Commercialization of Patents and External Financing during the R&D Phase

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Abstract

Using a unique database on Swedish patents owned by small firms and individuals, survival models estimate how different factors influence the decision to commercialize the patents. Such an analysis has seemingly never previously been undertaken. Since the owners know more about the patents than potential external financiers, problems related to asymmetrical information are present. To overcome these problems when inventors and small technology-based firms need financing, Sweden has for a long time relied on government support rather than private venture capital firms. The empirical results show that the larger is the share of patent-owners' costs covered by government financial support during the R&D phase, the lower is the probability of patents being commercialized. This lower degree of commercialization is likely to depend on: 1) the soft terms of the government loans, where the patent owner can avoid paying back the loan if the patent is never commercialized; and/or 2) that the government is not able to select promising projects. The first explanation is related to moral hazard and the second one to adverse selection. The policy suggestion is for government to change the design of the loans, to base them on firms rather than projects.

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1. Introduction

Patents are used to protect new products introduced in the market or for defensive strategic reasons, e.g. they deter competitors from using the invention or serve as shadow patents defending other patents.[1] In the long run, a sufficient share of patents must be commercialized if they are to contribute to economic welfare. The purpose of the present study is to analyze which factors are important for the choice of commercializing patents. The term 'commercialization' here means that the owners of the patent have taken measures to generate income from it. The owners may have: 1) introduced an innovation in the existing (original) firm; 2) introduced an innovation in a new firm; 3) licensed the patent; or 4) sold the patent. Thus, a minimum requirement is that the owners have received some income from the patent, but the commercialization does not need to be profitable for the original owners. Patents rather than inventions are here chosen as the unit of observation, since the former are much easier to identify and follow.

In the empirical analysis, a unique database of Swedish patents granted to medium-sized and small firms as well as individuals is used. Here, information about individual patents has been collected; for example, the place where the invention behind the patent was created, financing during the R&D phase, whether the patent has been commercialized, etc. Survival analysis is used for statistical testing of how different explanatory factors influence the time it takes until patents are commercialized. To the best of my knowledge, such survival analysis on the choice of commercializing patents has never previously been undertaken.

In the previous empirical literature, external financing has been shown to be important for patenting (e.g. Kortum and Lerner, 2000). However, such financing has not been empirically related to the commercialization decision. Therefore, the specific purpose of this study is to analyze how external financing influences the commercialization. There is often a lack of external financing for inventors and small R&D-performing firms due to information asymmetries and high transaction costs between inventors and external financiers (Kaplan and Strömberg, 2001). Different countries have applied various strategies to overcome this gap.

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[1] There are other reasons when the patent can be valuable to its owner even if it is not commercialized: 1) if the invention is of a basic-science nature, where it is hard to adopt it directly in commercialization; 2) if the patent serves as a signal to customers that the firm is knowledge intensive; or 3) if there is a tacit knowledge generated in the process of the making of the patent.

The Swedish government has assisted inventors and small firms with financing of patent projects – especially in the early stage (the 'R&D phase') before commercialization starts. The assistance takes the form of grants or favorable loans. These loans do not need to be repaid if the project fails, and if commercialization is undertaken, repayment is connected to turnover. The present study argues that these conditions create moral hazard problems, because there are few incentives for patent owners to continue with commercialization.

Since investments in technology projects are often characterized by asymmetrical information for insiders and outsiders, it is important that the external financiers are competent to select projects. Thus, a possible failure of government-financed projects might depend on a poor selection of projects. Furthermore, the government mostly finances small projects, which are more risky than projects undertaken by larger firms. This could also explain why government projects often fail.

The paper is organized as follows. Previous studies about patents and adequate theories are discussed in section 2. The database and basic statistics are described in section 3. The statistical model and hypotheses are set up in section 4. The empirical estimations are shown in section 5, and section 6 concludes.

2. Previous studies and theoretical discussion

2.1 Previous patent studies

Most previous studies that have tried to estimate the performance of patents have used data from one or several national patent offices, implying that the researchers did not know whether the patents had been commercialized. Patent databases with detailed information (not available from the national patent offices) have seldom been collected. The few previous studies with such databases have focused on estimating the profits from patenting or the market value of patents, rather than on analyzing problems related to commercialization (Cutler, 1984; Rossman and Sanders, 1957; Sanders, 1962, 1964; Sanders et al., 1958; Schmookler, 1966; SRI International, 1985).

Morgan et al. (2001) describe the commercialization rate of American patents across different groups. Industrial patents had a commercialization rate of 48.9%, whereas the rate for inventors in the education sector was 33.5%. However, the authors never try to relate this commercialization rate to other explanatory factors and do not run any survival model – perhaps due to lack of data.

Another strand of the patent literature has analyzed the renewal of patents (see e.g. Pakes, 1986; Schankerman and Pakes, 1986). Every single year, the owners must pay a renewal fee to keep their patents in force.[2] It can be argued that the owners will only renew their patents if it is economically profitable to keep them. The percentage of renewed patents indicates how large a share of the patents have economic value after different numbers of years. The models in these studies are based on the assumption that more valuable patents are renewed for longer periods than less valuable patents. The authors estimate both the distribution of the patent values and their rate of depreciation. The main conclusions of these studies are that most patents have a low value and one that fast depreciates, while only a few have a significant high value. In other words, the value distribution of patents is severely skewed to the right.

Although most commercialized patents can be expected to be renewed, and most non-commercialized patents to expire, this is not always true, as will be seen later in the statistical part. The main defect of the renewal measure is that it does not say anything about whether the patent has been commercialized and whether the patents have been associated with any innovations or entrepreneurship. There is also an identification problem in the renewal studies. It is impossible to say which patents have a high value and which have a low value. Furthermore, patents that are not renewed do not necessarily have a low value, since the product based on the patent might have been commercialized with a short lifetime. In this lifetime, the product could either have been profitable for the owner or not. The renewal statistics say nothing about this either. Finally, with the exception of Maurseth (2005), the renewal studies have seldom rigorously estimated how different factors influence the decision to renew patents.[3]

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[2] According to Van Pottelsberghe and Francois (2006), the total cost for a patent which is renewed for 20 years is EUR 120,000 (40,000) in 13 (3) EPC member states, EUR 14,500 in the US and EUR 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. EPO patents are much more expensive 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 EUR 89,000 (22,000) in 13 (3) member states, whereas this cost is considerably lower in the US and Japan. However, the renewal fees in a single European country like Sweden are of modest size. According to the Swedish National Patent Office (PRV), the size of the renewal fees increases stepwise annually and ranges from 22 Euro in the first year to 450 Euro in the last year. The renewal fees for 20 years add up to about EUR 3,700.

[3] Maurseth (2005) tests how patent citations affect the renewal of patents. He makes an intuitive distinction between citations across and within technology fields and finds that patents that receive citations across fields survive longer than average, whereas patents with citations within the same field expire earlier. The interpretation is that citations across technology fields indicate a scientific breakthrough, while citations within fields indicate many competing innovations.

Measuring the choice to commercialize the patent does not take into account whether the patent is profitable or the fact that non-commercialized patents might also be profitable for the owner. But it does say something about whether innovations are introduced in the market, and whether the owners are involved in some form of entrepreneurship activities, which have been neglected in the previous literature. An objection against the commercialization measure would be that some patents are never commercialized, although they are renewed during the whole statutory period (20 years) for strategic reasons; for example, they deter competitors from using the invention or serve as ‘shadow patents’. However, this is a strategy primarily used by large firms. Shadow patents are relatively rare among individuals and small firms, as will be shown in section 3.

