ELSEVIER

Research Policy 24 (1995) 127–136

research policy

Educational statistics as an indicator of technological activity **

Staffan Jacobsson *, Christer Oskarsson

Department of Industrial Management and Economics, Chalmers University of Technology, S-412 96 Göteborg, Sweden

Final version received September 1993

Abstract

The aim of this paper is to introduce a new indicator of technological activity, educational statistics. A set of important phenomena can be described and analysed with the help of this indicator. These include the diffusion of a new generic technology through an economy and the evolution of the technology base of firms and industries. The usefulness of this indicator is illustrated with a few empirical examples drawing mainly from the electronics field.

1. Introduction

The aim of this paper is to introduce a new indicator of technological activity, educational statistics, and to demonstrate its usefulness with a few empirical examples drawn chiefly from the electronics field. The critical assumptions underlying the development of this new method are that

(a) the main carriers of technology are engineers and scientists;
(b) these normally work with technical/scientific tasks; and
(c) although the substitutability between different categories of engineers and scientists may vary considerably, it is, on the whole, quite limited.

If these assumptions hold, and if we are able to trace the employment of such highly trained manpower, we ought to be able to say a great deal about how new technology [1] diffuses as well as how the technology base [2] of firms, industries and nations evolves.

The paper is organized as follows. In section 2, we describe the new indicator and discuss, in a tentative way, how it may supplement other indicators of technological activity. We also describe

* Corresponding author.

** This paper was written within the framework of the research program Economics and Management of Technology at the Department of Industrial Management and Economics, Chalmers University of Technology. The research was financed by Sweden's National Board for Industrial and Technical Development (NUTEK) and Chalmers University of Technology. We are grateful to Olle Gärdin at the Swedish Central Bureau of Statistics for very valuable help in our work and to two anonymous referees, Gunnar Eliasson, Anders Granberg, Per Lindberg and Lennart Stenberg for comments on an earlier draft. Lesley Palmer was kind enough to correct our English.

[1] With 'technology' we mean knowledge about the application of natural science and mathematical principles rather than artifacts, such as a machine.

[2] Granstrand and Sjölander [5] introduced the notion of technology base as the asset of technological competence that a company possesses. The technology base often consists of a set of different technological competences.

SSDI 0048-7333(93)00753-G

a particular data base which we have used in our empirical work. In section 3, we present some illustrative examples of what can be achieved with the new indicator. Finally, in section 4, we summarize our main results and make suggestions for further research.

2. Presentation of the educational statistics approach

It is clear that competitive advantage to a growing extent is based on the ability of firms and nations to generate, diffuse and utilize knowledge, primarily of a technological character.

To trace such technological activities of firms and nations a number of methods have been used: patent statistics (e.g. [1,6–8,18–20,23]); bibliometric techniques (e.g. [4,24]); R&D statistics (e.g. [13]); diffusion data on products (e.g. robots) incorporating new technologies (e.g. electronics) (e.g. [3]) and, finally, structural data on industrial output dividing industries into low, medium and high tech industries [16].

Our proposition is that a useful supplement to these indicators may be statistics which give the detailed educational background of staff with a higher education in engineering and science. As mentioned above, a first assumption underlying this approach is that engineers and scientists are the main carriers of advanced technology. This ought not to be a too heroic assumption given the growing complexity of present day technology. Indeed, Lekander [14] shows that there has been a clear increase in the use of engineers and scientists at key technological functions (R&D, design) in Swedish industry over the last 15 years.

Concerning the second assumption, that engineers and scientists are mainly employed in tasks of technical nature, it has been shown [15] that in Sweden, 74% of all engineers [3] work in technical areas and that 67% work with R&D or product/process development.

The third assumption is that the substitutability between different categories of engineers and scientists is limited. This is a more debatable assumption. Clearly, the substitutability between different types of graduates in some social science fields is great and for these, the educational system provides the student with a 'ticket' to certain jobs.

However, it is easy to understand that the advanced nature of present day technology makes it rather difficult for social scientists to substitute for engineers as well as for many engineers and scientists to substitute for engineers with a different area of specialization.

