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Patent Value Indicators and Technological Innovation

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Abstract

I provide empirical evidence that quality-adjusted patents can identify technological innovation in small and medium-sized enterprises. Survey data on commercialization of patents is related to patent quality indicators (patent renewal, patent family size and forward citations) from archival sources. Among the patent quality indicators, both the length of patent renewal and the size of the patent family indicate that a patent has been commercialized. Patent renewal for at least 6 years is sufficient to predict an accurate probability of commercialization. Furthermore, patent renewal is the only indicator revealing whether commercialization is successful or not. Forward citations have a weak relationship with both commercialization and successful innovation, which may reflect the fact that citations are outside the control of the patentees. Although the correlations of the patent value indicators with technological innovation are noisy, this study provides stronger empirical support for the true relative value of different indicators with respect to innovation.

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1. Introduction

Patent statistics are often used by policymakers to measure the output of research and development (R&D) and innovation. For example, the European Innovation Scoreboard index is based on multiple indicators of innovation, including education, scientific publications, R&D expenditures, Patent Cooperation Treaty (PCT) applications and knowledge-intensive exports (European Commission 2020). This index can be used to determine how competitive the EU is compared with other OECD countries as well as to determine the strengths and weaknesses of individual EU Member States. Furthermore, United Nations (2019) and WIPO (2019) regularly present patent statistics in their yearbooks.

A weakness of using patent data is that innovation is defined in a narrow sense: patents are considered product or process innovations only if they are commercialized. This approach excludes innovations linked to changes in the organizational structure or to new marketing methods, as defined in the OSLO manual (OECD 1997, 2005).[1] However, a strength in using patents as an innovation indicator is that the commercialization of a patent automatically means that a technological innovation is introduced, since patents are granted only to *novelties*. A practical problem is that almost no patent databases contain information on which patents have been commercialized, i.e., which specific patents have been introduced as innovations in the market. Consequently, prior research has instead relied on several quality indicators to identify patents deemed valuable (see van Zeebroeck 2011 and Thoma 2014 for overviews). Among these indicators, *patent renewal*, *patent family size* (patent equivalents), *forward citations* and *oppositions* are the most frequently used. How these patent quality indicators are related to the commercialization of patents is never or seldom examined in the literature.

[1] The introduction of the OSLO manual in 1997 and its extension in 2005 were important steps in the measurement of innovation output (OECD 1997, 2005). Its guidelines made it possible for the first time to collect harmonized and internationally comparable data on innovation output. In the OSLO manual, innovations include not only product and process innovations but also innovations related to organizational change/business practices and new marketing concepts/strategies (OECD 2005). An example of surveys based on this manual to identify innovations is the Community Innovation Survey (CIS) conducted by Eurostat (Gault 2013). In this survey, respondents provide information on four different types of innovations from the OSLO manual. However, since CIS is a cross-sectional survey, the main disadvantage is that the exact timing of the year of introduction of an innovation is not known (Mairesse and Mohnen 2010). Another disadvantage is that innovation measures are subjective in nature, as they depend on the judgment of respondents. Furthermore, the quality of innovations is likely to be uneven across firms and industries, with random errors of classification and measurement in both qualitative and quantitative variables (Mairesse and Mohnen 2010). However, in contrast to innovation (input) expenditures, the share of sales due to new products can be regarded as relatively accurate, although the measure is rounded to five or ten percent (Mairesse and Mohnen 2010).

This paper aims to show which traditional patent quality indicators can be used as indicators for technological innovations. The main contribution is to relate the patent quality indicators mentioned above from archival sources to survey measures of patent commercialization (technological innovation) and successful innovation. To the best of our knowledge, such a study has never been undertaken. Previous studies have related patent quality indicators to different measures of patent value, not commercialization (Harhoff *et al*. 1999, Fischer and Leidinger 2014, Thoma 2014, Abrams *et al.* 2019). For this purpose, we use a unique database on Swedish patents owned by small firms and individuals. The dataset is based on a survey and contains information on *whether*, *when* and *how* (existing firm, new firm, licensed or sold) patents were commercialized as well as whether the commercialization was profitable. Here, commercialization refers to the introduction of a product or process innovation in the market – a similar definition as used in the CIS surveys.[2] The database also contains traditional patent quality variables, such as patent renewal, forward citations and patent equivalents (family size) from archival sources.[3]

In the empirical part, we provide new estimates of how technological innovations are related to traditional patent quality indicators by using different qualitative response models (probit model and ordered probit model with sample selection). The estimations show that commercialization is strongly positively correlated with both patent renewal and patent equivalents but moderately positively correlated with forward citations. Furthermore, successful innovations are positively related to patent renewal in most cases. The results also show that one does not need to observe 20 years of renewal patterns to identify technological innovations. A patent that is renewed for at least 6 years is a good indication of a technological innovation. Similarly, patents renewed for at least 7−10 years indicate that an innovation is successful.

This paper is organized as follows. The theoretical background is outlined in section 2, which presents different measures of innovations and patent quality and explains what motivates their use. The database is described in section 3. In section 4, the statistical methods for relating patent quality indicators to innovations are specified. The results of the estimations are then presented in section 5, and the final section summarizes the conclusions of the study.

[2] In our survey, inventors were asked: Did you introduce a product or process based on the patent in the market?
[3] Unfortunately, oppositions are not available for Swedish patents.

2. Discussion of concepts and traditional patent quality indicators

2.1 Traditional patent quality indicators

In the literature, four main indicators of patent quality have been used to determine the value of patents: forward citations, patent equivalents (family size), patent renewal and oppositions (van Zeebroeck 2011).[4] The grant decision has also been used as an indicator of patent value in analyses of patent applications. However, this indicator is not considered in the present study, which focuses solely on granted patents.

Forward citations. In the patent literature, forward citations have frequently been used as a measure of patent quality or value, despite skepticism about whether forward citations actually measure the private value of patents or spillover effects (Hall *et al*. 2007). Forward citations indicate the existence of downstream research efforts and a potential market for a patent (van Zeebroeck 2011). Trajtenberg (1990) argues that forward citations measure the social value of patents. For a specific patent, a higher frequency of citations by later patents is associated with larger spillover effects and, hence, higher social value. A patent can be cited at any time after the application date, even after it has expired. Harhoff *et al.* (1999) and Harhoff *et al.* (2003) showed that there is a positive relationship between forward citations and the patentee's estimated value of the patents, although this relationship is somewhat noisy. Abrams *et al*. (2019) showed that the relationship between patent value (measured as novel licensing data) and citations is an inverted-U shape, with fewer citations at the high end of value than in the middle.