2.2 Theoretical discussion

Patents, like R&D projects, are typically characterized by high costs and no incomes in the early R&D phase, and by high uncertainty about future incomes. Besides technological problems, lack of financial resources is one of the largest problems during the R&D phase. In the later commercialization phase, several complementary resources are needed, e.g. financing, marketing and manufacturing capabilities. Large firms have these complementary capabilities as well as information about the market. Small firms have these resources in-house to a lower degree and individuals have none of these capabilities. Thus, the conditions under which inventions are commercialized differ completely between large and small firms and individuals. Therefore, external financing and advice are likely to be needed by individuals and also, to some degree, by small firms.

Clearly, inventors have more knowledge about the invention/patent than potential external financiers. Thus, problems with asymmetrical information and adverse selection are present. The search and transaction costs of finding interesting projects and evaluating the technical and commercial potential are, in other words, large for external financiers (Kaplan and Strömberg, 2001). It is especially difficult to make this evaluation in the R&D phase, when uncertainty about the project is very high. Therefore, market imperfections are likely to exist in the market for financing innovation projects. To overcome market failures and the gap between inventors and external financiers, different countries have applied various strategies (Bottazzi *et al.*, 2004; Braunerhjelm, 1999). In the United States, the government has facilitated private market solutions and the growth of private venture capital (PVC) firms (Gompers and Lerner, 2001). In Sweden, the government has intervened by offering financial assistance and loans to inventors and small technology-based firms.

Many studies have shown that R&D is important for economic growth and productivity and that the social return from business R&D is higher than the private return. The latter fact justifies government R&D support programs to inventors and R&D-performing firms. For example, Guellec and van Pottelsberghe (2004) have estimated on an aggregated level that business R&D both gives spillover effects and increases the firms' ability to absorb external technology. Governments in many countries have programs to support R&D, but also supporting entrepreneurial activity and the birth and growth of new start-up firms in general. The idea is to create jobs and stimulate economic growth. According to Kirzner (1985), these support programs can be divided into two groups: 1) reducing the costs of R&D and entrepreneurial activity; and 2) stimulating people to become entrepreneurs through teaching and encouragement. The former group mostly involves some kind of financial support to remove barriers to business formation. This kind of program is based on the assumption that financial markets disfavor small firms and entrepreneurs.

Although government support programs are common and widespread, they are seldom evaluated. Thus, little is known about their efficiency. One strand of the evaluation studies has analyzed the effects on the macroeconomic level. For example, Lichtenberg (1993) estimated that government-funded R&D performed by firms is less efficient than business-funded R&D. However, Guellec and van Pottelsberghe (2003) show that government funding – both direct funding and tax incentives – of R&D performed by firms has a positive impact on business R&D. They conclude that the negative relationship only holds for defense-related R&D. Another group of studies has estimated the effects on the firms' performance. For example, Maggioni *et al.* (1999) test the efficiency of government financial aid to technology-based start-up firms in Italy. They concluded that the program increased the number of high technology start-up firms, but that these firms were not completely efficient. Aided firms had a higher financial risk and did not grow more than non-aided firms.[4]

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[4] The authors explain this inefficiency by that easy access to initial resources: 1) it does not take account of high uncertainty faced by new ventures; and 2) it reduces the entrepreneurial skills, since the development of such skills is not favored.

In the early R&D phase – before manufacturing has started – the Swedish Government offers financial assistance and loans with soft terms to inventors and small technology-based firms. Considering the loans, the borrower pays a subsidized interest rate and begins to pay back the loan some years after the commercialization has started. However, if there is no commercialization or if commercialization fails, there is a high probability that the borrower need not pay back the loan at all. If the borrower does receive incomes during commercialization, the repayment of the loan is connected to product turnover.

The soft loans offered by the Swedish government authorities are described in detail in the Appendix. To give soft loans to a firm or an inventor in the R&D phase, the government authorities have had two selection criteria: 1) the project should have a good chance of success both technically and commercially; and 2) the project is a high-tech project. Government financing could cover up to 50-70% 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, but this financing was allowed to take the form of unpaid labor incomes. This is a cost that cannot be controlled by the government authority (raising moral hazard problems). In practice, the government loans could therefore cover more than 80% of the project's total R&D costs.

The design of the loan where repayment is connected to turnover rather than the profit means that projects with a low or medium expected profit level would probably not be commercialized at all, since the repayment of the loan would then erase the whole profit. However, this will not prevent commercialization if the expected profit level is high. Due to the design of the loans from government institutions, problems related to moral hazard are likely to emerge. Inventors who have received soft loans from the government need not care about further commercialization of the patent, since they know that there is a high probability of their not having to pay back the loans at all. It is often better to exit the project, escape from paying back the loans and start a new project. Last but not least, the loans are given to the project. This implies that the borrower can close down the project and use what he/she has learnt in a new project.

Private venture capital (PVC) firms and private persons (business angels) who assist with financing in the R&D phase own shares in the patent project/firm. The repayment is then connected to the profit 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 do not maximize their profit. Therefore, their administrators have few incentives to search for really good patent projects to which they lend money. The employees do not invest their own private money. On the other hand, PVC firms and business angels aim more consistently at profit-maximizing. Therefore, they are more likely to be careful than government institutions about the patent projects they choose to invest in, and should have a more active, and advisory, role already during the R&D phase. PVC firms not only provide financial capital, but also networks and competence in terms of knowledge about the market, marketing, juridical 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 more easily receive financing and advice in the commercialization phase.

A common opinion 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 specific soft government loans, as described above, are more attractive for inventors, and have a higher pecking order, than equity financing from private venture capitalists.[5] Thus, it is not likely that the government chooses among inferior projects that have been turned down by private investors. The authors give three reasons why such soft loans are attractive for firms and inventors. First, the patent 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. However, the soft government loans are backed by future incomes and therefore do not require any collateral.

3. Database and descriptive statistics

To analyze the commercialization of patents, it is necessary to have a detailed database about individual patents.[6] In a previous pilot questionnaire, most patents were

[5] 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.

[6] 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 impossible to find these new ideas, products and developments among all firms and individuals.

commercialized within five years after they had been applied for. Therefore, patents granted in 1998 are chosen for the current database.[7] In 1998, 2760 patents were granted in Sweden. 776 of these were granted to foreign firms, 902 to large Swedish firms with more than 1000 employees, and 1082 to Swedish individuals and firms with less than 1000 employees. Information for each patent about inventors, applying firms and their addresses was bought from the Swedish Patent and Registration Office (PRV). Thereafter, a questionnaire was sent out to the inventors of the patents.[8] In the pilot survey, it turned out that large Swedish firms refused to provide information on individual patents. Furthermore, it is impossible to persuade foreign firms to fill in questionnaires about patents. These firms are almost always large multinational firms. Therefore, the population consists of 1082 patents granted to Swedish individuals and firms with less than 1000 employees. This sample selection is not a problem, as long as the conclusions are drawn just for small firms and individuals.

As many as 867 of the inventors filled in and returned the questionnaire, i.e. the response rate was 80% (867 out of 1082). This response rate is satisfactorily high, taking into account that such a database has seldom been collected before and that inventors or applying firms usually consider information about inventions and patents to be secret. In the questionnaire, we asked the inventors about the work place where the invention was created and the financing of the invention during the R&D phase, whether the invention had been commercialized, which kind of commercialization mode was chosen, how the commercialization was financed, the inventors' incomes and profits from the patent, and if there were any problems with the commercialization – alternatively why the patent was never commercialized.

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. Therefore, the choice of the patent rather than the invention is the only practical alternative for an empirical study of the commercialization process.

[7] Granted rather than filed patents are used. Filed patents may also be commercialized, but many of these are never granted and do not qualify as real inventions. The decision to only include granted patents increases the homogeneity of the sample. There is also a trap when using granted patents. If the sample criteria had been all granted patents that are *filed in the same year* (e.g. in 1996), there would have been a sample selection problem, since it can take several years before patents are granted. Patents filed in 1996 and not yet granted at the end point of observation (2003) would then have been systematically omitted from the sample. By using all patents that are *granted in the same year*, the sample will include both patents for which it took a short and a long time until they were granted.

