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Patenting and Industrial Performance: The Case of the Machine Tool Industry

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ABSTRACT

Patenting and Industrial Performance: The Case of the Machine Tool Industry

by Manfred Fleischer

Using the case of an important capital goods industry the paper examines the impact of the national patent system on the performance of firms. Many theories attempt to explain the firms' innovative behavior using the concepts of national and sectorial systems of innovation. The patent law plays a particularly important role in these systems. At the level of the firm its importance rests on the possibility to appropriate profits. An empirical analysis of a sample of the 49 largest international manufacturers of machine tools shows that patents are a superior mechanism for appropriating the returns on R&D in this industry. This is indicated by a strong positive relationship between the market value of the firm and its patenting activities.

ZUSAMMENFASSUNG

Patentierverhalten und industrielle Leistungsfähigkeit: Das Beispiel der Werkzeugmaschinenindustrie

Am Beispiel einer wichtigen Investitionsgüterindustrie wird in diesem Beitrag der Einfluß nationaler Patentsysteme auf den Unternehmenserfolg untersucht. Zahlreiche Theorien gehen davon aus, daß das Innovationsverhalten von Unternehmen von nationalen und sektoralen Innovationssystemen beeinflußt wird. Das Patentrecht spielt in diesen Systemen eine wichtige Rolle. Auf der Unternehmensebene beeinflußt es die Möglichkeiten der Unternehmen Gewinne zu erzielen. Am Beispiel der 49 größten Unternehmen der internationalen Werkzeugmaschinenindustrie wird nachgewiesen, daß in diesem Industriezweig Patente ein wichtiges Instrument zur Erzielung von Gewinnen darstellen. Dies zeigt sich besonders deutlich an der engen positiven Beziehung, die zwischen dem Marktwert der Unternehmen und ihrem Patentierverhalten empirisch festgestellt wurde.

Patenting and Industrial Performance: The Case of the Machine Tool Industry[1]

by Manfred Fleischer

1 Introduction

The impact of product innovation and patenting on the performance of firms is a key problem in capital goods industries. With a few exceptions,[2] neither the industrial organization literature nor the literature on strategic management provide sufficient empirical knowledge regarding the economics of patenting in capital goods industries. Filling this gap would go far beyond this paper. However, some insights will be provided based on a case study of the machine tool industry. Further, the study explores the patent behavior by stressing its relationship to efficiency and performance. It focuses on the evolution of technological competition, concentrating on the special case of patenting in the international machine tool industry. This implies in particular a study of German, Japanese, and U.S. medium-sized manufacturers of capital goods.

The most remarkable features of any capital goods market include their tremendous heterogeneity, their relatively low economies of scale, and their moderate absolute cost advantages. Capital goods markets exhibit a high degree of product innovation and variety, as is the case in the consumer goods markets. Product innovation for capital goods is different, however, than with consumer goods. The type of product innovation in capital goods markets has more to do with the customization of physical product characteristics. This implies that firms have to obtain, and then maintain, access to the relevant basic technologies in order to constantly make improvement innovations. In global competition patenting becomes more and more important for improving the competitiveness of capital goods producers.

The empirical approach of this study is guided by a dynamic resource-based view of the competitive behavior of the firm as developed by Wernerfeldt (1984) and Albach's (1996) growth theory of the firm. These two approaches assume the following: A dynamic process exists by which firms and industries evolve over time and are shaped by three fundamental factors—technology, scale economies, and demand. Furthermore, the difference in knowledge conditions and technology underlying each specific industry is responsible for the pattern characteristic to that industry. The nature of innovative activity thus accounts for variations in industry evolution across markets. Product and process innovations by firms thus shift the competition-efficiency frontier forward. At the level of the firm, the resource-based theory argues that fit among unique firm-specific rent-yielding resources, strategy, and environment drives performance results. In a recent paper Johansson and Yip (1992) provide a structural equation model of global strategy, structure, and performance, which is tested using survey

[1] I would like to thank Thomas Brandt and Anna Magdalena Paradowska-Thimm for their valuable research assistance.

[2] See e.g. Ernst (1995) and Schmoch (1996).

data on a small number of American and Japanese multinational firms. However, Johansson and Yip do not address the role of firm-specific resources (like patents) directly.

In this study, it is argued that in the case of the international capital goods industry competitive strategies of the firms, and to a lesser extent institutional factors (via the provision of incentives for R&D), have led to an advantage in global competition. In particular, inventive behavior and the patenting of products and processes in the large US-market has supported this advantage. Furthermore, the study found that the exploitation of a second-mover advantage was considerable in the case of the development of NC machine tools. Based on the available patent data, however, no clear pattern regarding frequency can be drawn except for one example: the strong leader effect.

The study begins in section 2 by reviewing important strategy research regarding the capital goods industry and multidimensional indicators for the measurement of the economic performance of firms are presented. Finally a two-equation system for modelling the impact of patenting on performance is developed. In section 3 the sample of firms is introduced and the data sources are briefly described. The empirical results of the study are discussed in section 4.

2 Analytical Framework

The analytical framework is composed of three parts. First, in section 2.1 patenting in strategy research is discussed. Second, the instruments to measure the performance of firms are developed. And finally, a two-equation system to model the impact of patenting strategies on performance is developed.

2.1 Patenting in Strategy Research

2.1.1 Prior Strategy Measurement Studies in the Machine Tool Industry

Success factor research (known simply as strategy research) is an important approach in the study of patenting and performance. Success factor research tries to identify a small number of key factors which vitally affect the performance of firms. The assumption is that the resulting impact of these key factors contributes a significant portion of the enterprise’s performance. The determination of the relevant performance factors involved requires an analysis of the cause and effect relationships between these factors and at least one performance criteria.

The primary task of success factor research is to answer the question: what degree of influence does a specific factor have on a certain performance criterion? Its end goal is the clarification of an effect’s impact on the chosen success factors. It is also important to establish whether (or in what way) the effect depends on other parameters. Success factor research is not exclusively about the clarification of causal coherence, but also about the indirect factors influencing the analysis. Previous success factor research has shown that there can be considerable problems in the identification and measurement of success factors. It should also be mentioned that the main approaches of empirical analysis used in this type of research—multiple regression analysis and cluster analysis—provide only a few insights (if any at all) into the underlying causality. Researchers have encountered considerable difficulties with the complexity of their examined issues. This is an essential reason why the analysis here is focused only on patenting strategies as a decisive part of the innovation strategy utilized by machine tool firms. The propensity of firms to patent depends among others on the industry and the national patent system. That is, it is useful to refer to a few other studies exploring success factors in the capital goods industry.

Obviously, firms differ in their strategies and strategic moves. However, some theorists argue that the firms within an industry form groups according to the similarity of their competitive strategies (Newman 1978). It is assumed that these strategic groups are a stable element of the market structure and that they influence a firm's short-term decision-making. It is also assumed that these groups show persistent performance differences.