The substitutability between different categories of engineers and scientists depends on the trade-off in each specific education between generalist engineering knowledge and specialist knowledge. Engineering physicists (F), for instance, have a broad general education and therefore can be used for complicated problems in the mechanical, computer and electronic areas. Other categories of engineers are more specialized. Chemical engineers (K), for instance, are presumably not normally recruited to design electronic circuits or to do software work for factory automation systems. With the exception of engineering physicists, we would expect that the frequency of engineers working in technical areas in which they were not trained in at university is low. In a set of interviews conducted by us [11], it was, for example, made clear that consultancy firms working with electronics and computer science recruited almost only electronics and computer science specialists. [4]

Although more work needs to be undertaken to test the last of the three assumptions, we expect that data on the educational background of staff with an engineering or science back-

[3] Throughout this paper the term engineer is used for those who have graduated from a 4.5 year education at a University of Technology in Sweden. Formally, this is an MSc in engineering.

[4] Of course, firms which also have a strong presence in mechanical engineering, say machine tool firms, may be able to substitute such specialists with retrained mechanical engineers whose multidisciplinary background may even be looked upon as an asset.

ground should be able to give us a reasonably good indication of the 'technological landscape' of firms, industries and nations, including the dynamics of such landscapes. This landscape, and changes therein, would, however, presumably be sketched rather roughly as on-the-job learning and the individual's specialization within a broad field, such as electronics or mechanical engineering, would be difficult to incorporate. Neither would it capture the technological activities of, say, a mechanical engineer who uses his application knowledge in production engineering to develop appropriate computer software. Finally, in categorizing highly trained manpower according to academic disciplines, one emphasizes the scientific basis of technological knowledge. This introduces a potential bias in that the indicator may not fully capture technological activities which are less science based. In spite of these weaknesses, we can identify several potential advantages of such an indicator.

First, it would capture technological activities which do not result in patents or in scientific references. For instance, the knowledge may be tacit and not lend itself to patenting. It may also be knowledge which does not belong to the core activity of the firm and may therefore not necessarily be patented. An example may be when paper and pulp manufacturers automate their production process, they recruit electronics engineers to improve the performance of the process with software development.

Second, it captures technological activities which are often not classified as formal R&D in the statistics, for instance in smaller firms or in process engineering.

Third, a product-based industry definition, such as the ISIC classification, may not necessarily reflect the size and nature of the technological activities involved. For instance, many European and American firms source most of the components and sub-systems from Asian firms, leaving the Europeans and Americans with a relatively small technology base. In other cases, a new technology may be of vital importance for the technology base of firms and industry but by using a product-based industry classification this may be completely hidden. For instance, SAAB Automobiles has developed a microprocessor-controlled system for improving the function of the combustion engine. This electronics activity would presumably be reflected in the educational background of the staff in SAAB but not necessarily in the statistics on the output and employment of the Swedish electronics industry.

Fourth, technological activities of critical relevance for the industrial sector may be sourced from other sectors of society, for instance, the service sector or the universities. It is thus important to include those sectors in any painting of the technological landscape [5].

In order to explore the use of educational statistics as an indicator of technological activity, we have made use of a data base which registers about 85% [6] of all Swedish engineers. Data is available for the period 1980–89 and identifies nine different educational classes. These are:

- Mining and metallurgy (B)
- Electrical engineering (E)
- Computer science and engineering (D)
- Engineering physics (F)
- Chemical engineering (K)
- Civil engineering (V)
- Mechanical engineering (M)
- Physics and electronics (Y)
- Industrial engineering and management (I)

[5] It can also be a very early indicator, or warning, of activities in a particular field. This depends on whether the particular technological area is matched by an established educational specialization or not and if there is a sufficient supply of engineers with that particular educational background. If this is not so, perhaps because it is a new science or technology field, our indicator can instead be a delayed indicator due to the inflexibility in the education system.

[6] The data base belongs to the Swedish Association of Graduate Engineers (Civilingenjörsförbundet). This assertion was tested in two ways. First, we compared the number of newly graduated electronics engineers with the increase in the number of such engineers in our data base for the period 1981–87. The figures were 3089 and 3067 respectively. Second, we compared the stock of all engineers in our data base with that of the Central Bureau of Statistics which collects statistics on engineers for the purpose of providing data for the process of wage bargaining. The difference was as expected; 12300 versus close to 14000 (88%).

