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What percentage of innovations are patented? empirical estimates for European firms

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Abstract

A 1993 survey on the innovative activities of Europe's largest industrial firms obtained useable results on patenting activities for 604 respondents. The data are used to calculate the sales-weighted propensity rates for 19 industries. The propensity rates equal the percentage of innovations for which a patent application is made. The propensity rates for product innovations average 35.9%, varying between 8.1% in textiles and 79.2% in pharmaceuticals. The average for process innovations is 24.8%, varying from 8.1% in textiles to 46.8% for precision instruments. Only four sectors have patent propensity rates, for both product and process innovations combined, that exceed 50%: pharmaceuticals, chemicals, machinery, and precision instruments. Regression results that control for the effect of industry sector show that patent propensity rates increase with firm size and are higher among firms that find patents to be an important method for preventing competitors from copying both product and process innovations. The effect of secrecy is not so straightforward. Firms that find secrecy to be an important protection method for product innovations are less likely to patent, as expected, but secrecy has little effect on the propensity to patent process innovations. The R&D intensity of the firm has no effect on patent propensity rates for both product and process innovations. The sector of activity has a strong influence on product patent propensities but very little effect on process patent propensities, after controlling for the effect of other factors.

Keywords: Patents; Propensity; Innovation surveys; Europe; Industry

1. Introduction

The patent propensity rate is a potentially valuable indicator for both innovative activities and appropriation conditions. Several definitions are in use, which permit different interpretations of what patenting denotes in terms of innovative activity and appropriation conditions. The first definition was introduced by Scherer (1965, 1983) who defines patent propensity as the number of patents per unit of expenditure on R&D. This definition is complex to interpret because it is influenced by the efficiency of R&D, the reasons why firms patent, and other fac-

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tors such as technological opportunities. Nevertheless, a main advantage of this measure is that it can be calculated for a large number of countries that provide public statistics on R&D expenditures and the number of patents over time. Grefermann et al. (1974) and Kabla (1996) use a relatively restrictive definition consisting of the percentage of innovative firms in a sector that have applied for at least one patent over a defined time period. This can be used to measure the occurrence of some patenting activity among small firms, but this indicator is of less value for large manufacturing firms, almost all of which have applied for at least one patent. Licht and Zoz (1996) use a similar measure defined at the firm level in a study of the factors that influence a firm to patent one or more innovations.

Several definitions of the patent propensity rate derive from the use of percentage of patentable inventions that are patented by Mansfield (1986) . The term ‘patentable’ refers to the legal requirement for an invention to meet novelty, non-obviousness, and industrial application criteria. Mansfield’s definition is of particular value for research into appropriation conditions because it measures differences in the reasons why firms choose to patent an invention, with no interference from the productivity of R&D in terms of the number of innovations produced per unit of R&D expenditure. An extension of Mansfield’s definition is the percentage of *innovations*, rather than inventions, that are patented. This overcomes one of the drawbacks of Mansfield’s definition, which is that many inventions are never commercialised and hence have little economic value. This disadvantage is magnified by the fact that a single patent, although it does not necessarily correspond to one invention, is even less likely to correspond to one innovation. This could result in large discrepancies between the percentage of patented inventions versus patented innovations. For example, research by Acs and Audretsch (1988) shows that the number of patents per innovation can vary substantially, ranging by industrial sector from an average of 49 to 0.6 patents per innovation.

Estimates of the percentage of inventions or innovations that are patented, either by themselves or linked to other aspects of patenting strategies, can provide useful information for R&D managers, economists, and policy makers. For example, the effectiveness of changes to patent legislation to make patenting easier, and thereby either entice firms to patent a higher percentage of their innovations or even to invest more in innovation, should not be taken for granted. Such changes, for example, to reduce the cost of a patent application, could increase patent propensity rates in some sectors that currently have low rates while having little effect on firms or sectors where a majority of innovations are already patented. Similarly, the European Commission’s *Green Paper on Innovation* (European Commission, 1996) proposes policies to encourage firms to make more use of patent databases as a source of technical information. Yet the value of such databases to a firm partly depends on the propensity to patent in those sectors that are a source of useful technical information for the firm’s innovative activities. The technical information available in patent databases will be comparatively sparse if few innovations (or inventions) in the relevant sectors are patented.

Another issue is whether or not patents can be used to measure changes in inventive activity over time. The data presented by Grilliches (1990) show that the number of domestic patent applications in the US between 1880 and 1989 has increased much more slowly than real GNP and investment, although there has been a sharp increase in the number of patent applications and grants in the US in the late 1980s and early 1990s (Kortum and Lerner, 1997). Any investigation of the technical or economic causes of these changes must first deal with the possibility that they are due to changes in the percentage of inventions or innovations that are patented. Evenson (1993), for instance, discounts changes in such patent propensity rates in an analysis of a decline in the number of patents per scientific and engineering employee in the US, the UK, Germany and France between 1970 and 1990. He assumes that changes in patent propensity rates will affect all sectors equally and can therefore be safely discounted. We would argue that this is not necessarily a safe assumption, since other factors that can vary by sector over time, such as appropriation conditions or the intensity of competition, could lead to different rates of change in sectoral patent propensity rates.

Kortum and Lerner (1997) explore several explanations for the rise in patenting activity in the US from the mid 1980s. These include an increase in patent propensity in response to legislative changes in 1982 that strengthened the ability of patents to prevent infringement, an increase in technological opportunities, greater productivity of R&D, and a shift to more applied research, which would lead to more patentable inventions. Their results show that an increase in patent propensity could theoretically explain the recent increase in patenting, but they argue that other factors related to technology, such as an improvement in innovation management, are more likely to explain the recent increase in patenting activity.