[8] 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 indirectly be owners of the patent, 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.

The application year of the 867 patents is shown as light-gray bars in Figure 1. 85% of the patents were applied for between 1994 and 1997. In 2003, commercialization had been started for 537 of these patents (61%). The starting year of the commercialization is represented by dark bars, which almost follow a normal distribution. Although the last year of observation is 2003, it is not likely that many of the 330 non-commercialized patents will be commercialized after 2003.

******** [Figure 1] ********

The 867 patents and the commercialization rate are described across firm groups and ownership in Table 1. As many as 408 patents (47%) were granted to individual inventors, and 116, 201, 142 patents were respectively granted to medium-sized firms (101-1000 employees), small firms (11-100 employees) and micro companies (2-10 employees).[9] The commercialization rate for the whole sample is 61%. This rate should be compared to the few available studies that have measured commercialization of patents: 47% for American patents found by Morgan *et al.* (2001) and 55% in the studies surveyed by Griliches (1990).[10] The higher commercialization rate in the present study is explained by the fact that only patents owned by small firms and individual inventors are included – large (multinational) firms have many more defensive patents. Griliches (1990) confirms this view and reports that the commercialization rate is as high as 71% for small firms and inventors. In Table 1, the commercialization rate of the firm groups is between 66% and 74%, whereas the rate of the individuals is not higher than 52%. A contingency-table test suggests there to be a significant difference in the commercialization rate between firms and individuals. The chi-square value is 30.55 (with 3 d.f.), significant at the one-percent level.

******** [Table 1] ********

In Table 2, the commercialization rate is related to external financing in the R&D phase. Patents with external financing in the R&D phase have a significantly

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

[10] These other studies have a similar definition of commercialization as here, 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, it means that the patent is used commercially. In neither of these studies does the commercialization need to be profitable for the owner.

lower commercialization rate than those without. When dividing the external financing into different sources, the commercialization rate is significantly lower only for patents supported by government funds.[11] However, it is not shown when the patents were commercialized nor how large a share of the R&D was financed with government or private capital. Such a survival analysis will be undertaken in the statistical part.

******** [Table 2] ********

The distribution of external financing among firm groups is described in Table 3. It is obvious that external financing – irrespective of source – is more common among individuals and 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 commercialization rate among government-financed projects. However, in the group of 408 patents owned by individuals, the commercialization rate is 45% for government-financed projects and 54% for projects with no government financing.

******** [Table 3] ********

In Table 4, commercialized patents are compared to renewed patents. Owners must pay an annual renewal fee to the national patent office to keep their patents in force. If the renewal fee is not paid in one single year, the patent expires. As expected, renewed patents (71%) have been commercialized to a higher degree than expired patents (49%). The chi-square value below the table shows there to be a strong correlation between commercialized and renewed patents. However, 189 patents have been commercialized, but are already expired. This is either due to the products having a short lifecycle or the commercialization having failed. On the other hand, 139 of the non-commercialized patents are still alive. Many of these patents might be defensive patents, with the purpose of defending other patents, but then the owner should have

[11] In the group with other external financing (universities, research foundations), the financing might be government or private, but the intention with this kind of funding 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.

more similar granted patents. Among the commercialized patents in our database, 46% of the owners have at least one more similar patent. Among the non-commercialized patents, this percentage is only 33%. If the patent had not been commercialized, the inventor was also asked: why? Among the 337 non-commercialized patents, only 15 inventors answered that the patent served as a shadow patent as a reason for its not having been commercialized.[12] Thus, it may be concluded that keeping patents for strategic reasons is not common among individuals and small firms. This strategy is more frequent among large multinational firms.

******** [Table 4] ********

4. Statistical model and hypotheses

4.1 Statistical model

Since the analysis focuses on an "event" to occur, survival (duration) analysis is used in the statistical estimations. The event is here that the patent has been commercialized, and it is also measured when this commercialization started. To begin with, a survival distribution function and a hazard function will be estimated and plotted in the empirical analysis. The survival function, *S(t)* in equation (1), shows how a large share of the patents survives beyond a time point, *t*. The hazard function, *h(t)* in equation (2), shows the conditional probability of a patent being commercialized in a specific time period Δt, given that it has "survived" (has not been commercialized) until time point *t*. The hazard can also be expressed as a function of the probability density function, *f(t)*, and the survival function:

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

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

In the main empirical analysis, it is estimated how different explanatory factors affect the survival time of the patents. The dependent variable, T_i, is a random variable

[12] The most frequent reasons here were: 1) problems with financing (115 replies); 2) problems with marketing (75 replies); 3) problems in finding a manufacturing firm/licensor (74 replies); and 4) the product is not yet ready for commercialization (62 replies). Note that inventors may have mentioned more than one reason why the patent was not commercialized.

showing how many years it takes until commercialization started for patent *i*, measured from the time point of the patent application.[13] Most patents in the database were applied for between 1994-97 and the end point of observation in the database is 2003. Patents that have not yet been commercialized in 2003 are "right-censored" (337 observations). Furthermore, an expired patent cannot be commercialized. If the patent is not yet commercialized and expires before 2003, the patent is right-censored in this expiration year.[14] 199 patents are right-censored before 2003 due to expiration and 138 at the end point of observation.

Measurement of the starting point of commercialization in years is a rather rough measure. Therefore, *T* is "interval-censored" for the commercialized patents (530 observations).[15] If the patent is commercialized within the first year, *T* obtains an interval-censored value between 0.1 and 1, while the second year *T* lies between 1.1 and 2, etc.

Since interval-censored observations are included, the accelerated failure time (AFT) model is the appropriate statistical model (Allison, 1995):[16]

$$\log\left(T_i\right) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots\ldots + \beta_k x_{ik} + \sigma\varepsilon_i \quad , \tag{3}$$

where ε is a random disturbance term, the β's and σ are parameters to be estimated, and the x's are explanatory variables. The ε's can have various distributions, corresponding to different AFT models, e.g. the log-normal, log-logistic, exponential, Weibull and

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[13] The application year is the easiest starting time point to measure and is directly available from the Swedish National Patent Office (PRV).

[14] This assertion requires some modification. An expired patent cannot be commercialized. However, the invention behind the patent can still be commercialized. This occurs only once in the database. This observation is considered as a non-commercialized patent and is right-censored. The fact that non-commercialized patents are right-censored in the expiration year does not alter the results of the estimations.

[15] Some patent owners claimed that the invention behind the patent was commercialized before the application year. This is quite possible. Such observations would then be left-censored. However, I regard this as mainly depending on measurement errors. Such patents are instead considered as being commercialized in the first year. Using left-censoring or not does not affect the results of the estimations.

[16] I also estimated how explanatory variables influence the commercialization choice using the Cox (1972) proportional hazard model. The results for the main variables of the Cox estimations are similar to those of the AFT models. A disadvantage with the Cox model is that the dependent variable cannot be interval-censored. I make two adjustments to minimize this problem. First, if the patent is commercialized within the first year, *T* obtains the mid-point value of that period, i.e. 0.5, within the second year, *T* is 1.5, etc. Second, I use an approximation of the Cox model, called the "exact method", to take account of the fact that two events do actually not occur at the same moment, even if there are tied event times in the sample (Allison, 1995). On the other hand, an advantage with the Cox model compared to the AFT model is that one does not need to choose between different residual distributions. Another advantage is that the quantitative effects can be interpreted in terms of how an increase of the explanatory variables affects the hazard. However, all in all, the AFT model is considered as the main model, due to the interval censoring.

gamma models. All these models will be run in the empirical part. Using likelihood-ratio tests, it is possible to decide which of the models best fits the data. After recalculation of the parameters, it can be estimated how an increase in the explanatory variables influences the survival time.