Table 1
The number and share of electronics engineers [a] in the total stock of engineers in some Swedish industries, service sectors and public sector units, 1981 and 1987 (in numbers and %)

			1981		1987	
			No.	Share	No.	Share
Industry	Metal products	(ISIC 381)	16	23	18	9
	Non-electrical machinery	(ISIC 382 exc 3825)	271	18	322	20
	Computers and office machinery	(ISIC 3825)	213	69	812	62
	Electrical machinery	(ISIC 3831)	645	55	449	45
	Telecommunications	(ISIC 3832)	1221	71	1513	62
	Other electrical products	(ISIC 3833, 3839)	50	39	117	49
	Ship building and automobiles	(ISIC 3841 and 3843)	166	14	348	16
	Aerospace	(ISIC 3845)	134	30	147	23
	Instruments	(ISIC 385)	181	61	224	52
Service sector	Computer services	(ISIC 8323)	16	43	445	57
	Architects and Building consultants	(ISIC 8324, 8329)	237	17	601	36
Public sector units	PTT [b]		221	78	362	62
	The Swedish Water Board [b]		269	43	286	39
	Defence [b]		321	30	339	27
	Swedish Rail [b]		64	39	68	28

[a] Defined as those with a E, D, Y training.
[b] The data refer to 1990 instead of 1987.

The data base contains information about each member's establishment and educational background. It is thus possible to use the data base to specify how many engineers in each class are employed in an establishment at a given point in time. In the next section, we will provide some illustrative empirical examples of the use of this data base.

3. Empirical illustrations of the educational statistics approach

In this section, we will give a number of empirical examples illustrating the usefulness of our approach. We begin by analysing the diffusion of electronics and computer technology in the Swedish economy between 1981 and 1987. We proceed, on the basis of the empirical example of industrial electronics, to question the relevance of the conventional product-based industry concept. Finally, we use the method to measure the technology base of 25 Swedish industries and service sectors (4 digit ISIC level) as well as some public sector units, and to measure how they changed between 1980 and 1989.

3.1. The diffusion of electronics and computer technology in the Swedish economy

In Table 1, we indicate the diffusion of electronics and computer technology in some Swedish industries, service sectors and public sector units using the employment pattern of electronics and computer science engineers (E, D, Y) as the indicator of technological activity in those fields. In total, the data base identifies 8500 such engineers in 1987.

Several observations can be made from the table. First, it is clear that electronics and computer technology has diffused widely; eight industries (manufacturing and service) and several public sector institutions had in excess of 200 electronics engineers. Indeed, only 24% of the growth in the number of electronics engineers went to those industries normally thought of as the 'electronics industry' [7]. Still, however, it is striking that in the midst of the 'IT revolution', in some instances, the *share* of electronics engineers has in fact declined. This is a feature of the

[7] ISIC 3825, 3831, 3832 and 385.

Swedish technological landscape to which we shall return below.

Second, the most noticeable increase in electronics engineers did not take place in the industrial sector but in the service sector and in parts of the public sector. The service sector accounted for more than one-third of the increase in employment of electronics engineers in the private sector.

Third, within the industrial sector, the greatest increase took place in the automobile and computer industries and not in the mechanical engineering industry as might be expected from the strong Swedish position in mechatronics [2,11,18].

Fourth, it is evident that the share of electronics engineers in the total stock of engineers is quite high in many sectors of the economy. [8] This illustrates, of course, that electronics is not an industry but a technology which is widely diffused not only in industry but also in the private and public service sectors.

3.2. Distinguishing between industry and activity: the case of industrial electronics

Conventionally, the Central Bureau of Statistics uses a product-based definition for aggregating firms into industries. The wide diffusion of electronics and computer technology questions, however, the relevance of defining an 'electronics' industry. It is more relevant to think in terms of electronics 'activity'. This would allow us to include a number of 'hidden' electronics activities undertaken in establishments which use electronics as a 'supporting' technology (such as in the SAAB case mentioned above) and firms in the service sector which are closely integrated with the industrial sector and which, for all practical purposes, should be seen as a part of it. The distinction between industry and activity will be illustrated for the case of industrial electronics.