These studies on changes in patenting over time highlight the complexity of the factors that influence the relationship between patents and inventive activity. They also point to the need to establish baseline rates for patent propensity for future comparisons and the need to further our understanding of the major factors that influence the propensity to patent.

Good evidence has been available for some time, based on surveys of firms in the US and in Europe, that the percentage of innovations that are patented should vary by sector because of differences in the value of patents as a means of appropriating investments in innovation (Levin et al., 1987; Arundel et al., 1995; Harabi, 1995). Patents are of greatest value in a few sectors such as pharmaceuticals, chemicals, and machinery, where the cost of copying an innovation is considerably less than the initial cost of invention. In contrast, patents are relatively unimportant compared to alternative appropriation methods such as lead time advantages or technical complexity in sectors that produce complex products that are costly to copy, or where high investment costs and expertise levels create entry barriers that limit competition from new entrants, such as in aerospace. These differences in the usefulness of patents strongly suggest that there should also be large sectoral differences in patent propensity rates. Furthermore, given the importance of lead time advantages and concern over disclosure, we would expect many innovations not to be patented. This expectation is supported by the theoretical models of Horstman et al. (1985) and Harter (1993), which show that the propensity to patent should lie between 0 and 1 because of the effect on a firm's patenting strategies of the disclosure of different types of information to competitors.

We are aware of five studies, all based on surveys of firms, [1] that have reported some results for the propensity to patent inventions or innovations. The study of Mansfield (1986) gives results for 96 American manufacturing firms in the early 1980s. Approximately 84% of patentable inventions over a three-year period were patented in five sectors where patents are an important incentive for innovation. The patent propensity in six sectors where patents were relatively unimportant was 66%. Both of these estimates were weighted by the firm's sales. Taylor and Silberston (1973) report similar high patenting rates in the UK, though based on fewer firms, and the results of both studies suggest that patent propensity increases with firm size. An EPO (1994) survey of European firms with less than 1000 employees and which had applied for at least one patent reports that 50% of 1006 responding firms applied for a patent for over 50% of their patentable inventions. Unfortunately, the report does not provide more detailed results such as point estimates or results by sector or firm size. The results are also biased by excluding firms that did not apply for a patent. The largest survey so far for the United States is by Cohen et al. (1996) who give preliminary patent propensity rates for innovations, weighted by R&D expenditures, for a survey of 1065 American research laboratories in manufacturing. They report that a patent application was made for 51.5% of product innovations and for 33.0% of process innovations between 1991 and 1993.

The fifth survey, consisting of a joint survey by MERIT in the Netherlands and SESSI in France, [2] forms the basis of this study. Previous econometric analyses of the propensity to patent product innovations, using a part of this data, show that German

[1] Another method for determining patent propensity rates is to identify all major innovations, for example, by using new product announcements in trade and technical journals. One could then determine the percentage of these that were patented. There are no studies so far that have used this method, although two studies have obtained data on both product announcements and the number of patents held by each firm (Acs and Audretsch, 1988; Devinny, 1993).

[2] SESSI is the Statistical Service of the French Ministry of Industry. The survey was conducted in collaboration with the National Institute of Statistics and Economic Studies (INSEE), where the second author is based.

firms patent a higher proportion of their product innovations than firms in the UK, France, or other European countries [3] and that concern over the ease of imitation and information disclosure reduces the propensity to patent (Arundel and Kabla, forthcoming; Duguet and Kabla, forthcoming).

The purpose of the study reported here is to use the MERIT/SESSI data to provide empirical estimates of the propensity to patent both product and process innovations, by industrial sector, and to further explore the effect of firm-specific factors that influence the propensity to patent both types of innovations. The results show that patent propensity rates in Europe in the early 1990s are considerably lower than the rates estimated by Mansfield for the US in the early 1980s and slightly lower than the rates reported by Cohen et al. for a comparable time period as the MERIT/SESSI study. Furthermore, a few firm-specific factors, other than the sector of activity, influence the patent propensity rate. These factors include firm size, which is positively related to the propensity to patent both product and process innovations, the importance of patents and secrecy to prevent copying by competitors, and sales in markets outside of Europe.

2. Methodology

In 1993, MERIT in the Netherlands and SESSI in France, in collaboration with INSEE, conducted parallel surveys on the innovative activities of European firms. The MERIT survey, called PACE, was mailed to 1270 research directors from the European Union's 500 largest R&D performing industrial firms, excluding firms based in France. Separate PACE questionnaires were mailed to an average of 2.4 R&D managers within each firm, with the number sent to each firm depending on its size and number of lines of business. In France, questionnaires were sent to 2622 manufacturing firms with more than 50 employees. Contrary to PACE, the French survey was only sent to the main R&D director of each legally established firm. This meant that only firms that had established their divisions as legally defined separate units were sampled more than once. A common database was constructed based upon the PACE data and a comparable sample from the SESSI results, limited to 200 firms in the same size range as the firms surveyed in PACE. All firms performed R&D. The response rates were 55.6% for the PACE survey and approximately 70% for the SESSI survey. Non-response analysis of the PACE results showed no notable biases by industrial sector, firm size, R&D intensity, or the position within the firm of the respondent.

The PACE and SESSI results were carefully checked to prevent double-counting by deleting cases that gave results for an entire multi-divisional firm when results are also available at the division or line-of-business level. Some of the business units are substantially smaller than their parent firm. However, the small units are always linked through ownership to their larger parent and consequently the business environment faced by these units should differ substantially from that of independent small firms. For simplicity, the discussion below refers to each of these business units as a 'firm'. In total, data are available for a maximum of 787 firms active in 101 lines of business defined at the four-digit ISIC (third revision) level, though there are only one or two respondents for 46 of these business lines. The number of useable firms also varies due to item non-response, with a maximum of 604 firms available for sales-weighted estimates of patent propensity rates.