4.2 Hypotheses

Turning to the explanatory variables, factors are included that are expected to affect: 1) the time it takes to commercialize the patent (survival time) or the hazard of commercialization; and 2) the probability that the patent will be commercialized at all. Basic statistics and hypotheses of these factors are described in Table 5. Since the AFT model is the main model, the sign of the hypotheses in the table and in the text below is in accordance with the definition of equation (3). A positive parameter estimate means that the survival time is expected to increase, when the explanatory variable obtains a higher value.

******** [Table 5] ********

Factors that are specific for the commercialization, e.g. commercialization mode (licensing, new company, selling the patent, etc.), financing during the commercialization, or whether the inventors are active or passive during the commercialization, are not included in the estimations, since they cannot be measured for non-commercialized patents.

As discussed above, Swedish government institutes that assist in the financing of patent projects have a curious design of their loans. The borrower can escape from paying back the loan if the patent is not commercialized, or if the commercialization fails. If the patent is commercialized, repayment is connected to the turnover rather than the profit. This means that the expected profit of a commercialization must be higher than a threshold value – otherwise the repayment will erase the profit. Therefore, it is likely that the government financing during the R&D phase will create moral hazard problems. The loan conditions will attract inventors who own inventions with no real prospects of commercialization and will deter many good patents from being commercialized, because the expected profit level is not sufficiently high. *GOVFIN* measures how large a share of the patent's R&D costs (in percentage terms) was financed through government capital. A positive influence on survival time is expected.

In Table 3, it was seen that the government especially finances patent projects owned by individuals. Such projects should have a higher risk than projects owned 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 *GOVFIN*.[17] In practice, the parameter of *GOVFIN*, β_{GF}, is divided into two parts:

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

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

In a similar way, the variable *PRIVFIN* shows the percentage of the R&D costs financed through external private venture capital (PVC). Since private venture capitalists are regarded as strictly profit maximizing and invest only in projects in which they believe, external financiers should push harder for patents to be commercialized and create incomes. It is also likely that patents that had external private financing during the R&D phase more easily attract external venture capital (from the same private venture capitalists) during the commercialization phase. Therefore, a negative effect of *PRIVFIN* on survival time is expected.

There is also a third kind of external financing. *OTHERFIN* measures how large a share of the R&D costs was financed through universities and research foundations. Typically, patents created at universities have this kind of external financing, the purpose of which is not to assist a patent project, but rather to finance R&D in general. However, the financers seldom have any control over what the resources are actually used for. It is difficult for inventors to use the resources for patent applications, but easier to hide the labor costs necessary for creating the invention within this financing. A problem with this kind of financing is that it cannot be used for commercialization. Consequently, inventors often stand alone without financing when considering commercialization. A positive parameter estimate is therefore expected.

[17] Preferably, three different interaction dummies would be included – one for each firm group. However, as described in Table 3, there are only three patents with government financing in each of the 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 lead tos 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.

It is expected that firms that have marketing, manufacturing and financial resources in-house have better possibilities of commercializing their patents as compared to individuals. *FIRM1* is a dummy that takes on the value of 1 for medium-sized firms with 101-1000 employees and 0 otherwise. *FIRM2* equals 1 for small firms with 11-100 employees and 0 otherwise. Finally, *FIRM3* takes the value of 1 for micro companies with 2-10 employees and 0 otherwise.[18] Thus, the firm dummies here are related to the reference group of individual inventors. Therefore, the parameter estimates are expected to be negative, implying a shorter time until patents are commercialized. It is difficult to predict which of the three dummies would have the strongest impact. It is true that large firms have more resources available for commercialization, but it is not clear that larger firms are more likely to commercialize patents than smaller firms. Previous studies have, for example, shown that large multinational firms tend to patent more inventions (shadow patents) to protect other patents (Cohen *et al.*, 2000).

Basic research is relatively more common at universities. Thus, university patents are also likely to be more related to basic research and have a lower probability of commercialization (Jaffe and Lerner, 2001). In contrast to the US, university researchers in Sweden wholly own their patents. Swedish universities have no ownership, and consequently no interest in employed researchers commercializing their patents. The additive dummy *UNIV*, which equals 1 for university patents and 0 otherwise, is therefore expected to have a positive influence on survival time.

More complex products that require several patents might be more difficult to commercialize. On the other hand, if such a product is commercialized, the owner will have a good protection against competitors. In the latter case, there should be a strong incentive for commercialization. If complementary patents are needed to create a product, then the dummy *KOMPL* equals 1, and 0 otherwise. However, the impact on the commercialization decision is indeterminate.

MOREPAT is an additive dummy, which equals 1 if the inventors or the applying firm have more competitive patents in the same technology area and 0 otherwise. Applying for many similar patents is a strategy often chosen by owners – especially large firms – that want to protect a main patent. These additional 'shadow'

[18] The cut-off points for the firm dummies at 10 and 100 employees are chosen arbitrarily in order to get homogeneous groups of firms. Other cut-off points were also experimented with, for example, at 10, 50 and 200 employees, but this did not alter the results of the estimations.

patents are seldom commercialized. However, many patents can also be an indication of the owners having more knowledge and experience of the area, and should therefore increase the probability of commercialization. Therefore, the impact on survival time remains indeterminate. *OWNER* measures how large a (percentage) share of the patent the inventors own directly or indirectly. If the inventors who have the technological knowledge of the patent are also its owners, they have a larger incentive to work harder for commercialization if the patent has good prospects. The expected sign of the parameter estimate on the survival time is therefore negative. This variable is, however, heavily correlated with the firm group dummies. Among the inventions created in medium-sized firms, only 4% of the inventors are owners, small firms 48%, micro companies 86% and inventors 98%. The fact that *OWNER* is measured in percentage terms and is not a dummy might alleviate this problem. Most inventors are, however either full owners (100%) or not owners at all (0%).

INVNMBR here measures the number of inventors of the patent. This variable should be seen as an additional control variable and there is no specific expected impact on survival time. Some specific characteristics of the inventors are also included in the mode. *SX* measures the share of inventors who are female**.** No specific influence on the commercialization decision is expected. *ETH* measures the share of inventors who belong to ethnic minorities, i.e. an ethnic background other than West European or North American. It is expected that ethnic minorities have more problems with the commercialization. Thus, a positive parameter estimate is expected.

Different technologies are likely to be connected with different risks. Consequently, the technology class can affect the survival time and the conditional probability of a patent being commercialized. Patents are divided into 30 technology groups according to Breschi *et al.* (2004). These groups are based on the patents' main IPC class. However, all technology groups are not represented in the dataset and some groups do not have enough observations. Therefore, only 26 groups and 25 additive dummies are used in the present study.[19]

The data are 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,

[19] The technology classes without enough observations are instead merged with other closely related classes (Breschi *et al.*, 2004).

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, since the business cycle may affect when and whether a patent will be commercialized. The data have five application year periods (1985-90, 1991-92, 1993-94, 1995-96 and 1997-98) and four additive dummies are assigned for these periods.[20]

5. Empirical estimations

In Figure 2, the survival and hazard functions for the sample are estimated by the Life-table method (actuarial method). The patent application year is set to 0. The survival function falls steeply at the beginning, but it levels away after 4-5 years. The hazard function (conditional probability) is highest during the first three years after the application. In Figure 3, the same survival and hazard functions are estimated, but now the sample is divided into two groups: one with and the other without government financing. The survival functions suggest that the gap increases over time and the hazard is mainly higher for patents with no government financing. Both a log-rank test and a Wilcoxon test (see e.g. Allison, 1995) show the difference between the survival functions to be highly significant. The chi-square statistics are 9.45 and 9.66, respectively, significant at the 1% level for 1 d.f. The survival functions for patents with and without private venture capital are similar (not shown), and with respect to other external financing, the survival function is lower (higher commercialization rate) for those patents with no other external financing (not shown).