Patent equivalents. The number of patent equivalents is an important indicator of the private value of patents (Putnam 1996). Since patent filing and enforcement are costly in many countries, only patents with a sufficiently high expected value are filed in many countries. However, once a patent is filed with any patent office, the patent owner must file patents with other offices within a year to expand the patent rights to other countries (the priority year). Lanjouw and Schankerman (2001) and Harhoff *et al.* (2002) show that family size is positively correlated with patent or firm value. Fischer and Leidinger (2014) show that both forward citations and family size are positively related to patent value (measured as patent auction prices).[5] Although these factors explain only a small

[4] Some studies have also related the characteristics of patents with firm value (see, e.g., Griliches *et al.* 1987, Hall 1993, Lanjouw and Schankerman 2004).
[5] Fischer and Leidinger (2014) did not include patent renewals in the model to explain patent value.

portion of the variance in patent value, the full model explains a large share of the variance in patent value.

Patent renewal. Patent holders must pay an annual fee to keep their patents in force, and this fee increases over time until the maximum life span of 20 years is reached. According to Griliches (1990), rational owners will renew their patents only if it is economically profitable to keep them. Several previous studies have estimated the private value of patents by using the renewal scheme of patents (see, e.g., Pakes 1986, Schankerman and Pakes 1986, and successive studies). Pakes and Schankerman (1984) (and successive studies) show that most patents have a low value and depreciate quickly. Only a few patents have a significant high value and last for the maximum period.

Oppositions. A fourth traditional patent quality indicator addresses whether oppositions have been filed against a granted patent. Oppositions by a third party signal a patent's potential value in a given market. Therefore, oppositions indicate that there is a potential market for the patent and that the patent is sufficiently important to justify the costs and risks associated with a dispute (Lanjouw and Schankerman 1997, 2001, Harhoff *et al*. 2002, van Zeebroeck 2011).

2.2 Commercialization of patents

One strength of using patents as an indicator of innovation is that the commercialization of a patent automatically means that a technological innovation is introduced, since patents are granted only to *novelties*. In the few available studies that have measured the commercialization of patents, Morgan *et al.* (2001) found a commercialization rate of 47 percent for American patents. Griliches (1990) finds a commercialization rate of 55 percent but reports a commercialization rate as high as 71 percent for small firms and inventors. Morgan *et al.* (2001) define commercialization as the commercialization of a product or process or the granting of a licensing contract, whereas Griliches (1990) defines commercialization as the commercial use of a patent. Neither of these studies required the commercialization of the patent to be profitable for the owner.

Svensson (2007, 2013) analyzes the commercialization pattern of patents based on the same data set that is used in the present study. The main question was the probability of commercialization and the renewal length of patents subsidized by government research programs compared to a control group. Other studies have also used this data set. Braunerhjelm and Svensson (2010) investigate the performance of different commercialization strategies (entering the market or licensing/selling the patent). Maurseth and Svensson (2020) analyze the transfer of tacit knowledge when patents are commercialized. In the present study, the data set is used in another way. I attempt to determine which traditional patent value indicators can be used to identify technological innovation (commercialization) and successful innovations (profitable commercialization).

3. Database

I use a detailed data set of Swedish patents granted to small firms (fewer than 1,000 employees) and individual inventors in 1998. The data set is based on a survey conducted in 2003–04. The sample consists of 867 patents, and the survey response rate is 80 percent.[6] The data set is unique because it contains information on *whether*, *when* and *how* the patent has been commercialized as well as the profitability of the commercialization. The data set has been complemented with information on patent renewal, patent equivalents, forward citations and filing routes from the Espacenet (2019) website. Thus, the database includes information on several traditional patent quality indicators.

In the present study, commercialization is defined to indicate that a product or process innovation based on a patent has been introduced in the market—by the inventor, the inventing firm or an external firm that has licensed or acquired the patent. This definition is similar to that used in previous survey studies (Griliches 1990, Morgan *et al.* 2001) and similar to the definition used in the CIS surveys, i.e., that the patent has been used commercially.

The 867 patents and the patent commercialization rate are described across firm groups in Table 1.[7] As many as 408 patents (47 percent) were granted to individual inventors, and 116, 201 and 142 patents were granted to medium-sized firms (101–1,000 employees), small firms (11–100 employees) and micro-firms (2–10 employees), respectively.[8] The commercialization rate for the whole sample is 61 percent. The higher commercialization rate in the present study compared to that found in previous studies likely results from the focus solely on patents owned by small firms and individual inventors, as large (multinational) firms have many more defensive patents than

[6] For a more thorough description of the data set, data collection and non-respondents, see Svensson (2007).
[7] Turning to the filing routes, only eight of 867 patents were first filed abroad, and all of these were in the US. No patent was filed first with the EPO or WIPO and thereafter in Sweden. This pattern markedly contrasts with the filing routes undertaken by Swedish multinationals. Various explanations may account for this result; for example, the owners in the database used in this study are individuals and small firms, and the data cover patent filings in the 1990s, when it was still common to first file patents in the home country.
[8] The grouping of firm size classes is based on the grouping in the survey.

small firms. As shown in Table 1, the commercialization rate for firm groups is between 66 and 74 percent, whereas the rate for individuals is 51 percent.[9]

[Table 1 here]

The inventors were asked to estimate whether the commercialized invention would yield a profit, break even, or result in a loss. If they did not know, the reply was registered as a missing value (uncertain outcome).[10] In Table 2, discrete values for the outcome in terms of profit across firm groups are presented.[11] As shown in the table, outcomes differ substantially across firm groups, with the group of individual inventors having the least favorable outcome.

[Table 2 here]

4. Estimation techniques and explanatory variables

In this section, I present the estimation techniques that I use to test the relationships between the traditional patent quality indicators and 1) the probability of an innovation (the commercialization of a patent) and 2) the probability of a successful innovation.

4.1. Probability of an innovation

The dependent variable Com_i represents whether a patent i has been commercialized. It is dichotomous in nature and takes the value of 1 if a technological innovation has been introduced in the market and 0 otherwise. Therefore, a standard probit model based on the cumulative normal distribution function is used to predict variation in the dependent variable. The model can be written as:

$$c_i^* = X_i \beta + v_i \quad , \qquad (1)$$
$$c_i = 1 \; \textit{if} \; c_i^* > 0 \; \textit{and} \; 0 \; \textit{otherwise},$$

[9] A contingency table test suggests that this difference in the commercialization rate between firms and individuals is statistically significant at the one percent level (chi-square value of 30.55 with 3 d.f.).
[10] For the vast majorities of patents, commercialization had reached a stage such that there was no uncertainty about the patent's performance in 2003. In 2007, importation on the profitability of commercialization was updated via phone calls to inventors who had earlier announced an uncertain outcome.
[11] It would have been desirable to measure the outcome in terms of money, but such information was impossible to collect. Estimating profit flows is very complicated because most firms have many products in their statement of accounts, and many individual inventors do not have any statement of accounts at all.

where c_i* is a latent index; c_i is the selection variable indicating whether the patent is commercialized; $\mathbf{X_i}$ is a vector of explanatory variables, which influence the probability that the patent is commercialized; $\boldsymbol{\beta}$ is a vector of parameters to be estimated; and $\mathbf{v_i}$ ~ N(0, 1).