Although MERIT and SESSI collaborated closely on the development of the two questionnaires, there are several differences in the types of data collected and in the format of some of the questions because of differing objectives for each survey. [4] Due to confidentiality constraints, there is no data on R&D expenditures for the French firms and the French firms can only be classified to the two-digit ISIC level, with the exception of pharmaceutical firms.

[3] No satisfactory explanation for this result could be found. It was not due to differences in the industrial distribution, the size of German firms, or to the policy of German firms to give financial rewards to inventors. Two possible though untested explanations are a pro-patent business culture or a greater R&D efficiency among German firms.

[4] A full description of the PACE methodology is available in the work of Arundel et al. (1995). Copies of the PACE and French questionnaires are available on request from A. Arundel.

Consequently, most results by sector are given at this level of disaggregation. A few two-digit sectors, such as textiles and clothing, are combined to increase the number of respondents per sector to a minimum of five firms.

2.1. Estimating patent propensity

The definition of an innovation is crucial to the calculation of patent propensity rates. Recent innovation surveys, such as the European Community Innovation Survey, define an innovation to include both new products and processes that are developed through the in-house innovative activities of a firm and new products and processes that are obtained from sources external to the firm. [5] This definition of an innovation creates problems for estimates of patent propensity rates because the same innovation could be counted more than once. In contrast, the PACE and SESSI definitions focus on new products and processes that are developed, at least in part, through the firm's own R&D efforts and which are patented by the firm itself.

The PACE questionnaire defines an innovation as the commercial introduction of a 'new or technically changed product' or the implementation of 'improved production methods for existing products... or for making new products'. The questionnaire also makes it clear that these innovations are developed by the innovative activities of the firm itself. The focus on in-house innovation is explicit in several questions on patents and implicit throughout the questionnaire. Explicit questions ask about the patenting strategies of 'your unit's product and process innovations' or about 'a significant product or process innovation developed by your unit'. The implicit focus on in-house innovation begins with the second question, which asks the respondent (usually the R&D manager) to give 'several examples of products or processes that are an important focus of innovation in your unit'.

The SESSI questionnaire is slightly different. The first question asks if the firm has developed or introduced a technologically innovative product or process. The use of the term 'introduced' can refer to innovations developed outside of the firm. However, the focus on in-house innovation is apparent through the placement of the questions on patents, which immediately follows the first question, and the frequent reference to 'your new products' and 'your new processes'. The respondent is also asked if their firm has applied for a patent in each of four locations. Given the form of the patent questions, it is unlikely that the SESSI respondents interpret them to refer to innovations obtained from other firms.

The exact wording of the PACE/SESSI question on patent propensity is "In the last three years, a patent application was made for approximately what percentage of your unit's product and process innovations?" [6] The respondent is given five response options: 0–19%, 20–39%, 40–59%, 60–79%, and 80–100%. The question does not limit the field to 'patentable' innovations in order to give a better estimate of the use of patents to protect the full range of each firm's innovations, some of which may not be patentable but still of expected economic value, as shown by their commercialisation. The mid-point of each category is used to calculate patent propensity. Each firm was also asked to give the total number of technically unique patents that it had applied for over the same time period. Firms with no patent applications (14.5% of the total) are assumed to have patented zero percent of their innovations over this three-year period.

The estimated patent propensities are likely to overestimate the true proportion of innovations that are protected by patents because the measure of patent propensity that can be determined from these results is actually the patent *application* propensity rate, although for brevity this is referred to below simply as the patent propensity rate. Since not all patent applications are granted, the results overestimate the true patent propensity rate. For example, in 1992, 32% of patent applications to the EPO and 37% of US patent applications were not granted for various reasons (TSR, 1993). The patent grant rate also varies within European countries, which could influence the incentives to apply for a patent among firms in the PACE/SESSI sample. However, differ-

[5] For an overview of the methodology and results of the CIS and similar surveys, see the articles in Arundel and Garrelfs (1997).

[6] Of course, a firm could apply for more than one patent for an innovation.

ences in national patent systems should not markedly influence the results because of the size and international orientation of the firms in the sample. Almost all (93%) of the patent-applicant firms had applied for one or more patents outside their own home country, either via the EPO system or in the US or Japan.

The PACE/SESSI estimates of patent propensity rates are limited to the patenting and innovative activities of Europe's largest firms. These firms are responsible for the majority of both R&D and patent applications within Europe. For example, the firms included in the survey target population accounted for a minimum of 77% of all business expenditures on R&D in the UK. Given the importance of these firms to European innovation, patent propensity estimates based on this restricted sample are still of value. However, the degree to which these estimates could either over- or underestimate the patent propensity rates when firms of all sizes are included depends on whether or not patenting activity and the patent propensity rate varies by firm size and in which direction, a question which we partly address below.

The average patent propensity rates by sector are weighted by an indirect measure of the total number of innovations developed by each firm. The best estimate of this number is probably each firm's R&D expenditures, under the assumption that the number of innovations is linearly correlated with the amount of effort expended on R&D, but this cannot be done for the whole sample because of the lack of R&D expenditure data for France. Instead, the annual sales turnover is used. The reliability of sales as an estimate of innovative effort was tested by correlating estimated sales-weighted and R&D expenditure-weighted patent propensities for 21 sectors with five or more firms, using an identical set of 396 PACE firms with full data for all necessary variables. The two sets of estimates are strongly correlated, with R^2 values of 0.92 for product innovations and 0.82 for process innovations. [7] However, weighting the results by R&D expenditures produces a higher patent propensity rate than weightings based on a firm's sales.