******** [Figure 2] ********

******** [Figure 3] ********

5.1 Estimations of the Accelerated Failure Time model

The AFT model is run using three different variants to test for robustness: Model I with region dummies, Model II with technology dummies and Model III with both region

[20] Initially, time dummies for individual application years were used. But one of the models (the gamma model) did not converge for some reason. Therefore, time dummies for two-year periods are instead used. The usage of two-year periods does not alter the results for the other estimated parameters. Note that only one patent was applied for in 1985 and in 1986, respectively, and no patents during the 1987-89 period. Therefore, 1985, 1986 and 1990 have been merged into one group.

and technology dummies. Additive dummies for unique owners (firms/inventors) were also included in the estimations, but this caused multicollinearity problems.[21] Furthermore, there are five different models based on the residual distributions: the exponential, Weibull, log-logistic, log-normal and gamma models. Before turning to the estimated parameters of the explanatory variables, I first analyze the goodness-of-fit statistics of the models.

Goodness-of-fit tests based on the log-likelihoods of the models are presented in Table 6. The gamma model, which is the most general model, has the highest log-likelihood. The other models are tested against this model. As can be seen, the exponential, the Weibull and the log-normal models are all rejected. The log-logistic model has a very low log-likelihood, but it is not nested with the other models. No test can therefore be applied.

******** [Table 6] ********

Another way of analyzing goodness-of-fit is to consider the hazard function, which is closely connected to the residual characteristics of the different models. In Figure 2, the hazard function is a declining function, but not monotonously decreasing**.** The exponential model corresponds to a constant hazard function, the Weibull model to a monotonously declining or increasing hazard and the log-normal to an inverted U-shape hazard. Thus, it is not surprising that these models are rejected. A log-logistic model may also have a declining hazard, provided that the scale parameter is estimated to be larger than 1. In the estimation of the log-logistic model, the scale parameter equals 3.1. However, the log-logistic hazard is then – like the Weibull model – monotonously declining. Based on the hazard function in Figure 2, it is therefore somewhat dubious whether the log-logistic model is appropriate.

[21] Among the 867 patents in the sample, there are 740 unique owners (firms/inventors). 663 owners have only one granted patent in 1998, 54 owners have two patents, and only 23 owners have at least three patents. Dummies can only be assigned to the 77 owners with at least 2 patents. However, when including dummies for unique owners, the AFT gamma model never converged and the AFT log-logistic model was characterized by severe multicollinearity problems with extremely high standard errors. These problems occurred even when all technology and region dummies were excluded and when dummies were included only for those 23 owners with at least three patents. The commercialization decision would be expected to be correlated for patents that belong to the same project. The correlation would be positive or negative, depending on whether the patents are complements or substitutes. It is not possible to identify patents belonging to the same project in the database, but the number of such interrelated patents should be few in the sample, based on the limited number of patents that are owned by the same firm. The variables *MOREPAT* and *KOMPL* will partly take account of whether the owner has more similar or complementary patents that belong to the same project.

The estimations of both the log-logistic and the gamma models are shown in Table 7, but most reliance is placed on the gamma model, since this is the most flexible. The parameter estimates are higher in the log-logistic model, reflecting the fact that this model has a high value of the estimated scale parameter. The significance levels of the estimated parameters are similar across the log-logistic and the gamma models, with the exception of UNIV, which is significant in the log-logistic model. However, the results are robust across Models I-III, where different dummy variables for regions and technologies are included within each of the two residual models.

******** [Table 7] ********

Turning to the financial variables, *GOVFIN* has a positive and strongly significant influence on survival time in all estimations. The quantitative interpretation of the estimated parameter in the gamma Model III is as follows: if government financing during the R&D phase increases by 1 unit (in this case one percentage point), survival time increases by 1.27%.[22] Since the AFT model is not a proportional hazard model, the *quantitative* interpretation of the estimated parameters can only be made in terms of survival time. However, a longer survival time is equivalent to a lower conditional probability (hazard) of commercialization in each time period and, accordingly, a lower probability of the patent being commercialized in the long run. It may be suspected that the government's loan conditions create a sample selection bias of patents with no or poor prospects of commercialization. It is likely that many of the inventions behind the patents would never have been patented without government assistance. The loan conditions also deter many good patents from being commercialized, since the repayment, which is connected to the turnover, erases the profit. If it is considered that this selection bias would "disturb" the estimated effects of the other explanatory variables in the regressions, then it is fortunate that the variable, *GOVFIN*, which creates this disturbance, is actually included in the estimations. It is likely that *GOVFIN* will take account of the pool of bad patents.

An alternative interpretation of the poor performance of government-financed patents is that the government might assist patent projects with a higher risk level. As

[22] The quantitative interpretation of the effect of the explanatory variables (also dummies) on survival time is carried out in the following way. If the explanatory variable increases by 1 unit, the survival time changes by $100(e^{\beta}-1)\%$.

described in Table 3, the government mostly assists individual inventors with financing. Such patent projects should have a higher risk. Therefore, the effect of *GOVFIN* should be separately estimated for firms and individuals. In the first column of Table 8, an interactive dummy is used for *GOVFIN*. The estimated parameter of the interaction dummy is not significant, thereby indicating that there is no significant difference with respect to *GOVFIN* between individuals and firms. The parameter estimate for individuals is significant at the one-percent level and has a value of 0.0121, which in quantitative terms means that the survival time increases by 1.2% if government financing increases by one percentage point. For firms, the parameter estimate is 0.0168 (0.0121 + 0.0047), but it is only significant at the 10% level. If government financing increases by one percentage point, the survival time for firm patents increases by 1.7%.

******** [Table 8] ********

As expected, the estimated time until commercialization starts is significantly shorter for the three firm-size groups (*FIRM1-FIRM3*), as compared to individuals. Thus, patents owned by firms have a shorter time until commercialization starts, as compared to patents owned by individuals, indicating that firms have more complementary financial, manufacturing and marketing capabilities. However, the difference between the three firm groups is not significant. In Model III, two of the dummies are hardly significant. The reason why the significance levels are not higher is that the firm dummies are partly correlated with *OWNER*. When *OWNER* is dropped in the last column of Table 8, the standard errors of the estimated parameters of the firm dummies are reduced, but the parameter estimates are hardly affected. This is a typical sign of multicollinearity among the variables. The quantitative interpretation of the estimated parameters in the last column of Table 8 is as follows: if the firm group dummies take on the value of 1 instead of 0, the survival time decreases by 44.7%, 38.6% and 47.5% for *FIRM1*, *FIRM2* and *FIRM3*, respectively, as compared to individuals.

The estimated parameter of *PRIVFIN* has the expected negative sign, but is never significant. *OTHFIN* never turns out to have any significant effect. *UNIV* has the expected positive influence, but it is only significant in the log-logistic model. University researchers have a commercialization rate of only 34% as compared to 61% in the whole sample. A problem here is that the typical inventor (but not all of them) who receives external financing from universities and research foundations (i.e. *OTHFIN* has a positive value) is a university researcher. Thus, *OTHFIN* and *UNIV* partly measure the same thing. The correlation between the two variables is 0.52, not extremely strong but maybe sufficient to disturb the estimations. In the second and third columns of Table 8, one of the two variables is alternatively excluded when running the gamma model III. However, neither *OTHFIN* nor *UNIV* is significant.

KOMPL has a negative and significant impact on survival time. If complementary patents are needed to create a product, then the survival time decreases by 30.4%. None of the variables *MOREPAT*, *INVNMBR*, *SX* or *ETH* turn out to have any significant impact on the commercialization decision.