4.2. Probability of a successful innovation

The dependent variable *Success* measures the performance of the commercialization for the original patent owner in terms of profit. This variable can take three different discrete values, denoted by index *k*:

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

Since the three alternatives can be ordered, an ordered probit model is applied and is described in detail in Appendix A (Greene 1997). A possible objection against the sample and the chosen statistical model is that the patents, which are commercialized, do not constitute a random sample of patents but instead have specific characteristics that led them to be commercialized in the first place, potentially resulting in misleading parameter estimates. An appropriate statistical model is therefore an ordered probit model with sample selectivity based on the commercialization decision; see also Appendix A (Greene 2002).

4.3 Explanatory variables

In all estimations, patent quality indicators that are available in common patent databases (e.g. PatStat (2020) EPO database) are included.

Forward citations. The total number of forward citations that *a patent and its patent equivalents* have received during the period of five years after publication is used in two ways (as suggested by van Zeebroeck 2011). Self-citations are excluded from these measures. First, *all forward citations* that a patent and its equivalents have received within five years of publication, here called *Citations 1*, is used. Some patent offices, such as the United States Patent and Trademark Office (USPTO), cite patents more frequently than other patent offices. Therefore, the number of forward citations that the patent and its equivalents have received within five years of publication *from PCT applications and patents granted by the European Patent Office (EPO)*, here called *Citations 2*, is also used.

Equivalents. The variable *Equivalents* measures the total number of sister patents abroad of the patent. However, patent equivalents should not be regarded equally, as host countries vary in market size. In the database, foreign patent filings are dominated by the large markets. *Eq.EPO*, *Eq.US* and *Eq.Japan* are additive dummies that equal 1 if there is an administrative patent at EPO, a US patent, or a Japan patent, respectively, and 0 otherwise.

Patent renewals. The variable *Renewal* measures the number of years of patent renewal. The maximum value is 20 years. However, we do not wish to wait 20 years to identify an innovation. Therefore, additional dummies for the length of renewal are also used. For example, the dummy *Renewal5* equals 1 if the patent is renewed for at least 5 years and 0 otherwise, *Renewal6* equals 1 if renewed for at least 6 years, etc.

Data on oppositions are not available for Swedish patents at Espacenet (2019).[12] The traditional patent quality indicators are also squared in some of the estimations to determine whether a nonlinear relationship exists between these quality indicators and *Com/Success*. Definitions and descriptive statistics for the dependent and explanatory variables are shown in Appendix B, Table B1.

Control variables. In all estimations we use control variables in the form of industry class, region and time dummies as follows. Since patenting and innovations are known to vary greatly between industries and technology classes (Levin *et al.* 1987), I include additive dummies for 30 different industry classes designated by Breschi *et al.* (2004). These industry classes are based on the IPC system, and a patent may belong to several different IPC classes. However, it is not possible to determine the main IPC class because the classes are listed in alphabetical order for each patent in Espacenet (2019). Therefore, a patent in the database used in this study may belong to as many as four different industry classes. Consequently, the 30 industry dummies are not mutually exclusive.[13] The data are divided into six different kinds of regions according to NUTEK (1986): 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 since the business cycle may affect when and whether a

[12] Oppositions are only available for those Swedish patents that have a sister patent at EPO.
[13] In some estimations, we had to reduce the number of industry classes because of the limited number of observations in each class. For example, only 25 classes are included when I estimate the ordered probit model, and only 22 classes are used for the estimation with the EPO subsample.

patent will be commercialized. The data have five application year periods (1985–1990, 1991–1992, 1993–1994, 1995–1996 and 1997–1998) and four additive dummies are assigned for these periods.[14]

Furthermore, we include a range of firm- and patent-specific factors that might affect the decision of commercialization and the profit level of commercialization in every second model, for example, firm size, financing during the R&D-phase, complementary, ownership, number of inventors, sex, ethnical factors, etc., see Appendix Table B1. These explanatory variables were included when estimating the commercialization decision in Svensson (2007) and the profitability of commercialization in Braunerhjelm and Svensson (2010).

5. Results of the estimations

5.1. Bi-variate analysis

Table 3 shows that 318 (of 867) patents had forward citations according to the first measure but that only 209 had forward citations from the PCT or EPO. Some evidence suggests a positive relationship between commercialization and the two measures of forward citations. The Spearman rank correlations between commercialization and the citation variables are 0.14 and 0.07, which are significant at the 1 and 5 percent levels, respectively (Table 7).

[Table 3 here]

The 867 patents in the database together have 1,734 patent equivalents abroad, for an average of exactly two equivalents per patent. The frequency distribution of patent equivalents is shown in Table 4. Only 345 (40 percent) of the 867 patents have at least one equivalent. Moreover, given that a patent has at least one equivalent, the average number of equivalents per patent is 5.0. The maximum number of equivalents for a given patent is 24. Table 4 shows that patents with many equivalents have a higher probability of being commercialized. Further, the Spearman rank correlation between commercialization and patent equivalents is 0.24, which is significant at the 1 percent level (Table 7).

[Table 4 here]

[14] Note that only one patent was applied for in 1985 and in 1986, respectively, and no patents during the 1987–1989 period. Therefore, 1985, 1986 and 1990 have been merged into one group.

Triadic patents (i.e., patents that are filed in the three largest patent offices in the world—the EPO, the USPTO and the Japanese patent office) should be especially valuable. The database contains 79 Triadic patents, and 113 patents were filed in at least two Triadic markets. Moreover, there are 224 equivalents in the US and 141 in Japan, as well as 217 EPO patents. EPO patents must be validated in individual member countries, and EPO patents resulted in 1,104 individual patents in the EPO member countries, for an average of 5.1 individual patents per EPO patent.[15] The EPO patents in the database used in this study are filed most frequently in Germany, Great Britain and France—the large EPO countries.[16] Thus, patent equivalents are not distributed randomly across countries.[17]

As shown in Table 5, the results reveal a strong positive relationship between commercialization and an EPO equivalent, a US equivalent, equivalents in at least two Triadic markets and a Triadic patent (EPO, the US, and Japan). Chi-square tests indicate that the relationships are highly significant in all four cases; however, commercialization has a stronger relationship with EPO and US equivalents than with Triadic patents.

[Table 5 here]

Table 6 presents the results regarding the relationship between patent renewal and commercialization for the sample. Overall, 407 patents (47 percent) expired before 10 years, whereas 460 (53 percent) were renewed for at least 10 years. As many as 133 patents (15 percent) were renewed the maximum period of 20 years. The share of commercialized patents is higher for longer-lasting patents. The Spearman rank correlation between patent renewal and commercialization is 0.26, which is clearly significant at the 1 percent level (see Table 7).