3. Descriptive results

Table 1 provides estimated patent propensity rates for sectors with a minimum of five respondent firms. [8] For all firms, the average sales-weighted patent propensity is 35.9% for product innovations and 24.8% for process innovations. The unweighted patent propensity rates for the identical set of firms are similar, at 33.0% for product and 20.1% for process innovations. The sales-weighted patent propensity for product innovations is highest in sectors such as pharmaceuticals (79.2%), chemicals (57.3%) and machinery (52.4%) where patents have been identified in other studies as an important method of appropriation and lowest in low-technology sectors. These include textiles and clothing with a patent propensity rate for product innovations of 8.1% and basic metals with a rate of 14.6%.

These sales-weighted patent propensity rates for Europe are less than the R&D-weighted propensity rates reported by Cohen et al. (1996) for the United States, using an almost identical question, of 51.6% for product innovations and 33% for process innovations. Part of the difference is due to the different method of weighting the estimates. R&D-weighted estimates for European firms, limited to PACE firms, give patent propensity rates of 43.6% for product innovations and 25.9% for process innovations. These are closer to the reported propensity rates for the US than the sales-weighted estimates, particularly for product innovations. Other factors could also partly explain the difference between the American and European estimates. These include differences in the sectoral distribution of American and European firms and the fact that the American study sampled R&D laboratories while the European study sampled firms.

Table 1 shows that a considerably lower percentage of process compared to product innovations are patented in most sectors. The propensity rate is approximately equal to or higher for process than for

[7] The high R^2 values are partly explained by controlling for large differences in R&D intensities between sectors (for example, between basic metal and pharmaceutical firms) by comparing R&D weighted results with sales-weighted results within the same sector.

[8] Three sectors do not contain any firms from France: power utilities, food and tobacco, and transport and telecom services.

Table 1
Patent propensity rates by sector for European firms between 1990 and 1992

Sector	ISIC code	Sales-weighted patent Propensity Rates (%)			Sales and product/process-weighted Propensity Rates (%)		
		N	Product Innovations	Process Innovations	*N*	% Time on products	All innovation Propensity
Mining	10–14	11	27.7	32.5	10	47.9	30.9
Food, beverages and tobacco	15, 16	42	26.1	24.7	41	54.6	25.3
Textiles, clothing	17, 18	9	8.1	8.1	– [a]	–	–
Petroleum refining	23	17	22.6	29.0	15	62.4	25.1
Chemicals	24	88	57.3	39.0	65	62.9	57.1
Pharmaceuticals	2423	32	79.2	45.6	13	74.0	74.0
Rubber and plastic products	25	20	33.7	27.6	8	68.9	33.5
Glass, clay, ceramics	26	35	29.3	20.2	20	51.5	31.4
Basic metals (iron and steel)	27	13	14.6	15.1	13	46.8	14.9
Fabricated metal products	28	42	38.8	39.4	10	54.9	29.2
Machinery	29	69	52.4	16.3	44	71.5	53.9
Office and computing equip.	30	8	56.8	20.9	–	54.3	–
Electrical equipment	31	26	43.6	21.5	14	61.1	43.0
Communication equipment	32	37	46.6	22.7	22	76.4	36.5
Precision instruments	33	24	56.4	46.8	14	71.0	52.6
Automobiles	34	46	30.0	17.0	31	77.5	25.2
Other transport equipment	35	30	31.2	10.9	20	72.6	17.0
Power utilities	40	14	29.5	26.5	13	33.5	26.7
Transport and telecom services	60, 64	23	20.5	12.4	21	64.5	17.7
Other manufacturing sectors		19	–	–	9	–	–
All firms		604	35.9	24.8	400	62.9	32.3

[a] Results not given when there are fewer than five firms per sector or for 'other manufacturing', which includes less than five firms each in footwear, wood products, paper products, publishing, and furniture/nec.

product innovations in only five sectors: the mining industries, textiles and clothing, basic metals, petroleum refining, and fabricated metal products. These results are expected because secrecy should be an effective method of protecting process innovations that are not sold to other firms, while patenting a process innovation would disclose information that could be used by competitors in their own manufacturing processes. Firms should avoid patenting process innovations because of the difficulty in detecting infringement.

The second part of Table 1 gives the estimated patent propensity for both product and process innovations combined. These estimates are limited to the PACE firms, where data are available on the percentage of time spent by R&D personnel on five activities, including 'developing new or improved processes' and 'developing new or improved products'. The respondent could fill in any percentage as long as the sum for all five activities equalled 100%. The proportion of time spent on product or process innovation is assumed to be correlated with the number of product and process innovations. For example, we assume that product innovations will account for two-thirds of a firm's total innovations if its R&D staff spend two-thirds of their time on product innovation. Using this assumption, an average patent propensity rate is calculated for each firm, using the proportion of time spent on product and process activities. This average rate is then weighted by the firm's sales.