There is empirical evidence concerning the existence of strategic groups within a number of industries (for a review see McGee and Thomas 1986), and specifically within the West German machine tool industry (Zörgiebel 1983). However, the analysis raises doubts as to whether such groups persist over time. In a manner similar to Marshall's concept of industry, the concept of strategic groups is merely an analytical convenience to group the economic activities of firms. The basic question regarding the international machine tool industry is: whether there are groups of firms which choose to react to competitors' strategic initiatives in different manners? If this is not the case, then the entire industry would have to be considered as a single actor, and there would be no differences within the concept of industry at all (Caves and Porter 1977).

2.2.2 Patenting Strategy Measurement

Patent rights are granted for three main reasons: to promote invention, to encourage the development and commercial utilization of inventions, and to encourage inventors to make information on their invention public. Patents are granted upon all inventions meeting the established standards of novelty and utility.

The patent strategy of individuals or firms is related to the prospect of achieving a monopoly position and profits due to the development of new products based on the patented invention. Because of the patent right the patent owner may exercise monopoly power to set prices at whatever the market accepts. However, few products of the machine tool industry have such a monopoly position. Nevertheless, research and development is part of the competitive race, and is carried on to protect demand from invasion by competitors' new substitutes. With increasing technological competition, it is clear that no single firm can confidently shelve research findings and expect to find them still valuable years hence. The crucial question for the firms in the machine tool industry is whether patents offer much protection against the disparate ways of doing the same things that are characteristic of their technology. Clearly, they have to evaluate whether they can put a heavy premium on getting into the market first, establishing brand preference, and perfecting the product and technology.

A broad but focused product line is one way to exploit the unpredictable results of research in capital goods industries (see e.g. Fleischer 1997 for an analysis of the product strategy of German machine tool firms). The availability of capital, technological competence in the breaking-in stages, and the relationship with the present product line all create momentum toward exploiting a broad range of research results. Furthermore, multiple-product lines enhance the value of research because it is easier to figure out all the applications to research findings by distributing them throughout the firm and letting the engineers and salesmen look at them from their unique standpoints.

There are alternative inducements to the patent incentive that have to be considered in patenting strategy formulation. For example, if an invention can be kept secret it may be beneficial for the firm not to patent. The important issue here is whether rivals are able to imitate the invention. In fact, in the machine tool industry innovation strategies with respect to patenting are quite different. At least two groups emerge when ranked according their propensity to patent. One group has a high propensity and the other has a low propensity to patent. The reason is that patent protection is often weak and there can be many solutions to a technical problem. With machine tools it is often possible to “invent and develop around“ a given patented solution.

The analysis of patent data is useful to discover the various patenting strategies of firms. As Brockhoff (1992) has shown, there are at least five variables which have proven valuable in cross-sectional studies of overall patent data. These are: (1) total number of patent applications, (2) patents per application, (3) examination rate, (4) waiting time, and (5) concentration ratio.

Ernst (1995) applied this concept of patenting strategy measurement to a sample of 50 German machine tool manufacturing firms. He used the following indicators:

- *Overall national patent applications.* This is measured for each firm and related to the average patent activity within the sample. The measure is the relative patent activity (RPA). The adjustment for size leads to patent applications per employee (PA/EMP).
- *Patents granted.* The rate of patents granted (GP-Rate) was measured as the number of patents granted over patent applications minus patent applications under examination.
- *Valid patents.* This is an indicator for the importance of patents, because it is costly to maintain patents. The rate of valid patents (VP-Rate) is measured as the number of valid patents over granted patents.
- *Overall European patent applications.* The share of European patent applications per firm is measured relative to the average European patent applications within the research sample (REPA).
- *Patents cited.* The citation of granted patents in subsequent patent documents is recorded in relation to the total number of patents granted (CIT).
- *Concentration of patents in subclasses.* This concentration ratio is defined as an entropy measure (CON). A low value indicates a high concentration of patent application in a few subclasses, whereas a high value indicates a high dispersion of patents over patent subclasses.

Using these measures Ernst (1995) has identified four different clusters of patenting behavior. These clusters are somehow natural since they are based on the propensity to patent. The four clusters with the respective percentages of the 50 firms are:

- *Cluster 1 “Selective Patentees“ (40%):* <u>Low patenting</u> activity; <u>high rate of granted</u> and valid patents; above average concentration ratio.

- *Cluster 2 "Unsuccessful Patentees" (18%):* Low patenting activity; low rate of granted and valid patents; high concentration ratio; low citation ratio.
- *Cluster 3 "Internationally Highly Active Patentees" (32%):* High patenting activity; high rate of granted and valid patents; high amount of European patent applications; low concentration ratio.
- *Cluster 4 "Small Highly Active Patentees" (10%):* High patenting activity; low rate of granted patents and high rate of valid patents; low concentration ratio; high citation ratio.

Ernst (1995) used sales based performance indicators to assess the impact of patenting behavior on performance. The indicators used to test the impact are: relative sales growth, relative sales per employee, and relative development of sales per employee (1984-1991). Based on these three performance measures Ernst concludes that patent-active firms show better performance. Patent-active firms with narrow technological focus outperform all other firms on these three indicators. He has identified the lowest performance values for the "Unsuccessful Patentees" of Cluster 2.

Ernst has provided a very comprehensive and insightful analysis of a large sample of German machine tool firms. However, two reservations should be made. First, measures of sales performance are very limited for assessing the economic performance of firms. Second, the study of a national industry (although with strong export orientation) can offer only an indication of what happens with respect to global competition. Still to be answered are questions like, how important are patents granted by the U.S. Patent Office for global competition in the machine tool industry? Our analysis will deal with these two issues. This is done by first discussing the appropriateness of performance indicators, and second by testing the impact of patent behavior on the performance of a sample of 49 machine tool firms from major machine tool producing countries.

2.2 Measurement of Performance

2.2.1 Limitations of Unidimensional Criteria

There are several problems that must be addressed when choosing performance criteria. With respect to the unit of analysis, a decision must be made as to whether performance should be measured on the level of the business unit, the firm, or the industry. It should then be decided which type of performance criteria to accept. Are measures based on accounting data appropriate? Or is information concerning capacity utilization and productivity more appropriate? Finally, one has to fix the reference point and the time period for the measurement.

The explanatory power of a single one-dimensional performance criterion is limited. Accounting criteria might be biased. One has a certain amount of leverage in drawing up a balance sheet for instance, there are possibilities to choose among various rules for the valuation and depreciation of assets. Criteria like capacity utilization or productivity are restricted to just one element of production—be it the capacity of machines or the available labor. The important market share criteria are generally missing, as are the accumulated resources invested in its achievement. The same is true for quality criteria. The weaknesses of using a single criterion, suggest adoption of a measurement approach based on multidimensional criteria.