[Table 6 here]

Table 7 presents simple Spearman rank correlations between commercialization and the traditional patent quality indicators. As shown, commercialization (indicating an innovation) is clearly more strongly correlated with equivalents and patent renewal than with forward citations. Moreover, patent renewal, patent equivalents and forward citations are all positively and significantly correlated with each other.

[Table 7 here]

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[15] This average number of equivalents is the same as that for EPO patents in general (van Zeebroeck 2011).

[16] Only 30 equivalents in the database were filed directly at the national patent offices in the EPO area without filing an EPO patent first.

[17] van Zeebroeck and van Pottelsberghe (2011) show a strong positive correlation between market size and the probability that an EPO patent will be validated in a country. The skewed country distribution of patents above indicates that country characteristics are important for international patenting.

Table 8 reports the results regarding the correlations between the profitability of patent commercialization (three levels, as defined in a previous section) and the traditional patent quality indicators. Here, only commercialized patents are included in the analysis. The correlations between the commercialization variable and the traditional patent value indicators in Table 8 are somewhat weaker than those in Table 7.

[Table 8 here]

5.2 The probability of a technological innovation

The results of the probit estimations are shown in Table 9. Almost 70 percent of the observations are correctly predicted with respect to commercialization (*Com*). Several variants of the model are estimated. For example, several control variables are included, forward citations are alternatively represented by *Citations 1* and *Citations 2* (all citations vs. only citations from the EPO and PCT), and equivalents are measured as the total number of equivalents or as additive dummies for the Triadic market equivalents.

[Table 9 here]

Both the number of equivalents and the length of patent renewal have a strong positive relationship with the probability of commercialization, and the estimated parameters are significant at the 1 percent level (*Renewal* in all models and *Equivalents* in Models A, B, E and F). However, when the number of equivalents is substituted for dummies for EPO, US and Japanese equivalents, the parameters of these dummies are not significant (Models C, D, G and H).[18] Notably, the estimated parameters of forward citations are never significant. The marginal effects of the explanatory variables on the probability of an innovation (calculated around the means of X) are shown in Table 10. As shown, if one more equivalent is filed, then the probability of an innovation increases by 1.9−2.2 percentage points. If the patent is renewed for one more year, the probability of an innovation increases by 2.0−2.4 percentage points.

[Table 10 here]

Nonlinear relationships might exist between commercialization and some of the traditional patent quality indicators. For example, the probability of commercialization may increase with the number of equivalents, but the rate of increase may decline for high numbers of equivalents. Estimations with squared values of the number of citations, the number of equivalents and the number of years

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[18] The model is not improved by including an additive dummy for a Triadic patent instead of the three dummies for EPO, US, and Japanese equivalents.

of renewal do not alter the results. None of the squared variables is significantly related to commercialization.[19] Likelihood ratio tests between the estimations in Table 9 and those with squared values are not significant, indicating that the inclusion of squared values does not improve the models. Furthermore, the share of correct predictions of *Com* does not improve.

To identify technological innovations, one would ideally wait no more than 10 years to observe the renewal pattern rather than waiting 20 years. Therefore, *Renewal* is replaced by the additive dummy *RenewalX*, which shows whether the patent is alive after X years (with the limits: 4 years ≤ X ≤ 10 years). The results revealed that the best fit (log likelihood value) in Models A−H was achieved if the dummy *Renewal6* was used, as shown in the left part of Table 11. A patent that is renewed for at least six years has a 20 percentage points higher probability of being commercialized than those that are not renewed for six years. When two renewal dummies are used, the combination of *Renewal6* and *Renewal10* yields the highest log likelihood value in Models A−H.[20] *Thus, already after 6 years of renewal, one can obtain a good indication of whether a technological innovation has been introduced in the market.*

[Table 11 here]

5.3 The probability of a successful innovation

The results of the ordered probit estimations are presented in Table 12. The estimated parameter ρ is significant in seven of eight models, indicating that there is a sample selection problem and that the model should be estimated in two steps. Regarding the explanatory variables, forward citations are not related to successful commercialization. Moreover, the number of equivalents is either positively or negatively related to *Success*; but the estimated parameter is never significant. However, when equivalents are measured by the dummies for Triadic market equivalents, the results show that a US equivalent is positively related to *Success*, whereas a Japanese equivalent is strongly negatively related to *Success*. Additionally, the length of patent renewal is strongly and positively related to successful commercialization, with a significant estimated parameter at least at the 5 percent level in all models except Model D.

[Table 12 here (2 parts)]

The marginal effects of the explanatory variables on different commercialization outcomes (*Success*) are depicted in Table 13. If a patent is renewed for one more year, then the probability of

[19] These estimations are available from the author upon request.
[20] Compared to the alternatives (4, 6), (4, 7), (4, 8), (4, 9), (4, 10), (5, 7), (5, 8), (5, 9), (5, 10), (6, 8), (6, 9), (7, 9), (7, 10) and (8, 10) years.

a successful innovation increases by 1.2 (Model B) or 1.4 (Model G) percentage points. Furthermore, the marginal effect of a Japanese equivalent is negative and significant. The marginal effects of the other explanatory variables are non-significant. Note here that the marginal effects of the dummy variables (*Eq. EPO, Eq. US,* and *Eq. Japan*) are relatively large because these effects are calculated when the dummies change from 0 to 1, i.e., from the minimum to the maximum value.

[Table 13 here]

Moreover, we replace *Renewal* with *RenewalX* dummies. However, compared to the probit model, one must wait 7−10 years until it is possible to identify which innovations are successful. The results can be found in Table 14. The model with *Renewal8* yields the highest log likelihood value. Patents that are renewed for at least 8 years have a 11.4 percent higher probability of being successful than those that are not renewed 8 years. When two *RenewalX* dummies are used, the combination *Renewal6* and *Renewal8* gives the best fit.

[Table 14 here]

6. Concluding remarks

6.1 Main results

This study has empirically analyzed whether and how strong traditional patent quality indicators are related to 1) the probability that a patent is commercialized (i.e., the probability that a technological innovation is introduced in the market) and 2) whether the patent commercialization is successful. This study provides stronger empirical support for the true relative value of different patent value indicators with respect to technological innovation. To the best of my knowledge, such an analysis has never been presented in the existing literature. For the analysis, a unique database of Swedish patents with information on the commercialization process of individual patents based on a survey is used. Simple correlations and contingency table tests show that both patent commercialization and successful innovations are positively correlated with patent renewal and patent equivalents (family size) but only moderately positively correlated with forward citations. Although statistically significant, the correlation parameters are somewhat noisy, never exceeding 0,33.

