Appropriability, Technological Opportunity, Market Demand, and Technical Change - Empirical Evidence from Switzerland

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SUMMARY

The purpose of this paper is to analyze both theoretically and empirically those factors which underlay the - empirically observable - inter-industry differences in technical progress. At the theoretical level economists agree more and more that technical progress can be explained at the industry level by the following three factors: (1) the technological opportunities, (2) the appropriability conditions, meaning the ability to capture and protect the results of technical innovations and (3) the market demand conditions.

The basic theoretical model was tested with the help of two sets of Swiss data. One set was made available by Swiss Federal Office of Statistics and consists of quantitative information on R&D expenditures, R&D personnel, total employment and sales figures for 124 (4-digit SIC) industries for the year 1986. The second set was derived from a survey I carried out in the summer of 1988. 940 industry experts were approached; 358 of them, or 38%, covering 127 industries, completed the questionnaire. The items on the questionnaire were related to the two supply-side determinants of technical progress - items (1) and (2) above.

For the empirical specification of the theoretical model, technical progress (as the dependent variable) was measured by three indicators: an output indicator, representing the introduction rate of innovations since 1970; two input indicators, "share of R&D expenditures in sales" and "share of R&D personnel in total employment". All data were aggregated at the industry-level (4-digit SIC). Three equations were estimated individually, using the OLS, GLS and Tobit methods.

The most important results of the empirical analysis can be summarized as follows:

- The ability to appropriate the results of innovations exerts a positive impact on technical progress in all three models. In this context, the non-patent related means of appropriability "secrecy", "lead time", "moving downward on the learning curve" and "superior sales and service efforts" prove to be more important for the innovation process than the means "patents to protect against imitation" and "patents to secure royalty income".
- Of all external sources of technological opportunities, domestic and foreign university research makes the largest quantitative and statistically most significant contribution to technical progress.
- Science (i.e. education in 14 science fields) is on the whole relevant for technical progress. But its contribution to technical progress would increase, if at the R&D level its application could be better targeted.
- Of the six fields of basic science, only in mathematics and in theoretical computer science is education relevant for technical progress.

- The relevance of education and training in the applied sciences for technical progress is high and significant in the fields of medical science and electronics.
- The impact of sales as an indicator for market demand is negative. Industries with relatively low sales are relatively more innovative than those with a higher level of sales.

APPROPRIABILITY, TECHNOLOGICAL OPPORTUNITY, MARKET DEMAND, AND TECHNICAL CHANGE--EMPIRICAL EVIDENCE FROM SWITZERLAND

1. INTRODUCTION

Major classical and neo-classical economists, such as Adam Smith, Karl Marx and Alfred Marshall, discussed technical progress explicitly and intensively. Economists of later generations, however, especially those of the first half of the 20th century, considered technical progress to be a given fact, an exogenous "black box", and they explored only marginally its nature, its determinants and its effects[2]. But since the mid-1950s, a renewed interest in the question of technical progress has developed, an interest which is rapidly and constantly growing. There are various reasons for this. The fact that economists live in a real world which is increasingly penetrated by new technologies forces them - directly or indirectly - to consider the issue. But the profession's reviving interest in technical progress during recent decades also stems from sources within the discipline of economics itself (cf. Nelson 1987).

Empirical studies carried out during the 1950s for the US National Bureau of Economic Research stressed the key role of technology in explaining long-term economic growth (see, in particular, the studies by Abramovitz, Denison, Fabricant, Kuznets and Kendrick). The well-known article by Solow (1957), "Technical Change and the Aggregate Production Function", should be mentioned in particular. Further work based on these theoretical and empirical studies was carried out[2].

The highly influential works of Schumpeter are a second source. With regard to technical progress he came to the following conclusion: "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production and transformation, the new markets, the new forms of industrialization that capitalist enterprise creates." (Schumpeter 1950:83). Schumpeter's central theses have been tested empirically and further developed by industrial economists, both theoretically and empirically[3].

A third source is to be found in the field of agricultural economics, in particular, in the debate on the results of government spending for agricultural research and on the question whether or not such spending is theoretically justifiable at all (cf. e.g. Griliches 1958). This debate has since been extended to other fields, such as the economics of health . In turn, this brought new life into the question of market failure and into the discussion on the justification of state intervention in R&D.