Two criteria which have proven their validation in numerous empirical studies are the hexagon criterion of Albach, and the Z value of Altman. The choice of the dimensions of the hexagon criterion are based on a systematic analysis of excellent firms. Since these are important dimensions for the study of global competition we will introduce the hexagon criterion briefly.

The Z value is based on a multifactor model developed by Altman for the purpose of bankruptcy prediction. The dimensions are similar to the ones of the hexagon criterion. The Z value based on Altman's discriminant function might be regarded as an index to discriminate between bankrupt and healthy companies—it is essentially an index of the company's overall well-being.

2.2.2 The Hexagon Criterion of Albach

The hexagon criterion of Albach is composed of six single measures. These six measures are similar to those used by Peters and Waterman (1982) in their comprehensive empirical field work on excellent firms.[3] The overall criteria was designed by Albach as a model hexagon, where the surface of each of the six measures defines one coordinate of the hexagon (as with the surface of a radar chart). For the selection of the excellent firms, the performance measures (averaged over a long period) are used to define the hexagon. The surface for each single firm is then used to get the ranking of the firms in the whole sample. The greater the surface, the better the performance of the firm. The six measures defining the hexagon are:

1. the growth rate of fixed assets,
2. the growth rate of equity capital,
3. the ratio of market to book value of the firm,
4. return on total capital,
5. return on equity, and
6. return on sales.[4]

This combined criteria measures profitability, the achieved growth, and the intangible assets of the firms. The scaling of the single measures has an impact on the surface of the hexagon. It defines—jointly with the formula for the surface of the hexagon—the value of the overall criteria. The scaling and surface definition express the implicit weighting procedure of the

3 Peters and Waterman (1982, p. 12) define in their popular book excellent firms as firms "especially adroit at continually responding to change of any sort in their environments." That is an excellent firm is a well adapted firm able to match its strength with the opportunities in its environment. They measured the financial and innovative performance of their sample of firms for the period 1961 to 1980.

4 An application of the hexagon criterion to large German and Japanese firms can be found in Albach and Moerke (1996).

single criterion. As such is the case, they remain arbitrary, and it is reasonable to keep this reservation in mind.

Reservations concerning particular single criteria are to be taken seriously. As Davis and Kay (1990) note, capital intensity and gearing interfere with the ranking of firms, and while the usual profitability measures capture some aspect of the success of firms, none gives the whole picture. While Davis and Kay are in search of a single measure,[5] however, this study rests on two combined measures—the hexagon criterion of Albach and the Z value of Altman. Albach (1987), Altman (1968; 1971), and Peters and Waterman (1982) among others have shown that these two criteria are capable of discriminating excellently performing firms from poorly performing ones. It should be noted, however, that new measures, such as the added value measure by Davis and Kay (1990) will certainly enrich the field of performance measurement.

Figure 1 illustrates the hexagonal criteria for two German machine tool firms. In order to obtain a more equal scaling of the axis, the ratio “market value to book value“ was multiplied by 0.01 for the purpose of presentation. For the computation of the proper hexagonal values, the formula for the hexagon was applied. The graphic representation of the hexagon’s criteria has also to be adjusted for cases in which a single variable becomes negative. For this situation, computation rules have to be applied. In cases where two values are negative, they result in a negative expression and are subtracted (contrary to arithmetic where the product would be positive and it would have to be added). For more detail concerning the computation of the variables see Albach and Moerke (1996).

2.2.3 Efficiency Measures

Method

The production of goods and services is technically efficient when they are produced with the minimum value of inputs. This is obtained by minimizing the cost of each product-related activity. Technical efficiency has to be distinguished from allocative efficiency, which is related to market performance. Business practice shows that improvements in technical efficiency are achieved by utilizing existing inputs more efficiently. To express this idea, Leibenstein (1966) introduced the socio-economic notion of X-efficiency and, correspondingly, X-inefficiency. X-inefficiency is utilized in cases where there seems to be the possibility of increasing efficiency by a new combination of inputs or more intensive use of inputs. For the purposes of this paper, the meaning of X-efficiency and technical efficiency coincide.

The measurement of technical efficiency requires some sort of standard of optimal or best practice efficiency. For this requirement, economic theory has provides the concept of the production function. For the purpose of empirical testing, one needs a well-defined and specified production function for each product-related activity. Based on the typical production

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5 Davis and Kay propose to measure added value as a means of valuating the intangible assets of a firm. They assess the amount of capital employed by the firm. Then they calculate the capital costs using a normal rate of return. Finally, they deduct this from the operating profit of the firm. This measure recognizes the cost of capital, which is an important issue in the proper measurement of performance. This relates to the ongoing discussion of shareholder value. This study assumes that the hexagon criterion and the Z value are appropriate to capture the intangible assets by using the ratio of market to book value.

technology in plants in the mechanical engineering industry, some preliminary estimations of the Cobb-Douglas production function were made.

There are a number of critical points to be addressed. The most crucial one is the assumption that the input factors are nearly perfectly substitutable. In the long-run, this can be realistically assumed.

Average and frontier production functions for German industries are reviewed in Albach (1980). New estimations for the major German industries are reported in Albach (1996). A survey of the recent literature is included in Greene (1996). No serious attempt is made in this study to estimate a vintage model to capture technical progress since the information on capital inputs of machine tool firms in the sample is limited—for a significant number of firms, data concerning investment is only available for four years. Thus, two simple versions of the following methods of estimating the frontier production function were used: The linear programming model approach[6], and the fixed effects approach using the least squares dummy variable (LSDV) estimator to estimate a set of firm specific constants (see Greene 1996, pp. 45-47).

Both approaches are based on the Cobb-Douglas production function. The goal function of the linear programming model includes a Cobb-Douglas term as well as the LSDV model specification.

Input and Output Definitions

The data are based on the Global Vantage Database from Standard & Poor's. As the output measure *X* real value added could not be used.

Usually, the output as real value added is used and defined as:

Sales	
+/–	Increase or decrease of the inventories of finished goods and work-in progress
+	Other own cost capitalized
=	Total output
–	Expenses for raw materials, supplies, and purchased merchandise
–	Other operating expenses
–	Cost of purchases services
–	Depreciation and adjustment on plant, equipment, and intangible assets
=	Value added (real net output)

Capital *K* was defined as the stock of machinery and equipment (including office equipment). Due to the short observation period, no particular capital measurement, such as the perpetual

6 See Albach (1980, pp. 59-60).

inventory method, could be applied. Instead, capital was defined as the average of the stocks of machinery and equipment, minus depreciation at a rate of 14.5 percent a year, plus the annual average of two years investment. The average of the investment was taken to adjust for the fluctuation in investment in short periods of observation. Capital in period t is then defined as follows:

$$K_t = (1 - r)\, K_{t-1} + 0.5\, (I_t + I_{t-1})$$

with ρ as the depreciation rate and I_t as the new investment in period t minus reductions in machinery and equipment (disinvestment) plus transfer.