The conventional method of identifying the industrial electronics industry uses detailed information regarding the nature and composition of output for each establishment. The method has four drawbacks. First, the firms may have a very weak technology base in electronics even if they are registered as suppliers of electronics products. For instance, they may source complete VCRs from Japan and simply stick a new label on it. Second, with the very fast diffusion of electronics into more and more products, it may be very difficult to keep the product-based definition up to date. For instance, industrial robots did not figure as an industrial electronics product even in the statistics for 1990 in Sweden (in spite of having the world leader ABB Robotics in Sweden).

Third, firms may have a substantial industrial electronics activity in-house but it may not be reflected in the output of the firm, it is a hidden industrial electronics activity (doing software for the control of a washing machine or building firm-specific and proprietory-robotized production systems for the assembly of vacuum cleaners).

Fourth, it excludes the service sector. This is serious since the border between industry and service is gradually being eliminated with the growing degree of vertical disintegration (even larger industrial firms like Volvo are being turned into design and marketing organizations).

In order to be able to compare the conventional product-based definition of industrial electronics and our definition of industrial electronics 'activity', we used our method and data base to identify establishments involved in industrial electronics activity. We identified all Swedish establishments with four or more electronics engineers in 1987 (total 265 establishments) corresponding to 85% of all electronics engineers working in the Swedish private sector in 1987. We contacted all these establishments, and received written information concerning their technological and business activities. The return rate covered 96% of the identified engineers.

We distinguished between specialized industrial electronics firms and 'hidden' industrial

[8] If we somewhat arbitrarily set a lower limit of 20% of the share of electronics engineers in the total stock of engineers, and label those sectors electronics related, we find among these the aerospace and the mechanical engineering industries as well as parts of the service sector. Furthermore, in the public sector, the Swedish PTT, the Defence sector and the Swedish Water Board all come above that limit.

Table 2
The number of electronics engineers working with industrial electronics in Sweden in 1989

	Specialized industrial electronics firms		'Hidden' industrial electronics activity		
	as defined by SCB [a]	other industrial electronic firms	industrial firms	service sector firms	total
No.	718	287	684	260	1949
Percent	37	15	35	13	100

[a] Swedish Central Bureau of Statistics.
Source: Elaboration on Jacobsson et al. [11, table 3.1].

electronics activities. Specialized industrial electronics firms are those firms which sell industrial electronics products or services. [9] These firms are divided into those classified by the Swedish Central Bureau of Statistics as 'industrial electronics' firms and those which are not. 'Hidden' industrial electronics activities (i.e. industrial electronics activities which are found in firms not classified as industrial electronics firms) are found both in industrial firms and in the service sector. The results are given in Table 2.

In total, we estimated that about 1950 electronics engineers worked with industrial electronics in 1989. Only about 720 (37%) of these worked in firms defined as industrial electronics firms by the Swedish Central Bureau of Statistics. Most of the remaining electronics engineers were 'hidden' in other industrial firms (35%), (such as in the transport industry, the power equipment industry and in a whole set of mechanical engineering industries) and in the service sector (13%). We estimated that the remaining 15% worked in specialized industrial electronics firms which were not captured in the official statistics.

It is thus clear that industrial electronics activity is a far more significant feature of the Swedish economy than what a product-based definition of the industrial electronics industry would lead us to believe. This discrepancy would also lead us to question the relevance of a product-based industry definition.

This example also hints at the possibility of using our method to trace the evolution of the technology base of firms and industries, a subject which will be dealt with in the next section.

3.3. Applying educational statistics to measure the technology base of industries

The content of the technology base can be analysed at different levels; nation, industry, firm, business unit, and so on. In this section, we will use our method to analyse the technology base, and changes in it, of 25 4-digit ISIC industries in Sweden.

In Table 3, we present data on the total number of engineers using ten different educational categories for the 25 largest Swedish industries [10] in 1980 and 1989. A number of important observations concerning the technology base of these industries can be made from the table. First, 22 of the 25 industries increased the number of engineers between 1980 and 1989 [11].