Column 7 of Table 1 gives the average time spent by firms in each sector on product innovation out of the total for product and process innovation combined. One surprising result is the strong emphasis on product innovation, even in process-based sectors such as petroleum refining and food and tobacco. Only three sectors spend more time on process than product innovation: mining, basic metals, and power utilities. The product/process- and sales-weighted

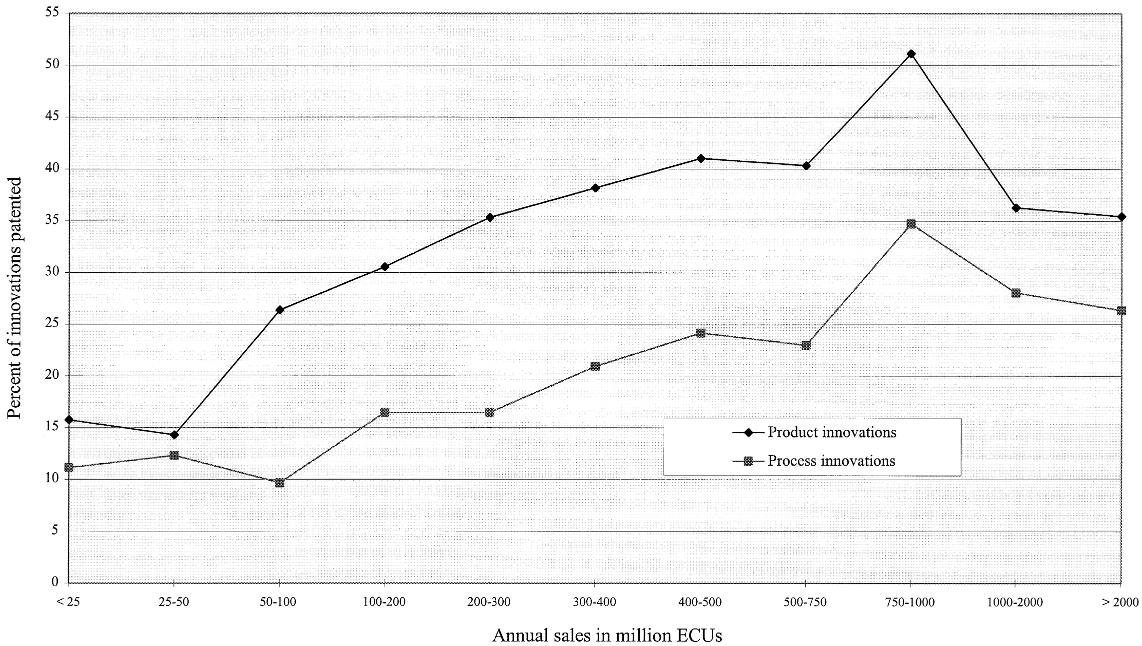

Fig. 1. Patent propensity by size class (604 firms).

patent propensity rates for the PACE respondents are given in column 8 for 17 sectors. Only four sectors apply for a patent for more than 50% of all of their innovations: pharmaceuticals (74.0%), chemicals (57.1%), machinery (53.9%), and precision instruments (52.6%).

The patent propensity for all firms increases with the firm's annual sales, as shown in Fig. 1, up to a maximum for firms with sales between 750 and 1000 million ECUs, and then declines. This decline is partly due to sectoral effects. For example, petroleum, basic metal, and other bulk product firms can have very high sales but all three are sectors with low patent propensity rates. This reduces the patent propensity rate in the largest sales classes. An analysis limited to 95 firms in four high-technology sectors combined (ISIC 30–33 inclusive) shows a monotonic increase in patent propensity rates by sales class.

4. Econometric analyses

In addition to the observed differences by firm size and sector, the propensity to patent should vary by several other factors for which data are available for the PACE/SESSI respondents. A primary influence is the importance given by each firm to patents and secrecy as a method for preventing competitors from copying their innovations. We would expect patent propensity rates to be higher among firms that find patents to be a very effective means of preventing copying and to be lower among firms that find secrecy to be effective for this purpose. [9] Another possible factor is the intensity of competition, which could increase the value of patents. Although there is no direct measure of the intensity of competition in the PACE/SESSI data, whether or not the firm sells

[9] Earlier research using the PACE/SESSI data shows that the most important reason why firms apply for a patent is to prevent copying and that this reason has the most important impact on the propensity to patent (Arundel and Kabla, forthcoming). Other reasons to patent, such as 'to use the patent in negotiations' or 'to access foreign markets' also had a positive effect on the patent propensity rate, but most of these secondary reasons were no longer significant in analyses that included dummy variables for industry, with the exception of 'to access foreign markets'. The analyses reported in this study use sales in foreign markets as an alternative.

products in either Japan or the United States is used as a proxy for exposure to greater competition. We assume that European firms that market products in these two countries are exposed to more intense competition than firms that only sell products within Europe or other regions. The PACE data also permit measuring exposure to foreign competition by using the percentage of sales due to exports. However, exports were never significant in any of the analyses and for this reason a variable for exports is not included in the results given below. The lack of significance could be due to the fact that it is not possible to separate exports to other European countries from exports to the United States, Japan, or other parts of the world.

Two other possible influences on the patent propensity rate can only be examined using the PACE dataset: the importance of earning license revenue and the firm's R&D intensity. Firms that find earning license revenue to be an important goal for their innovative activities could be more likely to patent in order to facilitate licensing. R&D intensity could be positively correlated to the patent propensity rate for several reasons. First, the percentage of innovations that meet the basic novelty requirements for a patent could increase with the firm's R&D intensity. Second, R&D intensive firms could develop a higher proportion of breakthrough innovations that are rewarded with broader patent width, which in turn increases the incentive to patent. Third,