In the statistical models, patent renewal and equivalents primarily have positive relationships with the probability of a technological innovation, whereas the relationship between forward citations and the probability of an innovation is generally non-significant. However, the estimations also show that one does not need to observe the renewal pattern for 20 years. Patents renewed for at least six years signal an accurate probability of commercialization.

With respect to the success of commercialization, only patent renewal is positively related to profitability. Moreover, one does not need to observe the renewal pattern over 20 years. Patents renewed for 7−10 years predict a relatively accurate probability of a profitable technological innovation.

Inventors must decide soon after patent application in which countries to file a patent (priority year); by contrast, the renewal decision is updated every year. Therefore, it is not surprising that the probability of a successful innovation is primarily positively related to the renewal decision. The weak relationship between commercialization and successful commercialization with forward citations might not be surprising, since citations are out of the control of the patentees. However, previous studies have found a positive relationship between forward citations and patent value, although this relationship has never been very strong (Harhoff *et al*. 1999, Harhoff *et al*. 2003, Fischer and Leidinger 2014).

6.2 Limitations

Since the database covers only patents owned by small firms and individuals, the results can be used to predict technological innovations and successful innovations only for patents owned by these groups. Larger firms likely have a higher share of non-commercialized patents, which are used for defensive purposes (blocking or negotiations) (Svensson 2002). However, this does not rule out that patent renewal and family size are also positively related to the commercialization decisions for large firms.

Finally, the study and method are unable to identify technological innovations in all sectors. In some sectors, firms traditionally prefer to protect their invented technologies by relying on secrecy and circumspection or strong lead times rather than patents (e.g., the car industry). By contrast, other sectors, primarily in large service areas, rely on other intellectual property rights (e.g., copyright) to protect artistic and literary works.

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

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

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

Kind of firm where the invention was created	Performance				Total
	Profit	Break-even	Loss	Missing value	
Medium-sized firms	55	18	3	1	77
Small firms	97	24	15	1	137
Micro-firms	60	17	27	1	105
Inventors	69	47	87	4	207
Total	281	106	132	7	526
Percent	53.4 %	20.2 %	25.1 %	1.3 %	100.0 %

Table 3. Relationship between commercialization and forward citations, number of patents.

Commercialized	*Citations 1*, number of forward citations (from all sources)								All
	0	1	2	3−4	5−6	7−8	9−10	≥11	
No	244	51	9	13	14	4	3	3	341
Yes	305	82	49	46	19	9	7	9	526
Total	549	133	58	59	33	13	10	12	867
Commercialized	*Citations 2*, number of forward citations (from PCT and EPO)								
	0	1	2	3−4	5−6	7−8	9−10	≥11	All
No	271	44	15	10	1	0	0	0	341
Yes	387	81	35	17	2	0	2	2	526
Total	658	125	50	27	3	0	2	2	867

Table 4. Relationship between commercialization and patent equivalents, number of patents.

Commercialized	Number of patent equivalents								All
	0	1−2	3−4	5−6	7−8	9−10	11−12	≥13	
No	258	34	18	12	9	2	5	3	341
Yes	274	90	45	38	25	19	10	25	526
Total	532	124	63	50	34	21	15	28	867

Table 5. Relationship between commercialization and patent equivalents in large markets.

Commercialized	EPO patent		US patent		Patent in 2 or 3 Triadic areas		Triadic patent		Total
	No	Yes	No	Yes	No	Yes	No	Yes	
No	289	52	285	56	314	27	322	19	341
Yes	361	165	358	168	440	86	466	60	526
Total	650	217	643	224	754	113	788	79	867
Chi-square test	28.65 ***		26.00 ***		12.98 ***		8.51 ***		

Note: ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively. A Triadic patent means that a patent was granted at EPO, in the US and in Japan.

Table 6. Relationship between commercialization and renewal of patents.

	Patent renewal, number of years										
Commercialized	2−3	4−5	6−7	8−9	10−11	12−13	14−15	16–17	18–19	20	All
No	35	56	62	49	34	28	31	20	8	18	341
Yes	20	40	84	61	45	49	40	47	25	115	526
Total	55	96	146	110	79	76	69	67	33	133	867

Table 7. Correlation matrix between commercialization and patent quality indicators, Spearman rank parameters.

Citations 1 (number, all)	0.14 ***			
Citations 2 (number, EPO + PCT)	0.07 **	0.78 ***		
Equivalents (number)	0.24 ***	0.61 ***	0.41 ***	
Renewal (years)	0.26 ***	0.21 ***	0.15 ***	0.38 ***
	Com	*Citations 1*	*Citations 2*	*Equivalents*

Note: n = 867. ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively.

Table 8. Correlation matrix between profitability of commercialization and patent quality indicators, Spearman rank parameters.

Citations 1 (number, all)	0.10 **			
Citations 2 (number, EPO + PCT)	0.07	0.75 ***		
Equivalents (number)	0.16 ***	0.57 ***	0.37 ***	
Renewal (years)	0.31 ***	0.14 ***	0.12 ***	0.32 ***
	Success	*Citations 1*	*Citations 2*	*Equivalents*

Note: n = 519. ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively.

Table 9. Results of the probit estimations.