Second, there was a general (and not only due to the diffusion of electronics competence) and statistically significant tendency towards increased technology diversity [12] in Swedish industry (and some service sectors) between 1980 and

[9] The following definition guided us in our classification work. Industrial electronics consists of 'electronic products or service which are incorporated in industrial products or systems other than "pure" electronics products and which are used in an industrial environment. "Pure" electronics products include computers, radio and telecommunications systems, space electronics, consumer electronics and medical electronics.

[10] The number of engineers employed in these industries in 1980 was 10 024, which is about 57% of all engineers working in Swedish companies in 1980. In 1989, 18856 engineers were employed in these industries, which corresponds to approximately 55% of the total. It shall be noted that the category 'others' are members within The Swedish Association of Graduate Engineers (Civilingenjörsförbundet) with academic degrees comparable to masters of science, for example biologists and chemists.

[11] These results are consistent with the results of Lekander [14] who found that for R&D activities in Swedish industry both the total number and the share of engineers increased in favour of staff with other educational backgrounds during the last 15 years.

[12] Kodama [13] and Pavitt [20] pioneered work on technology diversification.

1989 and many of the industries became multi-technology industries in the period 1980 to 1989. [13] The trends in technology diversification are formally tested by an entropy indicator [9,12,17]. Given p_{ij} to be the share of engineering category j of the total stock of engineers in industry i, then the industry entropy can be calculated as $\text{Entropy}_i = \text{SUM}(p_{ij} * \ln p_{ij})$. Two distinct factors will affect the value of the entropy measure. First, the number of engineering categories that an industry's engineers cover. Second, the eveness of the distribution of its engineers across the various categories. Thus, the more categories they cover and the more even the distribution of these across the categories, the higher is the entropy measure. For the industries covered in Table 3, 16 increased their technology diversity whilst only nine experienced a decrease in the entropy measure.

Third, mechanical engineering (M) is shown to be the most pervasive technology of all, including electronics. In 20 out of the 25 industries, mechanical engineering is the largest or the second largest category and the number of mechanical engineers grew greatly in this period. In the vehicle industry for example, the total number of mechanical engineers more than doubled between 1980 and 1989. Indeed, for these 25 industries, the growth of mechanical engineers was faster than that of electronics engineers [14].

Fourth, the technical service sector (8323 and 8324) grew extremely fast in its stock of engineers between 1980 and 1989. The firms in that sector are often very closely connected to manufacturing firms and provide industry with highly specialized inputs. This sector ought therefore to be part of any assessment of the technology base of industry.

[13] Granstrand and Sjölander [5] concerning multi-technology companies.

[14] This may not necessarily reflect the preferences of industry but the functioning of the educational system. It could, on the other hand, reflect an industry which is 'locked in' on mechanical engineering technology [10].

4. Conclusions and implications for future research

In this paper a new indicator of technological activity, educational statistics, has been introduced and we have demonstrated its usefulness through a few empirical examples. The method used has the advantage of indicating activity in a particular technology area independently of measurements of the products produced, of formal R&D expenditure and of patenting and publishing activities.

The study has shown consistent evidence for the rapid diffusion of electronics and computer technology to a broad set of industries, service sectors and public sector undertakings. Indeed, only 24% of the growth in the number of electronics engineers went to those industries normally thought of as the 'electronics' industry in the period 1981 to 1987.

The pervasiveness of electronics and computer technology questions the relevance of defining an 'electronics industry'. It may be more relevant to think in terms of 'electronics activity'. In a separate analysis of 'industrial electronics', this thesis was demonstrated by showing that only about 37% of all electronics engineers who were estimated to work with industrial electronics did so in firms identified by the Swedish Central Bureau of Statistics as 'industrial electronics' firms.

We have also illustrated how our method could be used to trace the evolution of the technology base of industries (and firms). We showed not only that the total number of engineers grew in most of 25 industries studied, but also that a process of technology diversification took place on a broad scale in the 1980s.