Labor L is defined as salaries and wages plus the employer’s share of social security contributions, payments into old age pension funds, and other benefit costs. These labor cost then are deflated by a labor cost index.

Due to the limitations of available data a still different specification was used for the estimations. Thus, the only feasible specification was one using—as inputs—the number of employees, and the value for property, plant, and equipment. Sales was used to measure the output. Thus, a practically classical production function with two variable inputs—capital K and labor L—was estimated using a frontier production function approach.

2.3 Modelling the Impact of Patenting on Performance

2.3.1 The Patent Equation

Research and development expenditure is an important part of the competitive strategy of the firm. There are a number of main elements in the R&D expenditure decision. First of all, R&D expenditure is competing for a share of the total supply of a firm’s funds, along with its internal competitors of market investment and investments in property, plant, and equipment. Decisions on R&D projects have to go to the same decision process as other investment decisions. However, it seems to be more difficult to forecast the market profitability of R&D projects when compared to other investment decisions.

There is a two-way causation regarding R&D and profitability. On the one hand profits generate the funds for R&D expenditures, and on the other R&D expenditures may change and/or strengthen the competitive position of firms and thereby generate further profits. Because of the high degree of uncertainty of R&D, a large part of R&D is financed out of retained profits.

The high uncertainty is one reason why the measurement of R&D effort plays a crucial role in economic analysis.[7] The most common hypothesis in these studies is: that more important innovations require (on average) a larger share of innovation costs allocated for R&D than less important innovations. A second hypothesis states that: larger firms devote a greater percentage of their total innovation costs to R&D than smaller firms. And a third assumption is: that the more experienced a firm becomes with R&D, the greater is the likelihood that it will

[7] For an overview of empirical research on R&D, see Cohen and Levin (1989). For detailed analysis of the distributions of R&D expenditures in various U.S. industries, see Cohen and Klepper (1992).

learn and, thus, become more efficient. From this assumption, one would expect experienced firms to use a smaller share of their innovation expenditures for R&D.

The question addressed by much of the economic literature concerning product innovation is: whether patenting activity can be used as a proxy for modelling and measuring the output of the innovation process? There are good reasons to use this indicator to model the innovation process (see a review of the literature in Scherer and Ross 1990). A first step in modelling the relationship between innovative inputs and innovative output is to utilize a simple production function relationship of the type used by Bound et al. (1984):

$$PAT = aRD_{\beta}{}^{1}$$

where PAT is the annual number of patents granted by the U.S. Patent Office and RD is the firm's expenditure on R&D. For the linear regression, the logarithmic values are used, that is:

$lg\ PAT = lg\ a + \beta_1\ lg\ RD$ with the estimated coefficients for the entire sample:

$$\underset{(8.41)}{lg\ PAT = 1.07} + \underset{(5.12)}{0.61\ lg\ RD} \qquad R^2_{Adj.} = 0.19 \qquad F = 26.1 \qquad N = 107$$

where the t-values are listed in parentheses. The estimated coefficient of lgRD is the elasticity of the innovative output (measured as the number of patents) with respect to the innovative input (measured as R&D expenditures). The estimated elasticity of 0.61 is somewhat different from the elasticities for R&D and patents estimated by Bound et al. (1984. Based on 2,582 firms and ranging from 0.32 to 0.38). The elasticity is measured for the means of PAT and RD. This equation will be estimated as the patent equation in a two-equations system.

2.3.2 The Performance Equation

It has been argued that high profits can be regarded as a major criterion of good performance in capital goods industries. But what if these are subject to measurement errors? Some have argued that reported profit rates provide a limited understanding of "real" economic profitability. For example, Fisher and McGowan (1983), and later Benston (1985), have questioned whether accounting profits can be used to draw conclusions about economic performance. In this paper it was argued that this can be compensated for by using multi-dimensional measures, such as the hexagon criterion or the Z value. However, it is recognized that accounting practices tend to distort meaningful comparisons. These distortions might then obscure the true relationships between profitability and other variables (see Mueller 1990 for a discussion of the arguments concerning "accounting returns versus economic returns").

In modelling the performance of a firm, we use the performance indicators discussed above. Although the efficiency of R&D needs an explanation in a number of variables internal to the firm and its R&D department, here we will focus on the economic core relationship. We recognize the argument that R&D is a very complex process involving a wide range of managerial, behavioral, and institutional influences. Therefore we refer to a descriptive analysis of the development of global competition with respect to the development of NC/CNC machine tools in the United States, Europe, and Japan (Fleischer 1997). This is very much in line with the results achieved in the econometric analysis.

Much attention has been focused in recent years on the measurement of intangible capital like R&D and patents (see e.g. Hall 1993, Jaffe 1986, and Pakes 1985). Since there is the mentioned concern about the use of accounting profits for the measurement of profit and there are problems in measuring intangible capital it is reasonable to use the market value of a firm. The market value of a firm must be equal to the sum of the replacement costs of each of the assets of the firm. This value is also equivalent to the present value of the flow of expected net revenues.

In modelling the market value relationship we use two measures of efficiency, that is the technical efficiency and the R&D efficiency as expressed by the patent rate, using the number of patents per 1,000 employees.

3 Sample and Data

3.1 The Sample: Machine Tool Firms with Published Accounts

Considerable structural changes occurred in the 1970s and 1980s in the international machine tool industry. There are four characteristics of this development (see Carlsson 1990). During the 1980s, distribution of the world production of machine tools moved from the traditional suppliers in the U.S.A. and Western Europe to firms in Japan. The Japanese gains are partly related to resulting losses for the West German and U.S. machine tool firms, as well as for firms in certain East European countries. This change is a result of increasing international trade and its specialization. This is particularly true for Japan, where the globalization of the automotive industry has played a decisive role for the development of the machine tool industry. During this process, conventional machine tools were replaced by numerically controlled machine tools. This development is still reflected in the most recent statistics of the world machine tool industry.

Worldwide, the largest machine tools manufacturer in 1995 was Fanuc. Fanuc has U.S.$ 1.138 billion (USD) in annual sales. This is primarily due to the sale of machine tools and computerized numerical control equipment. Second is Amada, primarily an engineering and marketing firm, with sales of U.S.$ 1.104 billion. The family-owned firm, Yamazaki Mazak, is third with sales of U.S.$ 1.021 billion. Fourth place is held by Fuji Machine (U.S.$ 893 million) and coming in fifth is Okuma with U.S.$ 722.7 million. The U.S. firm of Gidding & Lewis is ranked sixth (U.S.$ 659.4 million). Only one German machine tool manufacturer is among the largest 10 firms—seventh place Trumpf with U.S.$ 645.7 million in annual sales in 1995. Number eight is the Japanese Mori Seiki (U.S.$ 622.2 million). The final two are the U.S. firm, Western Atlas Inc. (U.S.$ 558 million), and the Fiat-owned, Comau Group in Italy, with sales of U.S.$ 547.2 million. Out of these ten of the world's largest manufacturers of machine tools six are included in our analysis. They are: Fanuc, Amada, Okuma, Gidding & Lewis, Mori Seiki, and Comau.

