main Cox equation. This, however, would imply an instrumental variable technique involving two survival functions. To the best of my knowledge, such a two step method does not yet exist.

7. Concluding remarks

This study has empirically estimated how government R&D financing influences the renewal of patents among individual inventors and small firms. The model assumes that more valuable patents are kept for longer periods. What sets this study apart from previous work is that the empirical 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 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 to expire than patents without such financing. The effect on the probability is non-negligible; soft government loans increase the hazard by 47 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 only significant 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.

The two different 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 relating 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 important.

A policy implication of this finding is that government institutions should make their loans more market-oriented already in the R&D-phase. Above all, the 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 bankruptcy. Hence, there are no incentives for borrowers to close down the project and use acquired knowledge in a new project. In addition 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. Furthermore, the repayment should be connected to the profit of the commercialization, instead of the turnover. This would provide incentives to commercialize, even if the expected profit is low.

One objection against the aforementioned results would be that it is natural that public funded projects have a worse performance 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 not be comparable with the control group. However, recent economic research has shown that this kind of soft government loans are more attractive for inventors and small firms than financing from private venture capitalists and business angels (Kaivanto and Stoneman, 2006). Thus, it is not likely that government choose among inferior projects, which have been turned down by private investors. Furthermore, as mentioned in Section 2.2, the Government requires that the project should have a good chance of success both technically and commercially in order to receive soft loans.

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Appendix: Soft loans provided by Swedish government authorities

Among the Swedish government institutions, SIC (Foundation Innovation Centre) and NUTEK (Swedish Agency for Economic and Regional Growth) offered loans with soft terms to individual inventors and small high-tech firms from the beginning of the 1990s until 2005. The loans were given during the R&D phase. SIC and NUTEK had a yearly budget of ca. 6 to 8 Millions of USD. The loans for individual projects could range from 10,000 to 150,000 USD.

To give soft loans to a firm or an inventor in the R&D phase, the government authorities had three selection criteria: 1) the project should have a good chance of success both technically and commercially; 2) the project must be a high-tech project; and 3) the firm should not have more than 100 employees. Sometimes, the authorities also required that the project should generate a specific number of jobs. One difference between the institutions was that SIC loans were given to a higher degree to individual inventors and NUTEK loans to firms.

The government loans could cover up to 50-70 percent of the total R&D costs depending on which government authority provided the loan. Thus, there was a requirement of co-financing by the borrower or somebody else. However this co-financing was allowed to take the form of unpaid labor incomes. This is a cost which cannot be controlled by the government authority (and may lead to moral hazard problems). In practice, the government loans could therefore cover more than 80 percent of the project's total R&D costs.

Three years after the loan was given, the borrower had to submit a report about the status of the project to the government authority. The repayment of the loan was linked to the turnover of the project and repayment possibly started after this report. If the project had failed, the loan was written off with a high probability. If the project was based on a patent, then a requirement for write-off was that the patent was ended. There were some differences in the loan terms depending on whether the borrower had a firm or not when he or she signed the loan contract.

1) The borrower already had a firm and incomes from other projects. The interest rate was 4 percent above the base rate of the Bank of Sweden. Interest was paid every third month, but not until the final report date (3 years after contract). Repayment was 5 percent of turnover of the project, or 35 percent of royalties in the case of licensing.

2) The borrower had neither a firm nor income. The interest rate was 3.75% above the interest rate of the Bank of Sweden. Interest was paid from the first date and capitalized

in the end of each year. Repayment was 7 percent of turnover of the project, or 35 percent of royalties in the case of licensing.

Practically, the borrower only needed to repay 50 percent of the loan if he had some income from the project when the report was submitted. SIC has ceased operations in 2003 and NUTEK in 2005, but similar loans have been offered by the government-owned firm Almi since 2003. The loan stocks of SIC and NUTEK were overtaken by Almi. In 2005, Almi evaluated the repayment of the loans offered by SIC and NUTEK. Only 13 percent of the SIC loans and 33 percent of the NUTEK loans had been repaid. Thus, the default rates on the soft loans were as high as 87 and 67 percent, respectively.

In the Netherlands similar soft loans have been given by Technisch Ontwikkelingskrediet (TOK). TOK had a default rate of 43 percent - considerably lower than in the Swedish case. This could be explained by the fact that the TOK loaned to medium-sized firms and, in addition, it had harder terms for co-financing and follow-up (Kaivanto and Stoneman, 2006).