Table 2
Ordered logit results for the propensity to patent product innovations

Variable	PACE–SESSI date combined				PACE data only	
	1		2		3	
	β	SE	β	SE	β	SE
Constant	**−2.572**	0.532	**−1.945**	0.646	**−1.481**	0.791
Germany	**0.641**	0.168	**0.585**	0.179	**0.590**	0.208
LSALES	**0.493**	0.096	**0.695**	0.108	**0.613**	0.131
PATENTS	**1.563**	0.176	**1.367**	0.188	**1.501**	0.237
SECRECY	**−0.326**	0.152	**−0.338**	0.160	−0.269	0.198
FORMARKT	**1.058**	0.204	**0.861**	0.217	**0.800**	0.235
LICENSE					*0.585*	0.352
RDINTENS					0.086	0.336
Transport and telecom services			**−2.743**	0.483	**−2.633**	0.552
Petroleum refining			**−2.644**	0.665	**−2.722**	0.721
Basic metals			**−2.165**	0.750	**−2.154**	0.773
Power utilities			**−2.088**	0.573	**−2.122**	0.616
Other transport			**−1.839**	0.482	**−2.209**	0.638
Electrical equipment			**−1.598**	0.603	*−1.331*	0.772
Fabricated metal products			**−1.584**	0.421	**−1.762**	0.730
Food, beverages, tobacco			**−1.570**	0.450	**−1.641**	0.511
Mining			**−1.542**	0.601	**−1.907**	0.719
Miscellaneous			**−1.389**	0.451	**−1.255**	0.614
Rubber and plastic products			**−1.338**	0.534	*−1.164*	0.669
Glass, clay, ceramics			**−1.320**	0.426	*−0.985*	0.544
Automobiles			**−1.188**	0.400	**−1.609**	0.504
Chemicals			**−1.094**	0.352	**−0.943**	0.445
Office and computer equip			−0.828	0.529	−0.547	0.612
Precision instruments			−0.640	0.581	−0.898	0.688
Machinery			−0.457	0.364	−0.292	0.477
Communication equipment			−0.388	0.411	−0.339	0.504
Model Chi-square	183.2	$p < 0.0000$	245.1	$p < 0.0001$	193.6	$p < 0.000$
N	567		567		379	

The reference sector is pharmaceuticals. The order of the sectors is based on model 2. Coefficients in **bold** when $p < 0.05$, in *italics* when $p < 0.10$. The estimated threshold values (μ) (not shown in the table) are statistically significant ($p < 0.0000$) in all models and increase monotonically. There is no equivalent of a pseudo R^2 for an ordered logit (or probit) model.

Table 3
Marginal effects (in %) for the propensity to patent more than 20% of product and process innovations (for model 1 of Tables 2 and 4)

	Product innovations	Process innovations
Germany	15.0	9.2
LSIZE	12.3	10.4
PATENTS	38.9	28.9
SECRECY	−8.1	7.3
FORMARKT	26.4	7.1

The marginal effects are computed using the zero value as the reference for the dummy variables and the sample mean as the reference for LSIZE.

a higher development cost for innovations in R&D intensive firms could be linked to the use of patents as an appropriation mechanism.

All regressions include a dummy control variable for location in Germany because of the earlier finding that German firms consistently patent a higher percentage of their innovations than firms in other European countries (Arundel and Kabla, forthcoming). The dummy variables for the importance of patents (PATENTS) and secrecy (SECRECY) to prevent copying and the importance of earning license revenue as a goal of innovation (LICENSE) are

Table 4
Ordered logit results for the propensity to patent process innovations

Variable	PACE-SESSI data combined				PACE data only	
	1		2		3	
	β	SE	β	SE	β	SE
Constant	**−2.925**	0.559	**−2.710**	0.671	**−2.697**	0.814
Germany	**0.471**	0.176	**0.537**	0.185	**0.442**	0.212
LSALES	**0.535**	0.101	**0.627**	0.108	**0.634**	0.134
PATENTS	**1.485**	0.179	**1.454**	0.186	**1.204**	0.225
SECRECY	**0.377**	0.166	*0.325*	0.171	0.299	0.215
FORMARKT	*0.363*	0.207	0.203	0.232	0.307	0.252
LICENSE					*0.703*	0.411
RDINTENS					0.189	0.118
Transport and telecom services			**−1.942**	0.515	**−1.606**	0.602
Automobiles			**−1.140**	0.438	−0.815	0.518
Office and computer equipment			−0.909	0.565	*−0.204*	0.663
Miscellaneous			*−0.856*	0.505	−0.549	0.658
Other transport			*−0.824*	0.467	−0.530	0.600
Basic metals			−0.626	0.826	−0.424	0.677
Machinery			−0.595	0.383	−0.189	0.484
Electrical equipment			−0.583	0.518	−0.095	0.695
Mining			−0.522	0.644	−0.732	0.757
Petroleum refining			−0.514	0.506	−0.430	0.632
Food, beverages, tobacco			−0.458	0.448	−0.295	0.498
Precision instruments			−0.368	0.550	−0.535	0.657
Rubber and plastic products			−0.320	0.572	0.288	0.734
Power utilities			−0.290	0.546	−0.113	0.653
Glass, clay, ceramics			−0.244	0.454	0.065	0.582
Communication equipment			−0.222	0.427	−0.596	0.565
Fabricated metal products			−0.195	0.399	−0.049	0.746
Chemicals			−0.185	0.362	0.239	0.449
Model Chi-square	151.4	$p < 0.0001$	176.1	$p < 0.0001$	114.6	$p < 0.0001$
N	567		567		377	

The reference sector is pharmaceuticals. The order of the sectors is based on model 2. Coefficients in **bold** when $p < 0.05$, in *italics* when $p < 0.10$. The estimated threshold values (μ) (not shown in the table) are statistically significant ($p < 0.0000$) in all models and increase monotonically. There is no equivalent of a pseudo R^2 for an ordered logit (or probit) model.

based on separate questions for product and process innovations. For example, the variable PATENTS in the analyses of the patent propensity rate for product innovations is equal to 1 when the firm reports that *product* patents are a 'very' or 'extremely' important method of protecting innovations from copying (and zero otherwise), while the variable refers to *process* patents in the analyses of the propensity rate for process innovations.