The selection of the firms for this study was based on the availability of the information needed to compute the discussed performance measures. This required information from the both the balance sheets and income statements of the firms. Usually, such information is only available for stock-companies. Based on a list of manufacturers of machine tools as classified in the Global Vantage database (GV) the present sample was generated. Firms that do not have the majority of their activities in the machine tool business were excluded. Among these are firms like Seiko. The correct sample was defined by using the directories of the German, Japanese, and U.S. associations of machine tool builders. The result is a sample of 49 firms (see table 1).

3.2 The Data

Performance Data

The data used are from the Global Vantage database issued in July 1997. This database contains financial information about industrial, financial, and insurance corporations quoted on the world's largest stock exchanges. The database is constructed from the annual business reports of the stock corporations. This database is primarily used in international comparative studies. It has the advantage that the data are made comparable, that is, flow variables are converted by using the average currency exchange rate for the reporting period. For stock variables the exchange rate for the end of the periods are used.

The availability of certain single items on the balance sheets and income statements varies due to the different reporting standards applying to the firms in the three countries. Further, most of the firms are medium-sized and they do not generally follow sophisticated reporting standards. However, the GV database reports the missing values for cases where the data is available. This is particularly true for labor costs. We have checked this for a number of German firms. Note, that the incompleteness regarding important single items is a serious drawback of the GV database for econometric performance studies.

Finally, it should be noted that a number of companies have changed their accounting systems due to legal and tax considerations. In the new system, the former core of the company (the AG) becomes a Holding. This implies that they no longer report the realistic sales and employment figures for the AG. These figures are only available using consolidated financial statements. This means that the unit of analysis has to be changed from the AG to the Group ("Konzern") using information from the consolidated balance sheets and income statements. There is no longer a choice of using unconsolidated or consolidated accounts for the purpose of an empirical analysis. However, these changes occurred by the end of the 1980s in the case of Japan and Germany. This has to be recognized when interpreting the data.

Patent Data

Patent data was gathered for the period of 1986-1995. Four separate databases were used for the patent counts. These four were used to acquire information concerning differences in the propensity to patent. The choice of the patent data was mainly driven by the fact that the largest machine tool producing countries are Japan and Germany, and the two largest markets for machine tools are the U.S.A. and Europe. This implied using patent data from the U.S., European, Japanese, and German patent offices.

An alternative strategy would have been to directly use a database which is specialized in providing access to international patent applications, like the DERWENT database. However, we decided to focus our analysis on data from the USPTO, the EPO, the JPO, and the German Patent Office.

U.S. patent data was collected by searching the U.S. Patent Database on the Worldwide Web.

European patent data was searched for on the ESPACE-ACCESS CD-ROMs with the European and PCT International Patent Application Bibliography.

An efficient access to Japanese patent data was provided by the English version of the JPO Patent Search Database located at the Technische Hochschule Ilmenau. The “original“ JPO-WWW-Database was still not complete at the time of the search in April and May 1998 and was time consuming to work with.

Information on patent applications at the German Patent Office were derived from the PATOS CD-ROM as supplied by Wila Verlag / Bertelsmann Informations Service.

4 Empirical Results

4.1 Variation of Patenting in the Sample

There is an enormous difference in the absolute number of entries. For the JPO the number is 13,175; for the EPO 3,373; and for the USPTO 2,507; for the GPO 635. The Japanese firms have filed 3.9 times more applications with the JPO as the whole sample has filed with the EPO. This result for the machine tool industry corresponds with what is already known about the Japanese patent behavior, that is the propensity to patent is higher in Japan compared to Europe and the U.S.A. (see e.g. van Leuven 1996; Schramm, Ludwig, and Töpfer 1997). There is no patent application from a non-Japanese firm at the JPO for our sample due to the limited coverage of the JPO patent abstract database used.

When looking at the patent shares an interesting result emerges regarding the entries with the patent offices. From the total of 19,690 entries, 8,861 or 45 percent are due to patenting effort of the FANUC corporation. That highlights an enormous technological leadership which can only be assessed in more detail with respect to both the fields of technology and its rivals in terms of global competition.

The distribution pattern of entries for the firms in the sample are shown in figure 2. The figure is based on one of the patenting efficiency measures, that is the number of patents per 1000 employees. The four quantile plots show the fraction of observations on the x-axis, and the respective values of the patent efficiency variable on the y-axis. Three patterns are very similar. These are the U.S. patents, the JPO applications, and the GPO applications. These three show for the upper quartile (75-100 percent) a concentration of the highest patent efficiency as measured by patent applications per 1000 employees. The pattern is different for the EPO. Here a sharp break comes with 95 percent of the observations. This is due to the counting of the so-called Euro-PCT filings made by FANUC. 72 percent of the applications at EPO can be attributed to FANUC. Thus, one might argue that there is a strong impact by FANUC on the patenting pattern of the sample. This is obviously true, however, FANUC is a key-player in global competition in the machine tool industry. That is the main reason for not dropping this firm from the sample.

4.2 The Impact of Patents on Performance

4.2.1 Estimation of Single Equations

Our econometric estimations using the whole set of performance measures has led to four preliminary results. First, variables based on patents granted by the USPTO lead to significantly better results as compared with JPO and GPO applications, that is there is a positive and significant impact of patenting activity and the various measures of performance. The reason might be that patents granted by the USPTO are a better indicator of intangible capital embodied in patents than mere patent applications. And, because of the arguments made in the literature with respect to the importance of U.S. patents, there is also an impact of the large U.S. market and the fact that USPTO only publish patents granted. However, as can be seen from our data and from comparable estimation results, EPO is reaching a similar position.

Second, a clear pattern emerged with respect to the performance indicators when using patents as the single set of performance determinants. We found a significant, although not strong positive relationship between the hexagon criterion and patenting as well as with the Z value and patenting. The Z value performed slightly better. From a purely empirical perspective we were surprised by how well the market value as a performance measure performed. That is, we found a very significant and positive relationship between patenting activity and the market value of the firm.

Third, as expected, the lagged variable of patent activity is a good predictor of performance. In particular, a lag of one year led to the best predictions.

Fourth, patent activity as measured by patent applications with the German Patent Office had a negative impact on performance when patent indicators for all four patent offices were used in the estimated equation. A part from problems of multicollinearity this might be due to the fact that the 635 applications in Germany account for only 3.2 percent of the overall patenting activity. Further, German firms in the sample have experienced significant losses since 1990.