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

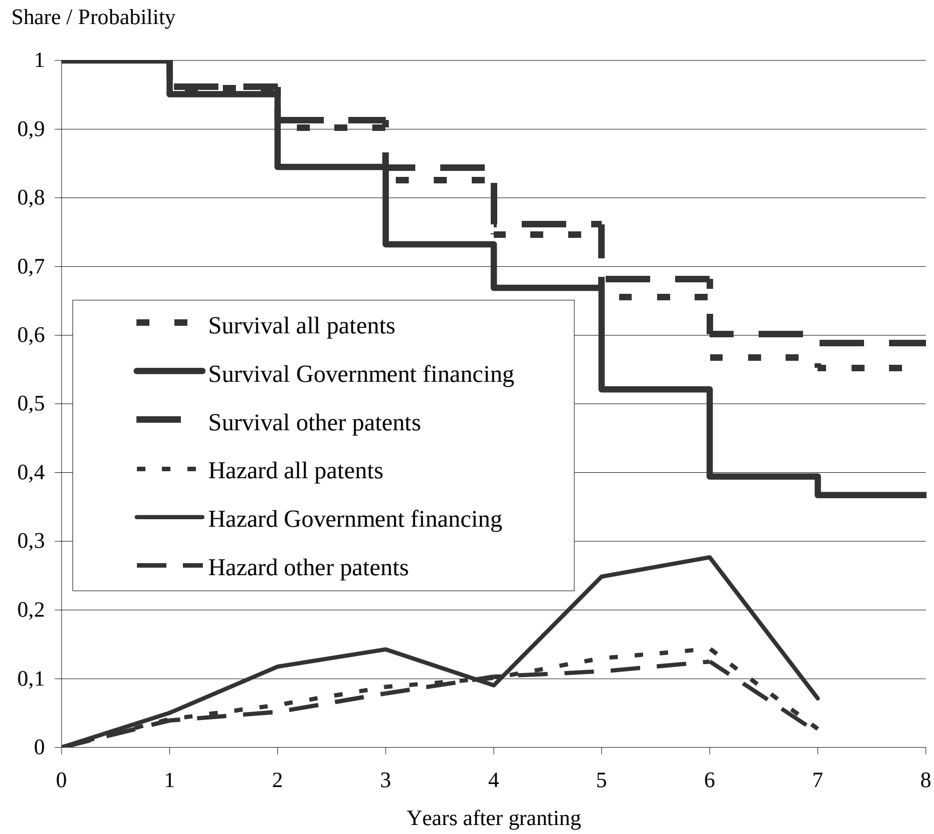

Table 1. Commercialization and renewal of patents across firm sizes, number of patents and percent.

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				
External financing during the R&D-phase	Renewal in 2004		Total	Percent
	Yes	No		
No	390	270	660	58.7 %
Yes	92	115	207	44.4 %
Total	482	385	867	55.4 %
Chi-square = 13.64 ***				
Government external financing	Renewal in 2004		Total	Percent
	Yes	No		
No	429	296	725	58.9 %
Yes	53	89	142	37.3 %
Total	482	385	867	55.4 %
Chi-square = 22.96 ***				
Private venture capital	Renewal in 2004		Total	Percent
	Yes	No		
No	459	360	819	55.8 %
Yes	23	25	48	47.9 %
Total	482	385	867	55.4 %
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	55.0 %
Yes	23	13	36	63.9 %
Total	482	385	867	55.4 %
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
GOVRD	Dummy that equals 1 if part of R&D was financed by government and 0 otherwise.	0.16	0.37	+
PRIVRD	Dummy that equals 1 if part of R&D was financed by private venture capital and 0 otherwise.	0.06	0.23	?
OTHRD	Dummy that equals 1 if part of R&D was financed by universities/research foundations	0.04	0.20	?
GOVCOM	Interactive dummy taking the value of 1 if commercialization was partly financed by government and 0 otherwise.	0.05	0.21	?
PRIVCOM	Interactive dummy taking the value of 1 if commercialization was partly financed by private venture capital and 0 otherwise.	0.05	0.22	?
COM	Time-dependent dummy that equals 1 when the patent is commercialized and 0 otherwise.	0.61	0.49	-
DEF	Dummy that equals 1 if the patent is a pure shadow patent and 0 otherwise.	0.02	0.13	-
CIT	No. of forward citations during a five-tear period	0.35	0.77	-
INTRA	No. of forward citations within technologies during a five-tear period	0.30	0.70	+
INTER	No. of forward citations between technologies during a five-tear period	0.05	0.16	-
MEDIUM	Dummy taking the value of 1 for medium-sized firms (101-1000 employees), and 0 otherwise.	0.13	0.34	
SMALL	Dummy taking the value of 1 for small firms (11-100 employees), and 0 otherwise.	0.23	0.42	
MICRO	Dummy taking the value of 1 for micro companies (2-10 employees), and 0 otherwise.	0.16	0.37	
UNIV	Dummy that equals 1 if the patent was created at a university, and 0 otherwise.	0.04	0.19	
MOREPAT	Dummy taking the value of 1 if the inventors have more similar (competitive) patents.	0.41	0.49	
COMPL	Dummy that equals 1 if complementary patents are needed to create a product and 0 otherwise.	0.23	0.42	
INVNMBR	Number of inventors of the patent.	1.34	0.66	
OWNER	Percent of the patent that is directly or indirectly owned by the inventors.	65.2	45.2	
SEX	Share of inventors who are females	0.02	0.14	
ETH	Share of inventors with an ethnical 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
GOVRD	0.366***	0.407***	0.390***	0.390***
	(0.144)	(0.148)	(0.150)	(0.150)
PRIVRD	0.204	0.358	0.287	0.289
	(0.255)	(0.260)	(0.263)	(0.263)
OTHRD	-0.588	-0.449	-0.453	-0.458
	(0.383)	(0.399)	(0.401)	(0.401)
GOVCOM	0.066	0.159	0.062	0.062
	(0.278)	(0.284)	(0.287)	(0.287)
PRIVCOM	-0.236	-0.331	-0.288	-0.290
	(0.304)	(0.315)	(0.317)	(0.317)
COM	-0.552***	-0.594***	-0.608***	-0.607***
	(0.121)	(0.123)	(0.124)	(0.124)
DEF	-1.33**	-1.40**	-1.41**	-1.41**
	(0.617)	(0.624)	(0.623)	(0.623)
CIT	-0.284***	-0.192*	-0.222**	------
	(0.105)	(0.104)	(0.105)	
INTRA	------	------	------	-0.214*
				(0.120)
INTER	------	------	------	-0.270
				(0.410)
MEDIUM	-1.35***	-1.28***	-1.33***	-1.33***
(dummy)	(0.301)	(0.308)	(0.310)	(0.310)
SMALL	-0.664***	-0.635***	-0.668***	-0.668***
(dummy)	(0.213)	(0.217)	(0.219)	(0.219)
MICRO	-0.447**	-0.418**	-0.419**	-0.417**
(dummy)	(0.182)	(0.188)	(0.188)	(0.189)
UNIV	0.278	0.310	0.275	0.274
(dummy)	(0.356)	(0.370)	(0.371)	(0.371)
MOREPAT	-0.202	-0.143	-0.144	-0.144
(dummy)	(0.125)	(0.127)	(0.128)	(0.128)
COMPL	-0.173	-0.142	-0.160	-0.161
(dummy)	(0.149)	(0.153)	(0.154)	(0.154)
INVNMBR	-0.057	7.83 E-3	6.9 E-3	7.2 E-3
	(0.093)	0.095	(0.096)	(0.096)
OWNER	-4.91 E-3**	-5.31 E-3**	-5.04 E-3**	-5.05 E-3**
	(2.15 E-3)	(2.14 E-3)	(2.15 E-3)	(2.15 E-3)
SEX	-0.466	-0.627	-0.641	-0.640
	(0.389)	(0.396)	(0.399)	(0.399)
ETH	0.061	0.133	0.169	0.170
	(0.347)	(0.357)	(0.358)	(0.359)
Region dummies	Yes	No	Yes	Yes
Technology dummies	No	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Log-likelihood	-1241.1	-1225.9	-1220.7	-1220.2
Likelihood-ratio test	137.7***	168.0***	178.5***	179.4***