6. Concluding remarks

In the present study, survival models were run to estimate how different explanatory factors affect the decision that patents are commercialized. This has seemingly never previously been done. A unique database on Swedish patents, owned by small firms and individuals, was used. Here, it is possible to observe if and when the patents were commercialized, i.e. whether the owners put effort into introducing innovations in the market. Such data have not been available in previous studies. In particular, the paper has analyzed how external financing from different sources during the R&D phase influences the probability of patents being commercialized.

The most interesting conclusion from the estimations is that the larger the share of the costs covered by government financial support during the R&D phase, the longer it takes until commercialization starts.[23] One potential explanation is that the inferior performance of government-financed patents rests on moral hazard problems, due to the design of the government loans. The borrower can avoid paying back the loan if the project fails, or if the patent is not commercialized. If commercialization is undertaken, repayment is connected to the turnover. This means that patents with a low or medium expected profit would seldom be commercialized. In fact, it seems that government financing creates a pool of patents that have limited prospects of commercialization. Many of the owners of these inventions would probably never apply for a patent at all, had it not been for the design of the government loans. There is also a possibility that

[23] An equivalent interpretation is that the conditional probability (the hazard) for commercialization is lower in each time period for these patents, implying a higher probability that they will never be commercialized at all.

the inferior performance of government projects depends on government-employed administrators not being able to select promising patent projects to which they could lend money. Thus, there might be problems with adverse selection. In this study, it is not possible to discriminate between the two possible explanations of moral hazard (bad design of loans) and adverse selection (bad selection of projects).

A third possible explanation for the low commercialization rate among government projects would be that the government often chooses to support individual inventors, whose projects are riskier than the average. However, this explanation is less likely than the other two, since the estimations showed that government projects had a lower probability of commercialization, both among individuals and among firms. Although there is no significant difference between individuals and firms, the effect is not so statistically strong for firms.

Patents with private external financing during the R&D phase are commercialized to the same extent as patents on average. On the other hand, university patents have a significantly lower conditional probability of commercialization in some of the estimations. Different sizes of firms had a strongly significant impact on the commercialization decision in the estimations. Patents created in firms (medium-sized and small firms as well as micro companies) are commercialized more quickly and with a higher probability than patents owned by individuals, thereby indicating how important complementary resources, like financing, marketing and manufacturing, are for commercialization.

Considering policy implications, the government should change the design of the loans. Above all, the loans in the early phase should be granted to the firm – and not to the project. The borrower can then avoid repayment only if the firm leaves the business. Hence, there are no longer any incentives for borrowers to close down the project and use the knowledge in a new project. All loans should also be repaid to the government, even if the project fails or the patent is never commercialized. This would deter opportunists with poor inventions from applying for government loans. Furthermore, the repayment should be connected to the profit of the commercialization, instead of the turnover. Then there are incentives to commercialize, even if the expected profit is low.

This study does not draw any conclusions on whether the government should support firms and inventors with external capital. There might be other positive effects on the social welfare of government financing beyond our measure (commercialization).

For example, many studies have shown that government funding of business R&D has spillover effects and enhances the absorptive capacity of the firms. Another important argument for government intervention in the case of small firms and inventors is that there might be imperfections in the market for external financing. As could be seen in Table 2, 16% of the patents had government financing during the R&D phase, whereas only 6% had private financing.

Finally, I give some suggestions for future research. In the present study, I have analyzed how different factors affect the choice of commercializing patents. I have not measured the value of the innovation. There are further steps to investigate, for example how different factors influence the performance of the commercialization. Some kinds of patent projects might have a higher expected profit level than others, depending on their characteristics (e.g. financing, risk, technology).

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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 inventors and high-tech small 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. 6-8m 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. A difference between the institutions was that SIC loans were given to a higher degree to inventors and NUTEK loans to firms.

The government financing could cover up to 50-70% 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 (moral hazard problems). Practically, the government loans could therefore cover more than 80% 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 connected 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 very 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 had already a firm and incomes from other projects. The interest rate was 4% 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% of turnover of the project, or 35% of royalties in the case of licensing.

2) The borrower had neither a firm nor incomes. 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% of turnover of the project, or 35% of royalties in the case of licensing.

Practically, the borrower only needed to repay 50% of the loan if he had some incomes from the project when the report was submitted. SIC was wound up in 2003 and NUTEK in 2005, but similar loans have been offered by 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% of the SIC loans and 33% of the NUTEK loans had been repaid. Thus, the default rates of the soft loans were as high as 87% and 67%, respectively.

In the Netherlands similar soft loans have been given by TOK (Technisch Ontwikkelingskrediet). TOK had a default rate of 43% - considerably lower than in the Swedish case. The explanations are that the Dutch loans were also given to medium-sized firms and TOK had harder terms for co-financing and follow-up (Kaivanto and Stoneman, 2006).

Figure 1. Application year and starting year of commercialization for patents granted in 1998

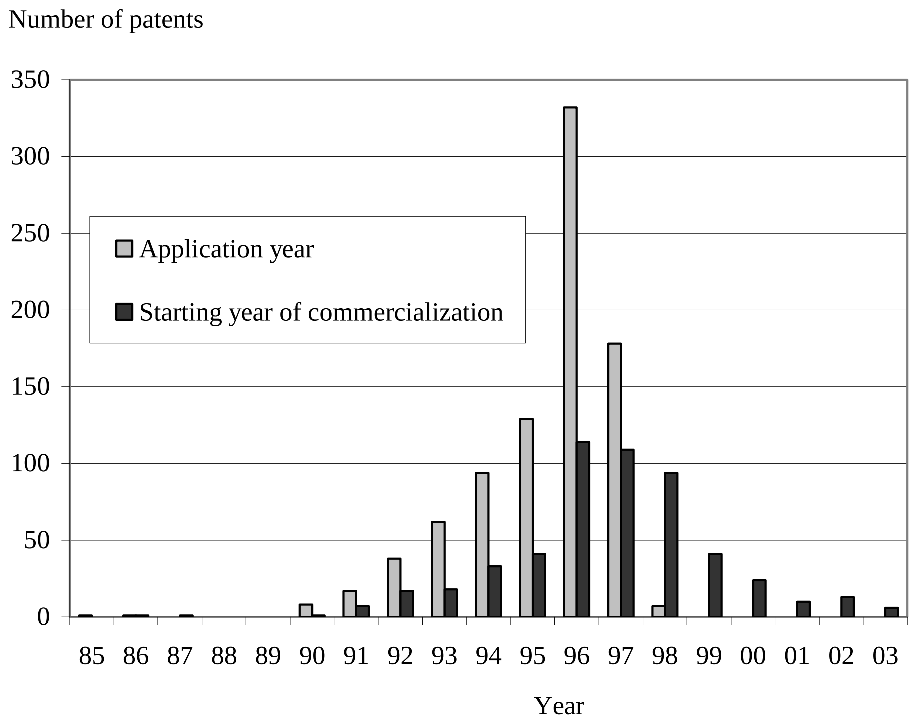

Figure 2. Survival distribution and Hazard functions for Swedish patents.