Dependent variable = *Com*								
Statistical model = Probit model								
Explanatory variable	A	B	C	D	E	F	G	H
Citations 1	0.024	0.024	0.018	0.021				
	(0.020)	(0.020)	(0.020)	(0.021)				
Citations 2					0.027	0.020	0.017	0.016
					(0.049)	(0.048)	(0.048)	(0.047)
Equivalents	0.053***	0.049***			0.056***	0.052***		
	(0.017)	(0.018)			(0.017)	(0.018)		
Eq. EPO			0.127	0.073			0.135	0.087
			(0.143)	(0.147)			(0.143)	(0.147)
Eq. US			0.184	0.152			0.217	0.190
			(0.146)	(0.151)			(0.141)	(0.146)
Eq. Japan			0.202	0.230			0.197	0.223
			(0.166)	(0.172)			(0.166)	(0.171)
Renewal	0.060***	0.053***	0.063***	0.058***	0.061***	0.054***	0.063***	0.058***
	(9.7 E-3)	(0.010)	(9.7 E-3)	(0.010)	(9.7 E-3)	(0.010)	().7 E-3)	(0.010)
FIRM1		-0.17		-0.19		-0.15		-0.17
		(0.23)		(0.23)		(0.23)		(0.23)
FIRM2		0.068		0.055		0.073		0.057
		(0.16)		(0.16)		(0.16)		(0.16)
FIRM3		0.37**		0.37**		0.38**		0.37**
		(0.15)		(0.15)		(0.15)		(0.15)
GOVFIN		-8.8 E-3***		-8.7 E-3***		-8.8 E-3***		-8.6 E-3***
		(2.8 E-3)		(2.8 E-3)		(2.8 E-3)		(2.8 E-3)
PRIVFIN		-1.3 E-3		1.1 E-3		1.4 E-3		1.1 E-3
		(3.7 E-3)		(3.8 E-3)		(3.7 E-3)		(3.8 E-3)
OTHFIN		-2.9 E-3		-3.2 E-3		-2.9 E-3		-3.2 E-3
		(4.2 E-3)		(4.2 E-3)		(4-2 E-3)		(4.2 E-3)
UNIV		-0.66**		-0.69**		-0.66**		-0.69**
		(0.33)		(0.33)		(0.33)		(0.33)
KOMPL		0.42***		0.41***		0.43***		0.42***
		(0.13)		(0.13)		(0.13)		(0.13)
MOREPAT		0.065		0.069		0.063		0.067
		(0.10)		(0.10)		(0.10)		(0.10)
OWNER		-0.14		-0.15		-0.13		-0.14
		(0.17)		(0.17)		(0.17)		(0.17)
INVNMBR		-0.067		-0.072		-0.069		-0.074
		(0.078)		(0.078)		(0.078)		(0.078)
SEX		0.21		0.25		0.20		0.25
		(0.35)		(0.35)		(0.35)		(0.35)
ETH		-0.20		-0.20		-0.18		-0.17
		(0.32)		(0.35)		(0.31)		(0.31)
Dummies:								
Industries	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−520.4	−496.8	−521.4	−498.0	−521.0	−497.5	−521.7	−498.5
Share of correct predictions	66.9	69.0	67.4	69.6	67.5	69.1	66.8	69.4

Note: n=867. Standard errors are in parentheses. ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively. Parameter estimates of intercept and industry class dummies are not reported but are available from the author on request.

Table 10. Marginal effects on the probability of an innovation.

Explanatory variable	A	B	C	D	E	F	G	H
Dependent variable = *Com*								
Statistical model = Probit model								
Citations 1	9.1 E-3	8.8 E-3	7.0 E-3	7.7 E-3				
	(7.6 E-3)	(7.8 E-3)	(7.7 E-3)	(8.0 E-3)				
Citations 2					0.010	6.8 E-3	6.9 E-3	5.4 E-3
					(0.019)	(0.018)	(0.018)	(0.018)
Equivalents	0.021***	0.019***			0.022***	0.020***		
	(6.5 E-3)	(6.7 E-3)			(6.4 E-3)	(6.6 E-3)		
Eq. EPO			0.049	0.030			0.052	0.035
			(0.053)	(0.055)			(0.053)	(0.055)
Eq. US			0.069	0.057			0.081	0.071
			(0.054)	(0.056)			(0.052)	(0.053)
Eq. Japan			0.078	0.086			0.076	0.083
			(0.060)	(0.061)			(0.060)	(0.061)
Renewal	0.023***	0.020***	0.024***	0.021***	0.023***	0.020***	0.024***	0.021***
	(3.7 E-3)	(3.9 E-3)	(3.7 E-3)	(3.9 E-3)	(3.7 E-3)	(3.9 E-3)	(3.7 E-3)	(3.9 E-3)

Note: n=867. The marginal effects are calculated around the means of the X's. Standard errors are in parentheses. ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively.

Table 11. Results of the probit estimations with renewal dummies, marginal effects.

Dependent variable = *Com*												
Statistical model = Probit model												
Explanatory variable	Model B, One renewal dummy, marginal effects							Model B, Two renewal dummies, marginal effects [a]				
Citations 1	9.9 E-3 (7.9 E-3)	9.7 E-3 (7.9 E-3)	8.3 E-3 (7.8 E-3)	9.3 E-3 (7.8 E-3)	9.4 E-3 (7.8 E-3)	9.7 E-3 (7.9 E-3)	9.4 E-3 (7.8 E-3)	8.3 E-3 (7.8 E-3)	8.3 E-3 (7.8 E-3)	8.3 E-3 (7.8 E-3)	8.1 E-3 (7.8 E-3)	9.1 E-3 (7.8 E-3)
Equivalents	0.031*** (6.3 E-3)	0.030*** (6.4 E-3)	0.027*** (6.4 E-3)	0.027*** (6.4 E-3)	0.027*** (6.5 E-3)	0.027*** (6.5 E-3)	0.026*** (6.6 E-3)	0.027*** (6.4 E-3)	0.026*** (6.5 E-3)	0.026*** (6.5 E-3)	0.025*** (6.6 E-3)	0.026*** (6.6 E-3)
Renewal4	0.144* (0.080)							-0.015 (0.088)				
Renewal5		0.105* (0.062)										
Renewal6			0.197*** (0.051)					0.202*** (0.059)	0.173*** (0.062)	0.179*** (0.054)	0.170*** (0.056)	
Renewal7				0.140*** (0.045)								0.107** (0.054)
Renewal8					0.117*** (0.042)				0.034 (0.051)			
Renewal9						0.098** (0.040)				0.031 (0.046)		
Renewal10							0.108*** (0.040)				0.053 (0.044)	0.055 (0.048)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry classes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−505.3	−505.4	−499.3	−502.1	−506.5	−504.1	−503.4	−499.3	−499.1	−499.1	−498.6	−501.4
Share of correct predictions	66.6	67.0	68.4	67.7	68.4	67.4	67.1	68.6	68.6	68.4	68.0	67.2

Note: n=867. Standard errors are in parentheses. ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively. Parameter estimates of intercept, control variables, industry class dummies, region dummies and time dummies are not reported but are available from the author on request. Similar results for the renewal dummies were achieved in Models A, C−H. These estimations are available from the author upon request.

[a] Only the five (of 14) combinations of renewal dummies with the highest log likelihood-value are shown.

Table 12. Results of the ordered probit estimations.