4.2.2 Estimation of the Two-Equation System

The goal of the estimation of the two-equation system is to test in a simple manner the efficiency of the innovative process. This is done by estimating a knowledge production function (“patenting equation“) and a “performance equation“ as developed in section 2.3. The latter equation describes the relationship between the market valuation of a firm and its productive (technical) efficiency and its efficiency to patent.

To estimate the system of equations we assumed a seemingly unrelated regression model. Seemingly unrelated regression appear to be joint estimates of several regression models, each with their own error term. They can be used to estimate a system of equations in case of cross-sectional time-series data.

The following two equations were estimated using the “sureg“ procedure as implemented in the STATA Version 5:

(1)	lg (U.S.-Patents)	=	lg(R&D Expenditures)	
	“pauslg“		“xrd_lg“	
(2)	Market Value	=	Technical Efficiency	+ U.S.-Patents per 1000 Employees
	“mkvali“		“eff_lp“	“pus_em“

The variable definitions and parameter estimations are shown in table 2 and 3. All parameter estimates are significantly different from zero. The patent equation explains 19 percent of the variance of the innovative output “patents“. The performance equation explains 56 percent of the variance of the market value of the firm. This result corresponds to numerous fixed- and random-effect model estimations we did for section 4.2.1.

5 Conclusion

Using the case of an important capital goods industry the paper examines the impact of the national patent system on the performance of firms. Many theories attempt to explain the firms’ innovative behavior using the concepts of national and sectorial systems of innovation. Patents play a particularly important role in these systems. At the level of the firm their importance rests on the possibility to appropriate profits. The empirical analysis of a sample of 49 manufacturers of machine tools show that patents are a superior mechanism for appropriating the returns on R&D in this industry. This is indicated by a strong positive relationship between the market value of the firm and its patenting activities. Recently, Foray (1995) has argued that there are two types of patents systems, the P-system (used in most western economies) and the D-system (the Japanese system), which have a different impact on the innovative behavior of firms. However, our results underscore the importance of the U.S. patent system for the global competitiveness of firms in a medium-sized capital goods industry. Using this newly constructed dataset on manufacturers of machine tools we document that Japanese firms have invested far more in domestic patenting than their global rivals. This paper suggests that this is due to the narrow scope of the Japanese patent law with its weak novelty requirements which rewards those who reverse engineer. However, our results underscore the importance of the U.S. patent system for the global competitiveness of firms in a medium-sized capital goods industry. Using a newly constructed dataset on manufacturers of machine tools we document that Japanese firms have invested far more in domestic patenting than their global rivals. This result contradicts - at least for the machine tool industry - Ordover’s (1991) conclusion that the Japanese system penalizes those firms who wish to protect their major technological breakthroughs. It may be that the D-system of protection for intellectual property could be effective in meeting the needs of a technological follower as well as the needs of a technological leader when being supported by the P-system.

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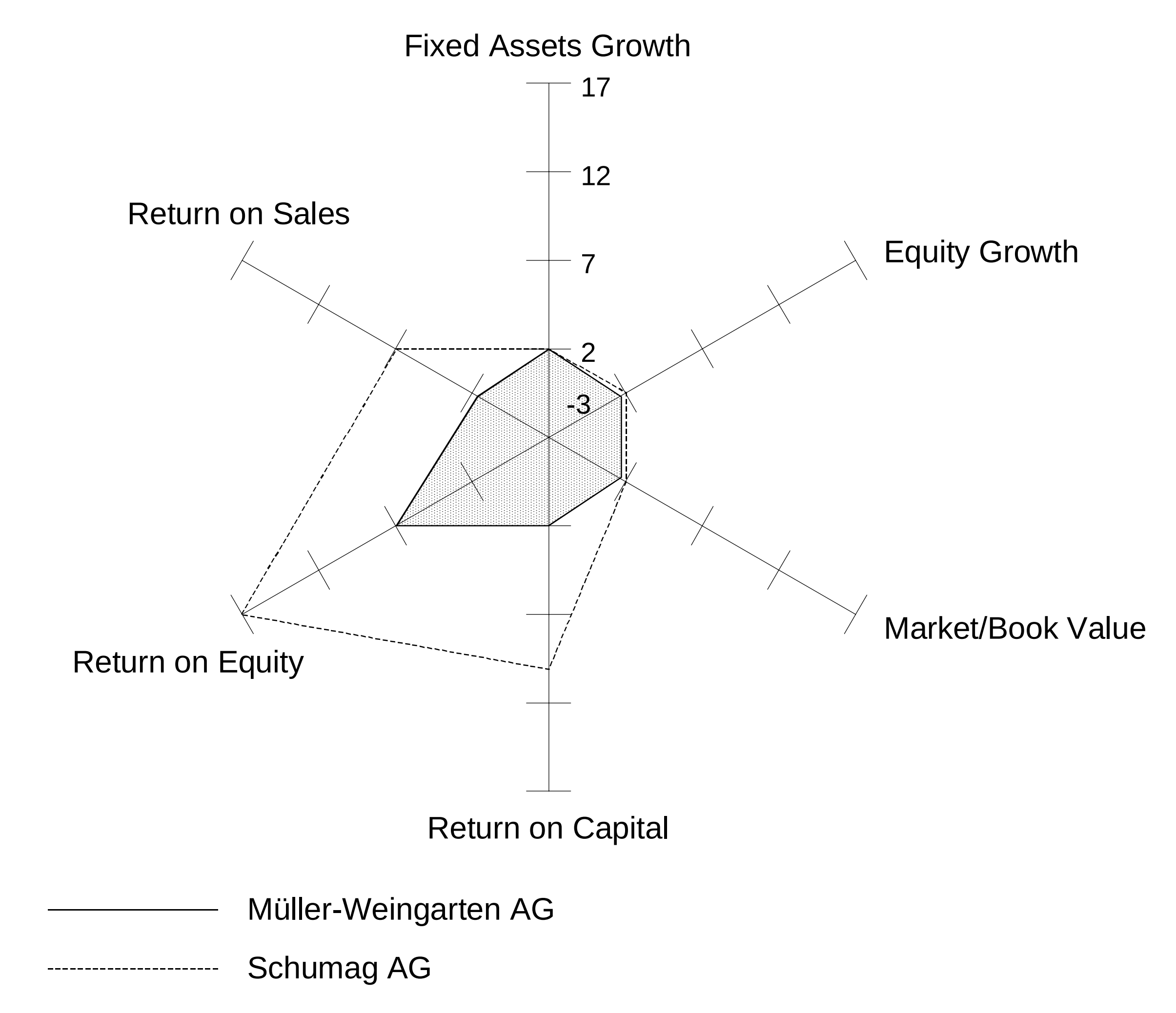
Figures and Tables

Figure 1: Hexagon Criterion for German Machine Tool Firms, 1991-1994



Source: Fleischer (1997), p.166.