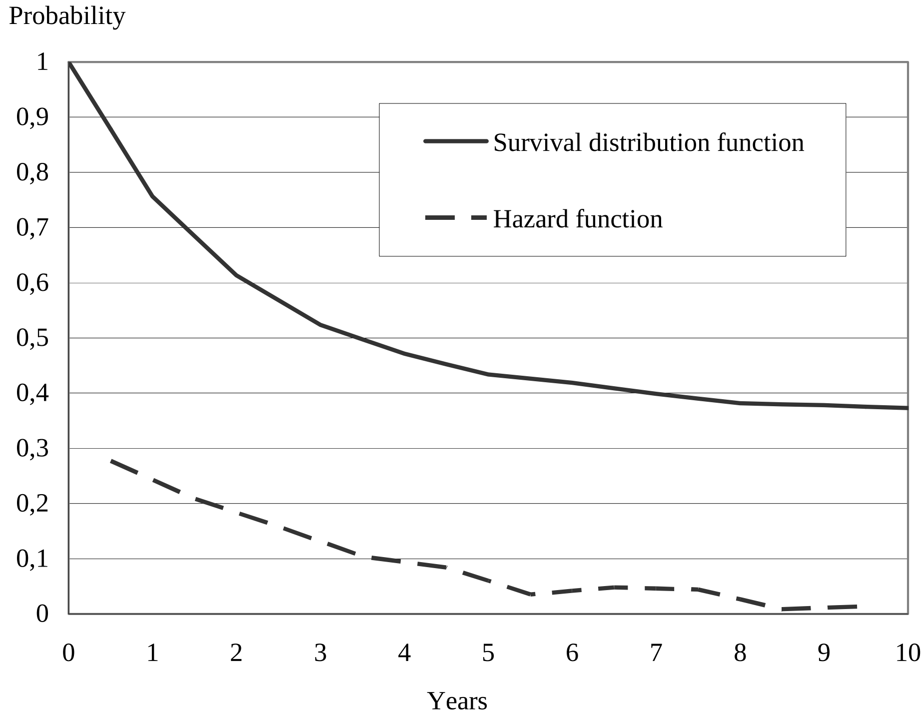

Figure 3. Survival distribution and Hazard functions across financing for Swedish patents.

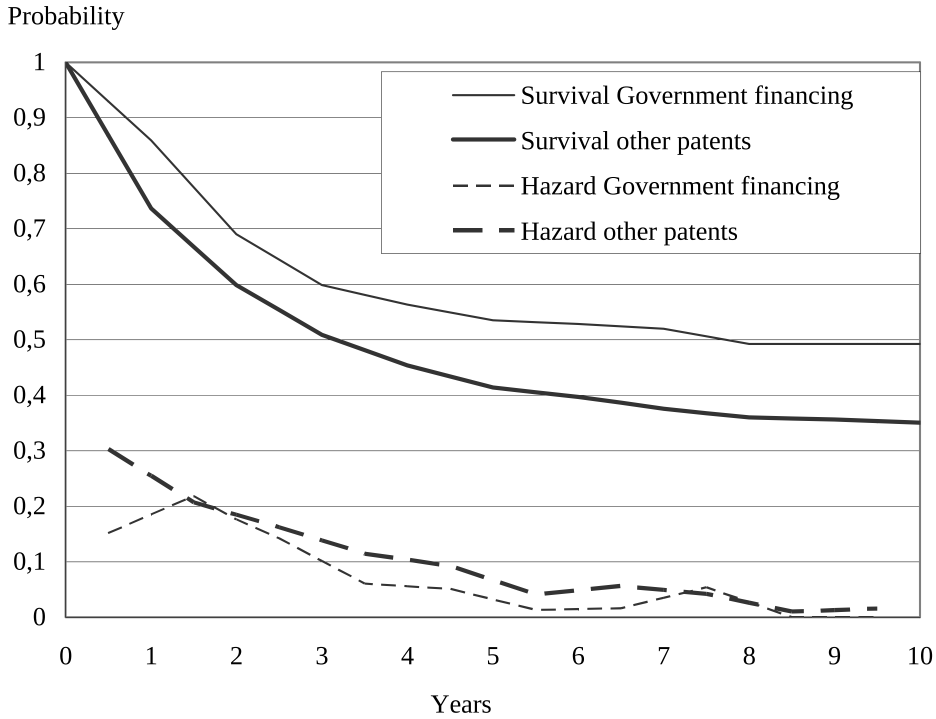

Table 1. Commercialization of patents across firm sizes and inventors' ownership

Kind of firm where invention was created	Number of patents: Commercialization Yes	Number of patents: Commercialization No	Total	Percent Commercialized
Medium-sized firms (101-1000 employees)	77	39	116	66 %
Small firms (11-100 employees)	137	64	201	68 %
Micro companies (2-10 employees)	105	37	142	74 %
Inventors (1-4 inventors)	211	197	408	52 %
Total	**530**	**337**	**867**	**61 %**

Table 2. External financing during the R&D phase and commercialization

Any external financing				
External financing during the R&D-phase	Commercialization Yes	Commercialization No	Total	Percent
No	422	238	660	63.6 %
Yes	108	99	207	52.2 %
Total	530	337	867	61.1 %
Chi-square-test = 9.18 ***				
Government external financing	Commercialization Yes	Commercialization No	Total	Percent
No	460	265	725	63.4 %
Yes	70	72	142	49.3 %
Total	530	337	867	61.1 %
Chi-square = 10.01 ***				
Private venture capital	Commercialization Yes	Commercialization No	Total	Percent
No	500	319	819	61.1 %
Yes	30	18	48	62.5 %
Total	530	337	867	61.1 %
Chi-square = 0.04				
Other external financing (e.g., universities, research foundations)				
Other external financing	Commercialization Yes	Commercialization No	Total	Percent
No	513	318	831	61.7 %
Yes	17	19	36	47.2 %
Total	530	337	867	61.1 %
Chi-square = 3.06 *				

Note: 207 patents have external financing, but 19 patents have financing from more than one source.

Table 3. External financing across firm groups

Firm groups	No. of patents with external financing during the R&D-phase: Government financing	Private financing	Other financing	Total number of patents
Medium-sized firms	3	1	4	116
Small firms	3	7	6	201
Micro companies	25	3	0	142
Inventors	111	37	26	408
Total	142	48	36	867

Table 4. Commercialized patents and patents still alive 2004

Patents still alive 2004	Commercialized patents latest in 2003			Percent Commercialized
	Yes	No	Total	
Yes	341	139	480	71 %
No	189	198	387	49 %
Total	530	337	867	61 %
Percent still alive	64 %	41 %	55 %	

Note: Chi-square-value is 44.46, significant at the 1 percent level for 1 d.f.

Table 5. Descriptive statistics and hypotheses for the explanatory variables

Notation	Description	Mean	St.dev.	Expected impact on survival time
GOVFIN	Percent of R&D financed by government	7.69	21.1	+
PRIVFIN	Percent of R&D financed by private venture capital	3.14	14.4	-
OTHFIN	Percent of R&D financed by universities/research foundations	2.73	14.4	+
FIRM1	Dummy taking the value of 1 for medium-sized firms (101-1000 employees), and 0 otherwise	0.13	0.34	-
FIRM2	Dummy taking the value of 1 for small firms (11-100 employees), and 0 otherwise	0.23	0.42	-
FIRM3	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	+
KOMPL	Dummy that equals 1 if complementary patents are needed to create a product, and 0 otherwise	0.23	0.42	?
MOREPAT	Dummy taking the value of 1 if the inventors have more similar (competitive) patents, and 0 otherwise	0.41	0.49	?
OWNER	Percent of the patent that is directly or indirectly owned by the inventors.	65.2	45.2	-
INVNMBR	Number of inventors of the patent	1.34	0.66	?
SEX	Share of inventors who are females	0.02	0.14	?
ETH	Share of inventors with an ethnic background other than Western European or North American	0.03	0.16	+

Table 6. Goodness-of-fit tests with Likelihood-ratio statistics.

Model	Log-likelihood	Test between models	d.f.	Likelihood-ratio Chi-square statistics
Exponential	-1525.36	Exponential vs. Weibull	1	56.28 ***
Weibull	-1497.22	Exponential vs. Gamma	2	179.68 ***
Log-logistic	-1906.52	Weibull vs. Gamma	1	123.40 ***
Log-normal	-1458.40	Log-normal vs. Gamma	1	45.76 ***
Gamma	-1435.52			

Note: The log-likelihoods are taken from Model III. ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. The conclusion with respect to significance of the tests would be the same if log-likelihoods from Models I or II are used. The log-logistic model is not nested with the other models.