Moreover, we showed that still the most pervasive technology in Sweden is mechanical engineering, which grew faster in terms of the number of engineers than even electronics and computer engineers (E,D,Y) combined. This is clearly in line with the results of various studies on patenting by Swedish industry which show a strong concentration on patents in metals and mechanical engineering. Jacobsson [10] even finds that the revealed technological comparative advantage

Table 3
The depth and width of the technology base in 25 Swedish industries in 1980 and 1989

Industry [a]	Year	Engineering categories [b]											Entropy [c] diversification index
		B	E	F	K	V	M	I	D	Y	Others	Total	
3411	1980	6	26	19	163	6	58	2	0	0	37	317	1.213
	1989	4	35	24	218	6	79	12	1	7	54	440	1.193
3511	1980	10	29	17	147	6	47	5	0	0	22	283	1.279
	1989	28	9	15	246	4	72	14	0	1	50	439	1.080
3521	1980	0	1	0	22	0	1	0	0	0	8	32	0.345
	1989	1	0	0	63	0	4	1	0	0	13	82	0.335
3522	1980	1	6	5	126	1	4	5	0	0	45	193	0.619
	1989	1	34	34	363	2	29	14	3	5	157	642	0.865
3529	1980	4	1	0	28	0	3	0	0	0	3	39	0.746
	1989	3	5	3	68	1	29	2	1	1	19	132	1.067
3690	1980	6	3	3	16	27	19	1	0	0	8	83	1.509
	1989	11	4	2	17	46	15	0	0	0	6	101	1.415
3710	1980	236	20	50	31	8	70	8	0	0	50	473	1.301
	1989	328	21	70	22	17	133	19	3	12	47	672	1.308
3720	1980	50	6	3	23	0	18	2	0	0	34	136	1.275
	1989	55	1	3	9	2	16	0	2	0	41	129	1.153
3810	1980	13	11	16	5	3	106	3	0	0	12	169	1.064
	1989	31	22	18	37	18	187	14	0	4	18	349	1.286
3820	1980	13	0	0	0	0	2	0	0	0	2	17	0.393
	1989	17	6	5	14	2	41	1	0	1	5	92	1.418
3821	1980	4	13	9	6	0	90	8	0	0	15	145	0.877
	1989	8	33	9	18	6	175	0	0	0	15	264	1.026
3823	1980	28	8	0	0	1	20	2	0	0	4	63	1.062
	1989	52	14	9	1	1	58	9	3	3	5	155	1.232
3824	1980	21	18	14	11	7	127	3	0	0	11	212	1.195
	1989	18	13	10	20	6	104	6	2	2	8	189	1.271
3825	1980	3	329	55	2	0	43	11	0	0	41	484	0.795
	1989	9	532	136	8	13	156	54	27	72	107	1114	1.027
3829	1980	67	143	87	86	15	324	18	0	0	58	798	1.473
	1989	34	149	120	81	23	451	46	4	35	98	1041	1.343
3831	1980	34	595	134	65	6	229	23	0	0	85	1171	1.233
	1989	57	639	215	78	22	378	66	27	68	143	1693	1.318
3832	1980	4	949	136	29	2	101	41	0	0	91	1353	0.815
	1989	26	1365	331	59	29	292	104	76	186	233	2701	1.027
3839	1980	1	82	7	15	0	19	4	0	0	9	137	1.042
	1989	8	84	25	27	0	39	15	3	9	17	227	1.349
3841	1980	0	13	10	5	3	193	0	0	0	6	230	0.575
	1989	3	29	19	0	12	130	0	0	5	11	209	1.037
3843	1980	15	118	62	12	20	504	24	0	0	81	836	0.985
	1989	38	316	173	67	94	1287	96	23	24	332	2450	1.105
3845	1980	2	125	38	6	2	149	4	0	0	68	394	1.109
	1989	10	94	55	12	14	369	40	17	68	88	767	1.074
3851	1980	0	48	9	0	0	8	1	0	0	3	69	0.775
	1989	1	119	30	12	1	53	6	14	17	14	267	1.091
5012	1980	41	3	0	2	569	9	2	0	0	32	658	0.380
	1989	29	3	0	0	974	13	0	0	0	27	1046	0.217
8323	1980	5	34	23	4	3	27	4	0	0	7	107	1.452
	1989	10	311	132	10	43	123	46	66	36	106	883	1.241
8324	1980	55	527	140	36	477	174	19	0	0	206	1634	1.451
	1989	84	576	185	130	760	501	24	52	143	317	2772	1.522
Total	1980	619	3108	837	840	1156	2345	190	0	0	929	10024	
	1989	866	4414	1623	1580	2096	4734	589	324	699	1931	18856	

Significance of the increase in technology diversification with Wilcoxon signed ranks test: ($P = 0.030$).

of Sweden lies *increasingly* in metal and mechanical engineering.