The PACE/SESSI data for patent propensity are based on six ordinal categories: zero percent of innovations patented plus five percentage classes of 20%. In this context, the propensity to patent is a latent variable because its exact value is unknown. The appropriate econometric model is to use an ordered logit (or probit) model. It is also possible to use an ordered probit with known thresholds, since the boundaries between each category are known. Both econometric techniques were used: an ordered probit with known thresholds for five classes (the zero category was combined with the 0–20% class), and an ordered logit without thresholds using the zero category plus five classes. The two methods give essentially identical results, with only a few differences in the significance or nonsignificance of some of the dummy variables for industrial sector. For simplicity, only the results of the simple ordered logit are given here. The model is described in Appendix A.

5. Results

5.1. Product innovations

Table 2 gives ordered logit model results for the propensity to patent product innovations. The first two models include data for France and therefore do not include R&D intensity (RDINTENS) or the importance of earning revenue from licensing product innovations (LICENSE), since these two variables are not available for French firms.

Location in Germany, as expected, is significant in all regressions, with the coefficient varying very little. Firm size, measured by the log of sales at the business unit level, where applicable (LSALES), is positive and significant in all regressions. Table 3 gives the marginal effects, calculated at the means, for model 1. The marginal effect for a one-unit change in the log of firm sales in model 1 (with mean sales of 315 million ECUs) is a 12.3% increase in the probability that the firm patents over 20% of its product innovations.

Firms that find patents to be a 'very' or 'extremely' effective method to deter or prevent competitors from copying product innovations (PATENTS) are significantly more likely to patent more of their product innovations than firms that do not find patents as effective for this purpose. As expected, firms that find secrecy an effective means to prevent the copying of product innovations are *less* likely to patent more of their product innovations, although the coefficient is not significant in the analysis limited to the PACE data only. A comparison of the marginal effects for model 1 shows that the importance of patents has a considerably larger impact than secrecy. Firms that find product patents of importance are 38.9% *more* likely to patent more than 20% of their innovations, while firms that find secrecy of importance are only 8.1% *less* likely to patent over 20% of their innovations. [10]

Firms that sell products in either the US or Japan (FORMARKT) are significantly more likely to patent a higher percentage of their product innovations than firms that do not sell products in either of these two markets. The goal of earning license revenue from product innovations is only significant at the 10% level, as shown in regression 3, while the R&D intensity of the firm has no effect on the propensity to patent product innovations.

[10] The accuracy of these results depends on the accuracy with which the separate effect of patents and secrecy can be measured. This accuracy can be weakened in two ways. The first is related to the questionnaire design, in which the question for secrecy closely follows the question on patents. We would expect the score for patents and secrecy to be strongly negatively correlated. However, analyses of groups of subjective questions shows that the responses are not completely independent. For example, a respondent who gives a score of '5' out of a five-point scale is more likely to give a score of '4' to questions that follow closely after than a score of '1'. In the PACE and SESSI questionnaires, the question on patents is in first place while the question on secrecy is in third place. Second, the respondents could mentally evaluate the effectiveness of patents in comparison to the effectiveness of secrecy (or other protection methods). Since the questions are subjective, rather than based on quantitative measures, there is no absolute benchmark for measurement.

All of the coefficients for each industrial sector in models 2 and 3 are negative because the reference sector is pharmaceuticals, which has the highest patent propensity rate. [11] As shown, there are significant differences in patent propensity rates between many sectors compared to pharmaceuticals.

5.2. Process innovations

The results for the propensity to patent process innovations are given in Table 4. The marginal effects for model 1 are also given in column 3 of Table 3. There are several notable changes in the results for process innovations compared to product innovations. First, the variable SECRECY is no longer negative in any of the regressions. Instead, it is positive and statistically significant in model 1 and positive and of borderline significance in model 2, when we would expect the propensity to patent process innovations to strongly decline with the importance of secrecy to prevent copying. One explanation of this unexpected result is that secrecy and patents are not alternatives for the protection of process inventions, but complementary, in the sense that there could be a qualitative difference in the type of process innovations that are protected by secrecy versus patents. Second, the significance of sales in foreign markets is considerably lower for process compared to product innovations. It is only of borderline significance in model 1, where $p = 0.08$. This suggests that process patents are not very important to the ability to compete abroad on the basis of price, possibly because process innovations can be more readily protected through other means.

Finally, there are far fewer statistically significant differences by sector for process innovations than for product innovations. This suggests that most of the sectoral differences in patent propensity rates, once controlling for other factors, are limited to product innovations. Differences in propensity rates for process innovations can be explained by a few firm-specific factors such as firm size and the importance of process patents to prevent copying.

[11] The sector results do not include textiles and clothing, as in Table 1, because there is not enough variation in the dependent variable for the analyses based on the PACE data only.

6. Conclusions

The estimated patent propensity rates for European firms in the early 1990s are slightly lower than roughly comparable rates for the United States. However, both the recent European and American data provide patent propensity rates that are considerably lower than the rates determined by Mansfield. We do not know if this is due to a real change in the propensity to patent or to differences in how Mansfield selected firms to interview.

The lower patent propensity rates in Europe compared to the US in the early 1990s could be due to a range of reasons. One possibility is the lower costs of applying for a patent in the US compared to Europe, both in terms of the actual application fees and in terms of the relative market size per unit application cost. The cost of a US patent in the early 1990s, including the fees of a patent attorney, was approximately 3000 ECUs, or one-third of the cost of an EPO patent valid in France, the UK, and Germany (Patent World, 1995). This cost difference could lead American firms to patent a higher percentage of innovations where the patent only provides a marginal benefit. Another possible cause is the effect of the changes to the US patent system in 1982 that strengthened the ability of firms to protect their patents from infringement (Lerner, 1995), which could have increased the value of patents.