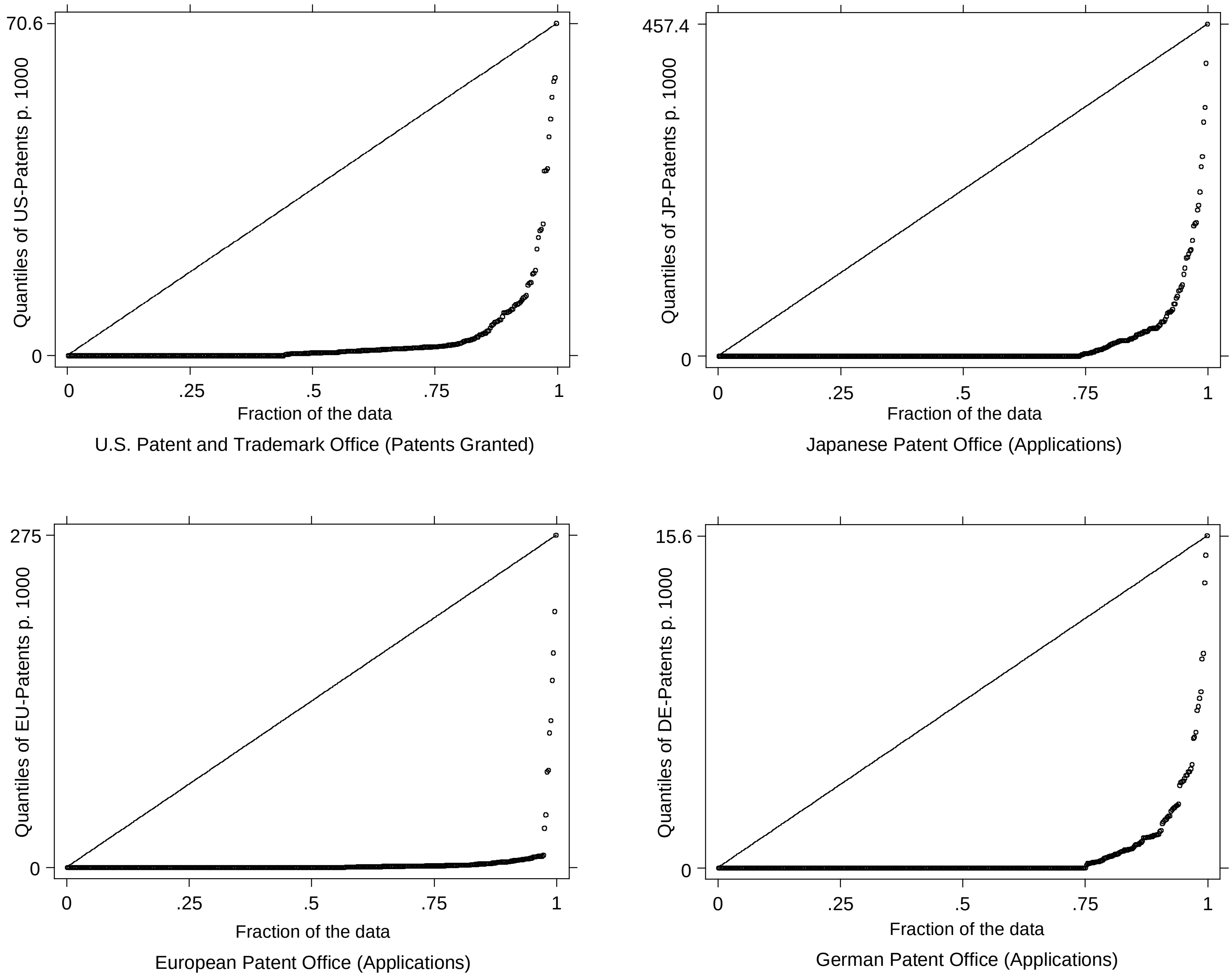


Figure 2: Quantile Plots for Patents Granted and for Patent Applications per 1000 Employees