Since the method presented in this paper is novel much remains to be done. Further research could be focussed on comparing the results using our indicator with those deriving from the use of patents and citations and such-like as indicators of technological activity. As an example, patent data could be used to analyse the extent of the 'hidden' electronics activities in Swedish industry (discussed in section 3.2). For instance, in the period 1980–1988, as much as 23% of Volvo's patents taken in the USA were in electronics (elaboration on data supplied to the Science Policy Research Unit, by the U.S. Department of Trade and Commerce, Patent and Trademark Office). As far as we know, Volvo does not have any significant sales of electronics products. This, quite substantial, innovative activity in electronics can therefore be expected to merely support Volvo's core areas. What is more important though, from a methodological point of view, is that educational statistics can be compared to patent data and provide a basis for discussing how well patent data (and other indicators of technological activity) reflects the competence profile of firms.

Such development could well be of considerable interest to policy makers. However, already now, the method can be used to improve the basis for decision making. For example, *educational* policy makers can get an improved understanding of the very diverse nature of firms and sectors which demand people with a training in a new generic area. Thus, it is abundantly clear that the future demand for a new generic technology, such as electronics, can not be estimated purely by interviewing the leading firms in that area, e.g. the electronics industry. With a strong pervasiveness, much of the demand for engineers with training in that generic area will come from firms which 'only' use the new technology as a supplement to their existing technology base.

Moreover, *industrial* policy makers can find our method useful as they can, for instance, use the method to trace the economy's allocation of its technological competence. It is, for example, even possible to identify [10] whole clusters of industries (users and suppliers), service and public sector units which make up the various technological systems of a nation [,2]. For instance, we have identified three clusters of industrial firms, private service sector firms and public institutions which account for approximately half of all electronics engineers [15] employed in Sweden. These firms and institutions are active in three broad application areas; tele/radio communications, defence and power generation/transmission. Approximately, there were 2000, 1300 and 950 such

[15] These are defined as graduates in E, D and Y, see Table 1.

Notes to Table 3:

[a] The studied industries are: Manufacture of pulp, paper and paper board (3411), Manufacture of basic industrial chemicals (3511), Manufacture of paints, varnishes and lacquers (3521), Manufacture of drugs and pharmaceuticals (3522), Manufacture of chemical products not classified elsewhere (3529), Manufacture of other (than glass) non-metallic mineral products (3690), Iron and steel basic industries (3710), Non-ferrous metal basic industries (3720), Manufacture of fabricated metal products, except machinery and equipment (3810), Manufacture of machinery except electrical (3820), Engines and turbines (3821), Manufacture of metal and wood working machinery (3823), Manufacture of special industrial machinery (3824), Manufacture of computers and business machines (3825), Machinery and equipment except electrical equipment not classified elsewhere (3829), Manufacture of electrical industrial machinery and apparatus (3831), Manufacture of telecommunication equipment (3832), Manufacture of electrical apparatus and supplies not elsewhere classified (3839), Ship building and repairing (3841), Manufacture of motor vehicles (3843), Manufacture of aircraft (3845), Manufacture of instruments (3851), Construction (5012), Data processing and tabulating (8323) and Engineering, architectural and technical services (8324).

[b] The categories are described above (section 2).

[c] = Entropy index. Given p_{ij} is the share of engineering category j of the total stock of engineers in company i, then the entropy of the firm can be calculated by $\text{Entropy}_i = -\text{SUM}(p_{ij} * \ln p_{ij})$.

Source: Elaboration on data supplied by the Swedish Association of Graduate Engineers.

engineers in these clusters in 1987 which constituted Sweden's main areas of strength in the electronics field. [16] Of course, our method can then be used to see how these clusters, as well as others, react to any public policy measures.

References

[1] D. Archibugi and M. Pianta, The Technological Specialization of Advanced Countries, draft report prepared for the Commission of the European Communities, Consiglio Nazionale delle Recerche, Roma, 1990.