Note: The total number of observations equals 867, 482 of which are right-censored. Standard errors are in parentheses and ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. Region, technology and year dummies are not shown, but are 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
GOVRD	0.374***	0.387***	------
	(0.150)	(0.149)	
PRIVRD	0.304	0.382	------
	(0.261)	(0.252)	
OTHRD	-0.429	-0.328	------
	(0.401)	(0.340)	
GOVCOM	0.083	0.084	------
	(0.286)	(0.286)	
PRIVCOM	-0.338	-0.321	------
	(0.314)	(0.313)	
COM	-0.614***	-0.640***	-0.642***
	(0.124)	(0.122)	(0.117)
DEF	-1.41**	-1.41**	-1.42**
	(0.622)	(0.612)	(0.620)
CIT	------	-0.233**	-0.213**
		(0.106)	(0.104)
MEDIUM	-1.38***	-0.886***	-1.44***
(dummy)	(0.309)	(0.223)	(0.299)
SMALL	-0.713***	-0.370***	-0.755***
(dummy)	(0.217)	(0.159)	(0.209)
MICRO	-0.449**	-0.280**	-0.450***
(dummy)	(0.187)	(0.169)	(0.184)
UNIV	0.212	------	0.073
(dummy)	(0.372)		(0.400)
MOREPAT	-0.160	------	-0.175
(dummy)	(0.128)		(0.126)
COMPL	-0.162	------	-0.171
(dummy)	(0.153)		(0.153)
INVNMBR	-9.24 E-3	------	-5.4 E-3
	(0.096)		(0.094)
OWNER	-5.30 E-3**	------	-5.01 E-3**
	(2.14 E-3)		(2.11 E-3)
SEX	-0.601	------	-0.631
	(0.398)		(0.401)
ETH	0.202	------	0.200
	(0.358)		(0.356)
Region dummies	Yes	Yes	Yes
Technology dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Log-likelihood	-1223.2	-1226.5	-1225.2
Likelihood-ratio test	173.4***	166.8***	169.4***

Note: The total number of observations equals 867, 482 of which are right-censored. Standard errors are in parentheses and ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. Region, technology and year dummies are not shown, but are available from the author upon request.