Table 7. Empirical estimations of the AFT model

Dependent variable	log (*T*)					
Statistical model	Accelerated failure time (AFT) model					
Explanatory variables	Log-logistic model			Gamma model		
	Model I	Model II	Model III	Model I	Model II	Model III
GOVFIN	0.040***	0.034***	0.035***	0.012***	0.012***	0.013***
	(0.012)	(0.012)	(0.012)	(3.5 E-3)	(3.6 E-3)	(3.5 E-3)
PRIVFIN	-0.020	-0.014	-0.014	-4.7 E-3	-4.1 E-3	-3.7 E-3
	(0.013)	(0.014)	(0.013)	(4.5 E-3)	(4.9 E-3)	(4.9 E-3)
OTHFIN	0.017	0.020	0.020	2.5 E-3	5.7 E-3	6.5 E-3
	(0.017)	(0.017)	(0.017)	(5.6 E-3)	(6.0 E-3)	(6.0 E-3)
FIRM1	-1.57*	-1.56*	-1.40*	-0.611**	-0.720 **	-0.541*
(dummy)	(0.812)	0.822)	0.822)	0.308)	(0.314)	(0.315)
FIRM2	-1.72***	-1.60**	-1.53**	-0.561***	-0.551***	-0.442*
(dummy)	(0.611)	(0.617)	(0.620)	(0.225)	(0.230)	(0.232)
FIRM3	-2.00***	-2.16***	-2.13***	-0.573***	-0.683***	-0.597***
(dummy)	(0.545)	(0.549)	(0.549)	(0.201)	(0.199)	(0.200)
UNIV	3.13**	3.69**	3.61**	0.474	0.716	0.529
(dummy)	(1.36)	(1.38)	(1.38)	(0.392)	(0.425)	(0.435)
KOMPL	-1.37***	-1.52***	-1.44***	-0.361**	-0.412***	-0.363**
(dummy)	(0.418)	(0.422)	(0.422)	(0.156)	(0.157)	(0.157)
MOREPAT	-0.551	-0.441	-0.537	-0.058	-0.033	-0.063
(dummy)	(0381)	(0379)	(0381)	(0.134)	(0.133)	(0.132)
OWNER	-2.4 E-3	-1.9 E-3	-1.4 E-3	-2.1 E-4	-6.2 E-4	-3.0 E-4
	(6.0 E-3)	(6.0 E-3)	(6.0 E-3)	(2.3 E-3)	(2.3 E-3)	(2.3 E-3)
INVNMBR	0.362	0.379	0.366	0.037	0.022	4.0 E-4
	(0.291)	(0.300)	(0.300)	(0.103)	(0.107)	(0.107)
SEX	-1.37	-1.46	-1.35	-0.246	-0.387	-0.216
	(1.26)	(1.29)	(1.28)	(0.453)	(0.443)	(0.442)
ETH	0.213	0.240	0.083	0.140	0.190	0.116
	(1.18)	(1.19)	(1.18)	(0.385)	(0.378)	(0.371)
Region dummies (5 d.f.)	6.29	-----	5.92	6.91	-----	9.70*
Technology dummies (25 d.f.)	-----	23.34	22.93	-----	24.52	27.75
Time dummies (4 d.f.)	10.63**	10.04**	10.09**	1.94	2.96	2.36
Scale parameter, σ	2.85	2.81	2.80	1.48	1.38	1.34
Shape parameter	-----	-----	-----	-1.55	-1.73	-1.81
Log-likelihood	-1917.86	-1909.44	-1906.52	-1448.75	-1440.46	-1435.52
Likelihood-ratio test	101.56***	118.40***	124.24***	71.66***	88.24***	98.12***

Note: The total number of observations equals 867, 529 of which are interval-censored observations and 338 right-censored. Standard errors are in parentheses and ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. For the region, technology and time dummies, only Wald chi-square values for the whole group of dummies are shown. Intercepts as well as individual region, technology and time dummies are available from the author upon request.

Table 8. Robustness tests of the AFT model, gamma model

Dependent variable	log (*T*)				
Statistical model	Accelerated failure time (AFT) model				
Explanatory variables	Gamma model				
	Model III	Model III	Model III	Model III	Model III
GOVFIN	0.012***	0.012***	0.012***	0.013***	0.012***
	(3.1 E-3)	(3.6 E-3)	(3.7 E-3)	(3.5 E-3)	(3.6 E-3)
*GOVFIN*D*	4.7 E-3	4.6 E-3	4.7 E-3	4.5 E-3	4.6 E-3
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
PRIVFIN	-3.6 E-3	-4.0 E-3	-3.5 E-3	-3.9 E-3	-4.0 E-3
	(4.8 E-3)	(4.9 E-3)	(4.8 E-3)	(4.8 E-3)	(4.7 E-3)
OTHFIN	6.5 E-3	8.3 E-3	-----	8.6 E-3	8.6 E-3
	(6.0 E-3)	(5.8 E-3)		(5.5 E-3)	(5.4 E-3)
FIRM1	-0.554*	-0.573*	-0.576*	-0.566*	-0.594***
(dummy)	(0.316)	(0.317)	(0.315)	(0.314)	(0.211)
FIRM2	-0.458*	-0.475**	-0.463**	-0.469**	-0.488***
(dummy)	(0.235)	(0.235)	(0.234)	(0.232)	(0.173)
FIRM3	-0.632***	-0.639***	-0.646***	-0.636***	-0.645***
(dummy)	(0.215)	(0.216)	(0.215)	(0.215)	(0.200)
UNIV	0.530	-----	0.658	-----	-----
(dummy)	(0.436)		(0.423)		
KOMPL	-0.364**	-0.356**	-0.352**	-0.355**	-0.356**
(dummy)	(0.156)	(0.156)	(0.156)	(0.156)	(0.156)
MOREPAT	-0.059	-0.062	-0.051	-0.061	-0.060
(dummy)	(0.133)	(0.132)	(0.133)	(0.132)	(0.131)
OWNER	2.0 E-4	2.0 E-4	1.1 E-4	3.0 E-4	-----
	(2.3 E-3)	(2.3 E-3)	(2.3 E-3)	(2.3 E-3)	
INVNMBR	3.8 E-3	0.016	0.030	-----	-----
	(0.107)	(0.106)	(0.104)		
SEX	-0.210	-0.185	-0.205	-0.183	-0.182
	(0.443)	(0.438)	(0.441)	(0.437)	(0.437)
ETH	0.120	0.142	0.132	0.138	0.140
	(0.371)	(0.364)	(0.370)	(0.363)	(0.363)
Region dummies (5 d.f.)	9.82*	11.10**	9.55*	11.18**	11.25**
Technology dummies (25 d.f.)	27.63	28.30	26.73	28.57	28.58
Time dummies (4 d.f.)	2.35	2.51	2.35	2.56	2.55
Scale parameter, σ	1.34	1.29	1.34	1.29	1.29
Shape parameter	-1.81	-1.94	-1.82	-1.95	-1.95
Log-likelihood	-1435.42	-1436.11	-1435.97	-1436.12	-1436.13
Likelihood-ratio test	98.32***	96.94***	97.22***	96.92***	96.90***

Note: The total number of observations equals 867, 529 of which are interval-censored observations and 338 right-censored. Standard errors are in parentheses, and ***, ** and * indicate significance at the 1, 5 and 10 percent level, respectively. For the region, technology and time dummies, only Wald chi-square values for the whole group of dummies are shown. Intercepts as well as individual region, technology and time dummies are available from the author upon request.