Dep. variable: *Success*	Statistical model: Ordered probit model							
	without sample selection				with sample selection			
Explanatory variables	A	B	C	D	A	B	C	D
Citations 1	0.031 (0.019)	0.021 (0.021)	0.019 (0.019)	8.2 E-3 (0.021)	0.015 (0.021)	7.2 E-3 (0.026)	0.019 (0.019)	2.5 E-3 (0.031)
Equivalents	−4.1 E-3 (0.016)	5.0 E-3 (0.016)			−0.017 (0.014)	−7.4 E-3 (0.015)		
Eq. EPO			0.088 (0.16)	0.22 (0.17)			0.088 (0.16)	0.19 (0.18)
Eq. US			0.36** (0.15)	0.33** (0.17)			0.36** (0.16)	0.28 (0.21)
Eq. Japan			−0.41** (0.18)	−0.51*** (0.19)			−0.41** (0.18)	−0.53*** (0.20)
Renewal	0.083*** (0.011)	0.066*** (0.012)	0.079*** (0.011)	0.063*** (0.012)	0.037*** (0.012)	0.036** (0.015)	0.079*** (0.011)	0.046* (0.024)
FIRM1		0.86*** (0.27)		0.86*** (0.27)		0.78*** (0.27)		0.85*** (0.29)
FIRM2		0.73*** (0.19)		0.78*** (0.19)		0.59*** (0.20)		0.71*** (0.24)
FIRM3		0.51*** (0.16)		0.51*** (0.16)		0.27*** (0.17)		0.38* (0.22)
GOVFIN		-9.3 E-3** (4.5 E-3)		-9.1 E-3** (4.5 E-3)		-3.2 E-3** (4.7 E-3)		-5.9 E-3 (6.1 E-3)
PRIVFIN		5.4 E-3 (4.6 E-3)		6.0 E-3 (4.6 E-3)		3.9 E-3 (3.9 E-3)		5.4 E-3 (4.2 E-3)
OTHFIN		2.5 E-3 (6.4 E-3)		2.8 E-3 (6.4 E-3)		2.9 E-3 (5.6 E-3)		3.2 E-3 (6.2 E-3)
UNIV		-0.50 (0.55)		-0.39 (0.55)		-0.061 (0.79)		-0.14 (0.97)
KOMPL		0.19 (0.14)		0.19 (0.14)		0.012 (0.14)		0.086 (0.19)
MOREPAT		0.13 (0.12)		0.13 (0.13)		0.063 (0.12)		0.10 (0.14)
OWNER		-0.015 (0.19)		-9.6 E-3 (0.19)		0.054 (0.19)		0.029 (0.20)
INVNMBR		0.068 (0.11)		0.094 (0.11)		0.087 (0.11)		0.11 (0.12)
SEX		0.014 (0.41)		-0.011 (0.41)		-0.058 (0.35)		-0.069 (0.38)
ETH		0.23 (0.42)		0.30 (0.43)		0.27 (0.37)		0.32 (0.39)
Intercept	−0.40	−0.61	−0.41	−0.66	0.55	0.15	0.45	-0.18
ω (threshold value)	0.03	0.72	0.66	0.73	0.50	0.60	0.55	0.69
Dummies:								
Industries	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ρ					−0.92***	−0.79***	−0.81***	−0.49
Log Likelihood	−982.1	−928.7	−978.9	−924.5	−979.4	−927.3	−977.8	−924.3
Test vs. restricted model					5.41**	2.90*	2.04	0.54

Table 12. Results of the ordered probit estimations (continued).

Dep. variable: *Success*	Statistical model: Ordered probit model							
	without sample selection				with sample selection			
Explanatory variables	E	F	G	H	E	F	G	H
Citations 2	−9.2 E-3	−0.023	−0.016	−0.032	0.035	−0.033	−0.021	−0.035
	(0.042)	(0.042)	(0.042)	(0.043)	(0.059)	(0.064)	(0.046)	(0.069)
Equivalents	2.1 E-3	0.010			0.065	5.7 E-3		
	(0.016)	(0.016)			(0.017)	(0.014)		
Eq. EPO			0.12	0.25			0.044	0.20
			(0.16)	(0.17)			(0.15)	(0.18)
Eq. US			0.39**	0.34**			0.25	0.26
			(0.16)	(0.16)			(0.17)	(0.19)
Eq. Japan			−0.41**	−0.50***			−0.39**	−0.51***
			(0.18)	(0.19)			(0.18)	(0.20)
Renewal	0.083***	0.067***	0.080***	0.064***	0.058**	0.031**	0.041***	0.041**
	(0.011)	(0.012)	(0.011)	(0.011)	(0.010)	(0.013)	(0.016)	(0.020)
FIRM1		0.88***		0.88***		0.76***		0.84***
		(0.27)		(0.27)		(0.26)		(0.29)
FIRM2		0.73***		0.78***		0.55***		0.68***
		(0.19)		(0.19)		(0.19)		(0.22)
FIRM3		0.51***		0.51***		0.23		0.35*
		(0.16)		(0.16)		(0.16)		(0.20)
GOVFIN		-9.5 E-3**		-9.2 E-3**		-1.8 E-3		-5.0 E-3
		(4.5 E-3)		(4.5 E-3)		(4.3 E-3)		(5.5 E-3)
PRIVFIN		5.5 E-3		6.0 E-3		3.6 E-3		5.1 E-3
		(4.6 E-3)		(4.6 E-3)		(3.7 E-3)		(4.1 E-3)
OTHFIN		3.6 E-3		3.6 E-3		3.7 E-3		3.7 E-3
		(6.3 E-3)		(6.4 E-3)		(5.4 E-3)		(6.0 E-3)
UNIV		-0.43		-0.33		0.062		-0.27
		(0.55)		(0.55)		(0.79)		(0.96)
KOMPL		0.20		0.20		-2.0 E-3		0.068
		(0.14)		(0.14)		(0.14)		(0.17)
MOREPAT		0.13		0.13		0.044		0.04
		(0.12)		(0.13)		(0.12)		(0.13)
OWNER		-6.2 E-3		-3.0 E-3		0.071		0.043
		(0.19)		(0.19)		(0.18)		(0.19)
INVNMBR		0.055		0.088		0.080		0.10
		(0.10)		(0.11)		(0.10)		(0.11)
SEX		0.020		-0.030		-0.11		-0.10
		(0.41)		(0.41)		(0.34)		(0.37)
ETH		0.33		0.34		0.29		0.34
		(0.42)		(0.42)		(0.35)		(0.38)
Intercept	−0.40	−0.60	−0.41	−0.66	0.57	0.26	0.45	-0.047
ω (threshold value)	0.65	0.72	0.61	0.73	0.50	0.57	0.55	0.66
Dummies:								
Industries	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ρ					−0.93***	−0.89***	−0.80***	−0.61*
Log Likelihood	−984.0	−929.7	−979.6	−924.8	−981.1	−927.3	−978.6	−924.3
Test vs. restricted model					5.94***	4.73**	2.10	0.33

Note: n=860. Standard errors are in parentheses. ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively. Parameter estimates of industry class dummies are not reported but are available from the author on request.

Table 13. Marginal effects on probability of successful innovation in the ordered probit estimations.

Dependent variable = *Success*						
Statistical model: Ordered probit model with sample selection						
Explanatory variables	Model B			Model G		
	P(0)	P(1)	P(2)	P(0)	P(1)	P(2)
Citations 1	−1.5 E−3	−1.0 E−3	2.5 E−3			
Citations 2				4.5 E−3	2.6 E−3	−7.1 E−3
Equivalents	1.5 E−3	1.0 E−3	−2.5 E−3			
Eq. EPO [a]				−9.6 E-3	−5.5 E-3	0.015
Eq. US [a]				−0.053	-0.031	0.084
Eq. Japan [a]				0.086**	0.048**	−0.134**
Renewal	−7.4 E-3***	−4.9 E-3***	0.012***	−8.9 E-3***	−5.2 E-3***	0.014***

Note: ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively. All marginal effects are calculated around the means of the X's. The sum of the marginal effects on the probabilities equals zero.
[a] Marginal effect on probabilities when dummy variable increases from 0 to 1.