[2] B. Carlsson and S. Jacobsson, What makes the Automation Industry Strategic? Economics of Innovation and New Technology 1 (4) (1991).

[3] C. Edquist and S. Jacobsson, Flexible Automation. The Global Diffusion of New Technology in the Engineering Industry (Basil Blackwell, Oxford, 1988).

[3a] B. Carlsson and R. Stankiewicz, On the nature, function and composition of technological systems, Journal of Evolutionary Economics 1 (2) (1991) 93–118.

[4] A. Granberg, A Bibliometric survey of fibre-optics research in Sweden, West Germany and Japan, In H. Grupp (Editor), Problems of Measuring Technological Change (Verlag TUV Rheinland, Köln, 1986).

[5] O. Granstrand and S. Sjölander, Managing Innovation in Multi-Technology Corporations, Research Policy 19 (1) (February 1990) 35–60.

[6] Z. Griliches, Hybrid corn: an Exploration in the Economics of Technological Change, Econometrica 25 (1957) 501–522.

[7] H. Grupp, Technometrics as a Missing Link in Science and Technology Indicators, in: J. Sigurdsson (Editor), Measuring the Dynamics of Technological Change (Pinter, London, 1990).

[8] H. Grupp, and O. Hohmeyer, The ISI-approach to Technometrics: Outline of the Conceptual Framework and Assessment of Technological Standards, in: H. Grupp (Editor), Problems of Measuring Technological Change (Verlag TUV Rheinland, Köln, 1986).

[16] Process control and instrument is a further area of strength [18] which, however, partly overlaps with the above areas.

[9] R.E. Hoskisson, M.A. Hitt, R.A. Johnson and D.M. Douglas, Construct Validity of an Objective (Entropy) Categorical Measure of Diversification Strategy, Strategic Management Journal 14 (1993) 215–235.

[10] S. Jacobsson, Sweden's Technological System and Future Competitiveness, mimeo, Dept of Industrial Management and Economics, Chalmers University of Technology, Göteborg, 1992.

[11] S. Jacobsson, S. Oskarsson and L. Bångens, Industriell elektronik i Sverige – aktörsstruktur och tillväxtmönster, Industrial Management and Economics, CIM-Report, R (1989) 06.

[12] A.P. Jacquemin and C.H. Berry, Entropy Measure of Diversification and Corporate Growth, Journal of Industrial Economics 27 (1979) 359–369.

[13] F. Kodama, Technological Diversification of Japanese Industry, Science 233 (18 July) 291–296.

[14] P. Lekander, Industriella FoU-insatser i Sverige 1973–1989–en trendanalys. Chalmers Tekniska Högskola, Department of Industrial Management and Economics, CIM-Report R (1990) 02.

[15] A. Nylen, Teknikerns arbete under en 10-årsperiod, Master Thesis, No. 1989-33, Department of Industrial Management and Economics, Chalmers University of Technology, Göteborg, 1989.

[16] OECD Science and Technology Indicators No. 2: R&D, Invention and competitiveness, Paris, 1986.

[17] K. Palepu, Diversification Strategy, Profit Performance, and the Entropy Measure, Strategic Management Journal 6 (1985) 239–255.

[18] P. Patel and K. Pavitt, The Technological Activities of the World's Largest Firms: A Preliminary Analysis, Paper presented at the Prince Bertil Symposium on Corporate and Industry Strategies for Europe, Stockholm School of Economics, 9–11 November 1988.

[19] K. Pavitt, Patent Statistics as Indicators of Innovative Activities: Possibilities and Problems, Scientometrics 7 (1–2) (1985) 77–99.

[20] K. Pavitt, Uses and abuses of patent statistics, in: A.F.J. van Raan (Editor), Handbook of Quantitative Studies of Science and Technology (Elsevier Science Publishers B.V. (North-Holland), Amsterdam 1988) Ch. 16, pp. 509–536.

[23] J. Schmookler, Invention and Economic Growth (Harvard University Press, Cambridge MA, 1966).

[24] V. Walsh, The use of Patents and Other Indicators in the Study of Invention and Innovation in the Chemical Industry, Conference Paper at STIU/OECD, Paris, 1982.