Table 1: The Sample of 49 Machine Tool Firms: Performance and Patent Indicators

ID Number		Company Name	Country	Number of Empl.	Sales in mill. USD	Pretax ROA	Operat. Margin	R&D Intensity	Patents Granted by USPTO		Patent Appl. at EPO		Patent Appl. at JPO		Patent Appl. at German PO	
GVKEY	No	CONM	CINC	EMP	SALE	PROA	OMAD	RD_SALES	PAT_US		PAT_EU		PAT_JP		PAT_DE	
				1995	1995	1995	1995	1995	1986-95	Share	1986-95	Share	1986-95	Share	1986-95	Share
100059	1	600 GROUP PLC (THE)	GBR	1420	229.07	12.14	10.68	1.27	3	0.12	0	0.00	0	0.00	0	0.00
101710	2	AGIE HOLDING AG	CHE	1120	263.40	3.26	5.12	.	41	1.64	55	1.63	0	0.00	63	9.92
101551	3	AIDA ENGINEERING LTD	JPN	680	309.24	3.55	6.80	0.02	50	1.99	36	1.07	544	4.13	7	1.10
1297	4	ALLIED PRODUCTS	USA	1600	260.86	10.99	9.51	.	21	0.84	5	0.15	0	0.00	0	0.00
100234	5	AMADA CO LTD	JPN	1310	1032.09	1.36	-1.65	4.34	214	8.54	87	2.58	2401	18.22	45	7.09
200152	6	AMADA SONOIKE CO LTD	JPN	470	354.31	1.22	-1.74	0.43	1	0.04	0	0.00	0	0.00	0	0.00
200153	7	AMADA WASINO CO LTD	JPN	480	204.28	-3.57	-5.58	2.31	7	0.28	3	0.09	0	0.00	6	0.94
2433	8	BROWN & SHARPE MFG CO	USA	2370	320.90	0.89	3.72	2.42	17	0.68	26	0.77	0	0.00	0	0.00
2999	9	CHICAGO RIVET & MACHINE CO	USA	300	23.72	17.07	13.95	.	0	0.00	0	0.00	0	0.00	0	0.00
3041	10	CINCINNATI MILACRON INC	USA	11790	1649.30	11.41	6.64	2.08	198	7.90	101	2.99	0	0.00	3	0.47
15904	11	COMAU FIANANZIARI	ITA	4050	1048.01	3.51	3.64	.	36	1.44	38	1.13	0	0.00	11	1.73
102904	12	DANIELI	ITA		698.36	1.96	-0.44	.	107	4.27	159	4.71	0	0.00	1	0.16
202040	13	ENSHU LTD	JPN	980	284.71	-4.39	-1.13	.	1	0.04	3	0.09	213	1.62	0	0.00
103526	14	EX-CELL-O HOLDING AG	DEU	1420	246.93	-9.82	-4.55	.	96	3.83	0	0.00	0	0.00	6	0.94
4568	15	FANSTEEL INC/DE	USA	910	102.60	7.40	4.32	.	13	0.52	1	0.03	0	0.00	2	0.31
100048	16	FANUC LTD	JPN	2120	1572.39	9.64	27.86	.	955	38.09	2429	72.01	5476	41.56	1	0.16
16475	17	GIDDINGS & LEWIS INC/WI	USA	3970	730.55	3.43	9.37	0.53	17	0.68	3	0.09	0	0.00	10	1.57
101937	18	GILDEMEISTER AG	DEU	2570	521.16	-2.46	-3.49	.	9	0.36	22	0.65	0	0.00	32	5.04
5181	19	GLEASON CORP	USA	1460	197.05	10.64	10.24	2.58	63	2.51	70	2.08	0	0.00	1	0.16
210325	20	HERMLE BERTHOLD AG	DEU	430	60.67	7.00	4.29	.	0	0.00	11	0.33	0	0.00	12	1.89
101899	21	HITACHI KOKI CO LTD	JPN		1185.19	3.51	4.82	.	253	10.09	29	0.86	1912	14.51	195	30.71
102538	22	HITACHI SEIKI CO LTD	JPN	1100	340.02	-5.03	-7.03	2.10	7	0.28	4	0.12	512	3.89	2	0.31
101974	23	HOWA MACHINERY LTD	JPN	2120	376.57	1.80	0.90	0.05	0	0.00	39	1.16	0	0.00	6	0.94
203247	24	IKEGAI CORP	JPN		.	.	.	.	2	0.08	1	0.03	48	0.36	0	0.00
100449	25	IWKA AG	DEU	7720	1483.16	4.71	3.34	.	.	.	.	.	.	.	.	.
100236	26	MAKINO MILLING MACHINE CO LT	JPN		482.78	1.48	1.82	.	3	0.12	4	0.12	341	2.59	2	0.31
102178	27	MIKRON HOLDING AG	CHE	1380	277.03	4.32	5.78	.	0	0.00	3	0.09	0	0.00	7	1.10
7515	28	MONARCH MACHINE TOOL CO	USA	700	114.99	1.15	1.06	1.46	15	0.60	3	0.09	0	0.00	1	0.16
102256	29	MORI SEIKI CO LTD	JPN	1740	692.61	3.29	1.93	.	9	0.36	6	0.18	124	0.94	2	0.31
220302	30	MULLER-WEINGARTEN AG-MASCHIN	DEU	2200	278.49	-12.55	-13.17	.	7	0.28	44	1.30	0	0.00	85	13.39
7873	31	NEWCOR INC	USA	890	116.63	1.62	2.45	.	8	0.32	1	0.03	0	0.00	0	0.00
100632	32	NIIGATA ENGINEERING CO LTD	JPN	3120	1670.97	-0.46	-0.54	0.08	18	0.72	21	0.62	719	5.46	0	0.00
102908	33	O-M LTD	JPN	500	103.14	-2.85	-4.24	0.16	2	0.08	0	0.00	0	0.00	0	0.00
102682	34	OKK CORPORATION	JPN	760	201.28	-8.60	-10.80	1.41	0	0.00	0	0.00	0	0.00	0	0.00
205367	35	OKUMA & HOWA MACHINERY LTD	JPN	520	161.48	-2.22	-1.41	2.20	0	0.00	0	0.00	0	0.00	0	0.00
100064	36	OKUMA CORPORATION	JPN	1350	725.07	2.10	1.56	2.95	106	4.23	1	0.03	0	0.00	6	0.94
101841	37	PITTLER MASCHINENFABRIK AG	DEU	660	79.61	-7.22	-2.48	.	0	0.00	8	0.24	0	0.00	3	0.47
211460	38	SCHUMAG AG	DEU	1000	167.72	17.72	12.45	.	3	0.12	4	0.12	0	0.00	0	0.00
102678	39	SCINTILLA AG	CHE	2060	705.97	13.25	7.59	.	5	0.20	19	0.56	0	0.00	36	5.67
9556	40	SPX CORP	USA	8300	1098.10	0.20	3.92	1.34	59	2.35	4	0.12	0	0.00	4	0.63
102849	41	TEIJIN SEIKI CO LTD	JPN	1500	644.92	-6.06	-5.03	0.70	0	0.00	78	2.31	601	4.56	4	0.63
209100	42	TOKYO KIKAI SEISAKUSHO LTD	JPN	610	235.34	1.69	3.00	0.29	90	3.59	14	0.42	224	1.70	31	4.88
102167	43	TOSHIBA MACHINE CO LTD	JPN	2920	1069.56	-3.28	-3.66	0.48	47	1.87	4	0.12	0	0.00	16	2.52
209195	44	TOYODA MACHINE WORKS LTD	JPN	4510	1432.29	2.59	1.95	2.62	1	0.04	0	0.00	0	0.00	0	0.00
101962	45	TRAUB AG	DEU	2370	364.19	-2.87	-8.15	.	8	0.32	20	0.59	0	0.00	28	4.41
101077	46	TSUGAMI CORPORATION	JPN		124.07	-3.12	-0.85	.	3	0.12	3	0.09	60	0.46	0	0.00
220393	47	USINES METALLURGIQUES DE VAL	CHE		36.96	3.69	4.05	.	0	0.00	0	0.00	0	0.00	0	0.00
209468	48	VERSON INTER'L GROUP PLC	GBR	1460	167.74	-4.64	0.27	.	7	0.28	3	0.09	0	0.00	0	0.00
209454	49	WALTER AG	DEU	1120	187.82	16.00	12.35	.	5	0.20	11	0.33	0	0.00	7	1.10
		Totals		90060	24633.30				2507	100	3373	100	13175	100	635	100

Table 2: Variable Definitions for a Two-Equation System

Dependent variables	
PAT_US	Number of patents granted by the U.S. Patent Office—taken as the log-form (lg).
MKVALI	Market value of the firms (measured in millions of U.S. dollars). The value is based on the price of shares and the issued stocks.
Independent variables	
XRD	R&D expenditures—taken as the log-form (lg).
EFF_LP	Annual technical efficiency of the firms based on a Cobb-Douglas production function and an estimation using a linear programming approach.
PUS_EM	Patenting efficiency as measured by the number of patents granted by the U.S. Patent Office.

Table 3: Estimated Regression Coefficients Using Data for 1986-1995 for European, Japanese, and U.S. Firms (Seemingly Unrelated Regression with t-Statistics in brackets)

VARIABLE:	Patenting Equation	Performance Equation
	lg U.S. Patents	Market Value
Intercept	1.10*** (7.32)	-788.41*** (-5.23)
lg R&D Expenditures	0.67*** (4.84)	
Efficiency		22.30*** (8.68)
U.S. Patents per 1000 Empl.		79.76*** (8.23)
N obs.	90	90
F	23.45***	66.83***
R^2	0.19	0.57

Significance level: *** 0.1%

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