An important conclusion that can be drawn from these results concerns the common use of patents to measure innovativeness or to compare the innovative output of sectors or countries (European Commission, 1994). Both the wide range in patent propensity rates, varying from a low of 17.7% in transport and telecom services to a high of 74% in pharmaceuticals for the sales and product/process weighted estimates, and the low rate in many sectors, indicates that great caution must be taken when using patents as a measure of innovative output, particularly when these rates are adjusted downwards by another 30% to account for the percentage of patent applications that are rejected or withdrawn.

Patents are a particularly poor measure of innovativeness in sectors such as food and tobacco, petroleum refining, basic metals, automobiles, and other transport equipment. In these sectors, the large majority of innovations are not patented. Patents could still be used to compare the innovativeness of firms within specific sectors *if* the most economically valuable patents were still patented. However, we do not know if this is true or not. There are also problems of a different type with the use of patents as a measure of innovativeness in the chemical and pharmaceutical sectors, where the majority of innovations are patented. It is common for firms in these sectors to apply for a large number of multiple patents in order to build a protective wall around a single new chemical of commercial significance (Cook et al., 1991). This means that we must assume that such multiple patenting is randomly distributed in order to be able to use simple patent counts as a measure of innovative activity. A more accurate picture of innovativeness, used by Sharp and Patel (1997) for the pharmaceutical sector, can be obtained by using several indicators in addition to patent counts, such as the number of chemicals under development, R&D expenditures, and the number of the 50 top-selling products owned by each firm.

The regression results show that the patent propensity rate for both product and process innovations increase with firm size. This indicates that the PACE/SESSI patent propensity rates, based on Europe's largest firms (although many of the divisions are much smaller), will overestimate patent propensity rates for the entire population of firms, although very small firms, none of which are included in this survey, could have higher patent propensity rates. Neither the degree to which the PACE/SESSI results overestimate patent propensities, or underestimate them if there is significant patenting activity by very small firms, is likely to be substantial however, since the PACE/SESSI survey encompasses the majority of both sales and R&D expenditures by innovative European firms.

The regression results also provide some evidence to show that large R&D intensive firms do not patent a higher percentage of their innovations than large firms with low R&D intensities. This indicates that there is little difference in the value of patents to firms of different R&D intensities. One explanation is that the patenting strategies of large firms, other things being equal, are similar. This could be because they share similar R&D cultures and access to in-house patent departments. Other analyses of the PACE data, for example, show that a large R&D unit in the food sector behaves similarly to a large R&D unit in the electronics industry, even though these two sectors have very different R&D intensities (Arundel et al., 1995). The implication is that there is no need for policies to strengthen patenting as part of a general framework to assist the innovative capabilities of large R&D intensive firms. Of course, conditions could differ considerably among small independent firms.

The regression results for process innovations suggest that sectoral effects are less important than firm-level characteristics, such as firm size. In contrast with the results for product innovations, there are very few significant differences by sector, while firm size is consistently positive and significant for the propensity to patent both product and process innovations. The latter is not an intuitively obvious result. Large firms, as suggested by Cohen and Klepper (1996), should invest more effort in process innovation than small firms because they are able to spread the development costs over an increasingly large output. Yet, large firms should also be more likely to only use their process innovations in their own production lines, whereas smaller firms may need to sell or license their process innovations in order to recoup their development costs. One would therefore expect large firms to be less likely than small firms to patent process innovations because of concern over the disclosure of information to competitors. The fact that this does not happen suggests that other factors are influencing the decision of large firms to patent process innovations. One possibility is that large firms are more likely than small firms to patent routinely, rather than carefully evaluating the need to patent each innovation, as suggested in a study of patenting among Dutch firms (Arundel et al., 1997). This effect was linked to the presence of in-house patent expertise which reduced the cost of applying for a patent. A similar result was reported by Scherer (1965) who found that the number of patents held by a firm was more highly correlated with an estimate of the number of in-house attorneys than with the number of R&D employees. Another possible explanation is that large firms are better able than small firms to enforce their patents, even when their potential area of use, the production line of competitors, should largely be hidden from scrutiny.

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Appendix A

The ordered logit model can be used to examine the impact of a range of exogeneous variables on a dependent variable which takes a finite set of ordered values, without a loss of generality $(1,2 \ldots n)$. The model assumes that the dependent variable y is generated by a continuous latent variable $y*$ whose values are unobserved (Greene, 1993, Liao, 1994). The model assumes that there are a set of ordered values $(r1, r2, \ldots, rn-1)$ and a variable $y*$ such that:

$$\begin{aligned} &y = 1 \text{ if } y* < r1 \\ &y = k \text{ if } rk - 1 < y* < rk \text{ for } 1 < k < n \\ &y = n \text{ if } rn - 1 < y*. \end{aligned} \tag{1}$$

The unobserved variable $y*$ is modelled as a linear function of the (N,k) vector of exogeneous variables X:

$$y_i* = \beta X_i + \varepsilon_i \quad i = 1, \ldots, N, \tag{2}$$

where ε_i has a distribution function f derived from the logistic cumulative distribution function:

$$F(x) = 1/(1 + e^{-x}). \tag{3}$$

Given the characteristics X_i of individual i, the probability that y_i is found in category k is:

$$\begin{aligned} &\text{Prob}(Y_i = 1/Xi) = F(r1 - \beta X_i) \\ &\text{Prob}(Y_i = k/Xi) = F(rk - \beta X_i) \\ &\qquad\qquad\qquad\qquad - F((rk-1) - \beta X_i) \\ &\text{Prob}(Y_i = n/Xi) = 1 - F((rn-1) - \beta X_i) \end{aligned} \tag{4}$$

The method of estimation is maximum likelihood.

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