Table 14. Results of the ordered probit estimations with renewal dummies, marginal effects.

Dependent variable = *Success*							
Statistical model: Ordered probit model with sample selection, marginal effects							
Explanatory variables	Model B, One renewal dummy				Model B, Two renewal dummies		
	P(2)	P(2)	P(2)	P(2)	P(2)	P(2)	P(2)
Citations 1	1.1 E−3	1.1 E−3	1.2 E−3	1.5 E−3	1.4 E−3	1.4 E−3	1.8 E−3
Equivalents	4.7 E−4	−2.9 E−4	−1.4 E−3	−5.0 E−4	−1.4 E−3	−1.3 E−3	−1.1 E−3
Renewal5 [a]					0.080		
Renewal6 [a]	0,125**					0.078	0.128*
Renewal7 [a]		0,109**					
Renewal8 [a]			0,114**		0.102**	0.097*	
Renewal9 [a]				0,102**			
Renewal10 [a]							0.092
Industry classes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ρ	−0.90***	−0.93***	−0.91***	−0.84***	−0.87***	−0.85***	−0.74***
Log Likelihood	928.4	−927.5	−927.0	−928.9	−926.1	−926.1	−926.7

Note: ***, ** and * indicate significance at the 1%-, 5%- and 10%-level, respectively. All marginal effects are calculated around the means of the X's. Only the marginal effects on P(2), profitable innovation, are shown. P(1) and P(0) are available from the author upon request. Estimation were also undertaken with *Renewal4, Renewal5, Renewal6, Renewal7* and *Renewal8* in the left part of the table and with other combinations of *RenewalX* in the right part, but these estimations had lower log likelihood values and are not shown.
[a] Marginal effect on probabilities when dummy variable increases from 0 to 1.

Appendix A

The ordered probit model can be described as (Greene 1997):

$$y_i^* = X_i\,\alpha + \varepsilon_i \quad , \qquad (A1)$$

where **X_i** is a vector of patent quality indicators and technology dummies; **α** is a vector of coefficients that indicates the influence of the independent variables on the profit level; and **ε_i** is a residual vector that represents the combined effects of unobserved random variables and random disturbances. The residuals are assumed to have a normal distribution, and the mean and variance are normalized to 0 and 1. The vector with the latent variable, **y_i^***, is unobserved. The model is based on the cumulative normal distribution function, $F(X\alpha)$**,** and is estimated via maximum likelihood procedures. The difference between this model and the two-response probit model is that in this model a parameter (threshold value), ω, is estimated by **α**. The probabilities $P_i(y=k)$ for the three outcomes are:

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

$$P_i(1) = F(\omega - X\alpha) - F(-X\alpha) \quad , \qquad (A2)$$

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

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

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

To take account of selectivity, in the first step, a probit model estimates how different factors influence the decision to commercialize a patent (Greene 2002):

$$d_i^* = X_i\theta + u_i \quad , \qquad (A3)$$
$$d_i = 1 \;\; if \;\; d_i^* > 0 \;\; and \;\; 0 \;\; otherwise,$$

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

From the probit estimates, the selection variable d_i is then used to estimate a full information maximum likelihood model of the ordered probit model (Greene 2002). In addition, the first step probit model is re-estimated. The residuals [ε, u] are assumed to have a bivariate standard normal distribution and correlation ρ. There is selectivity if ρ is not equal to zero. Note that this specification is not a two-step Heckman model. No lambda is computed and used in the second step.

Appendix B

Table B1. Descriptive statistics of dependent and explanatory variables.

Dependent variables	Definition	All observations (n=867)		Commercialized patents (n=526)	
		Mean	Std. dev.	Mean	Std. dev
Com	Dummy that equals 1 if commercialization, and 0 otherwise	0.61	0.49	-----	-----
Success	Profitability of commercialization. 2 = profit, 1 = break-even, 0 = loss	-----	-----	1.29	0.85
Explanatory variables					
Citations 1	Number of forward citations from all sources within five years after publishing	1.21	2.99	1.45	3.46
Citations 2	Number of forward citations from EPO and PCT within five years after publishing	0.44	1.15	0.50	1.32
Equivalents	Number of patent equivalents abroad	2.00	3.79	2.64	4.32
Eq. EPO	Dummy that equals 1 if an administrative patent at EPO, and 0 otherwise	0.25	0.43	0.31	0.46
Eq. US	Dummy that equals 1 if a US patent, and 0 otherwise	0.26	0.44	0.32	0.47
Eq. Japan	Dummy that equals 1 if a Japanese patent, and 0 otherwise	0.16	0.37	0.20	0.40
Renewal	The number of years of patent renewal	10.40	4.59	11.30	4.49
RenewalX	Dummy that equals 1 if the patent is still alive after *X* years, and 0 otherwise. *X* ranges from 4 to 10.	-----	-----	-----	-----
FIRM1	Dummy taking the value of 1 for medium-sized firms (101–1000 employees), and 0 otherwise	0.13	0.34	0.15	0.35
FIRM2	Dummy taking the value of 1 for small firms (11–100 employees), and 0 otherwise	0.23	0.42	0.26	0.44
FIRM3	Dummy taking the value of 1 for micro companies (2–10 employees), and 0 otherwise	0.16	0.37	0.20	0.40
GOVFIN	Percent of R&D financed by government	7.06	18.6	4.45	13.4
PRIVFIN	Percent of R&D financed by private venture capital	3.14	14.4	3.14	11.3
OTHFIN	Percent of R&D financed by universities/ research foundations	2.73	14.4	1.88	14.4
UNIV	Dummy that equals 1 if the patent was created at a university, and 0 otherwise	0.037	0.19	0.021	0.14
KOMPL	Dummy that equals 1 if complementary patents are needed to create a product, and 0 otherwise	0.23	0.42	0.27	0.45
MOREPAT	Dummy taking the value of 1 if the inventors have more similar (competitive) patents, and 0 otherwise	0.41	0.49	0.46	0.50
OWNER	Percent of the patent that is directly or indirectly owned by the inventors	0.72	0.45	0.69	0.46
INVNMBR	Number of inventors of the patent	1.34	0.66	1.33	0.65
SEX	Share of inventors who are females	0.023	0.14	0.023	0.14
ETH	Share of inventors with an ethnic back-ground other than Western European or North American.	0.030	0.16	0.023	0.15