Finally, there are Leontief's early empirical studies (1966). Leontief showed, surprisingly, that, generally speaking, the USA did not export capital-intensive or technology-intensive goods at that time. This was another motive for economists to study technical progress and its consequences for international trade.

Thus, the present intensity of debate on the issue of technical progress has diverse historical roots and can be traced back to a variety of developments in economic research. Technical progress is now recognized by most economists as an economic phenomenon which requires their full attention, not in the least because its contribution to economic growth is very important. Depending on the method of calculation technical progress accounts for 30% to 50% of growth. It should, however, be pointed out that not only the rate of technical progress, but also its contribution to economic growth, differs quantitatively from country to country and among sectors of the economy. Considerable differences in technical progress, and therefore in economic growth, exist both at the inter-industry and at the international level.

In Switzerland, as in other open economies, the future of the economy will be strongly influenced by two factors: the ability of

Swiss industries to innovate and, closely related to this, their ability to compete internationally. In both cases, R&D and the resulting technical innovations play a key role. This is one reason why the Swiss Federal Office of Statistics regularly collects data on R&D expenditure and R&D personnel in the Swiss private sector. This provides all those who have an interest in R&D with a very important quantitative-statistical basis. However, a policy-oriented interpretation of the available quantitative information requires additional knowledge about the qualitative factors that determine technical progress. The purpose of my work, which is summarized in this paper, is to fill this research gap in Switzerland. My analysis is based on the following key questions:

- How can technical progress be measured on the basis of the data available on Swiss industry?
- Theoretically, what are the determinants of technical progress, especially at the industry level?
- How can the inter-industrial differences in technical progress be "explained" empirically in the framework of a theoretically well-founded model?

In other words, the idea is to determine theoretically, as well as to test empirically, the central factors which are behind the empirically observable inter-industrial differences in technical progress. I will first present the theoretical framework within which I will be working, then the econometric models which I will be testing, using data on Swiss industry. Finally I will present the results of the empirical analysis and draw some conclusions.

2. THEORETICAL FRAMEWORK

2.1 The concept of technical progress

Technical progress expresses itself "in the production of new or improved products or in the introduction of new production processes which enable a larger volume of production for an unchanged product at equal costs, or the same volume of production at lower costs" (Geigant et al. 1979). The qualitative improvement of both products and production processes is the result of increased scientific knowledge on the one hand and increased technical-organizational know-how on the other.

J. A. Schumpeter divided the process of technical progress into three phases: (1) invention, (2) innovation and (3) imitation or diffusion. Assuming that inventions stem from R&D-activities, the process of technical progress can be subdivided into five phases:

1. Research
2. Development
3. Invention
4. Innovation
5. Imitation or diffusion

Together, the first three phases constitute technological progress. One only speaks of technical progress after a new or improved product or production process has been successfully introduced into the market (i.e. phase 4). Moreover, these phases should not be seen in isolation and independent from one another. The process of technical progress does not proceed in a linear fashion from one phase to the next, rather it is circular. The various phases are interrelated and dependent on feedback from the others. The orientation of R&D activities in particular is becoming more and more dependent on market requirements, embodied in phase 4.

2.2 Measuring technical progress

When one wants to measure technical progress, one encounters four basic concepts in the literature on industrial economics:

- Input concepts

- Output concepts
- Input-output concepts
- Process concepts

These concepts are generally used to identify possible indicators for measuring either the level of technical progress (static) or its rate of growth (dynamic).

Under the rubric "Input concepts" we include methods aimed at identifying indicators for technical progress which are tied to the input side of the production process, i.e. the factors of production. These include:

1. R&D expenditures as a percentage of particular economic variables at the national level (e.g. GDP), at the level of individual firms or industries (sales or value-added)
2. R&D employees as a percentage of total employment
3. Bibliometric indicators
4. Number of patents and licensing agreements (as an output of R&D-activities)
5. Age structure of physical capital

Input concepts 1-5 all suffer from the basic disadvantage that input variables can be used only to a limited extent for drawing direct conclusions about the output of the innovation process (i.e. the total of all new or improved products and production processes).

Output concepts, on the other hand, are designed to estimate technical progress in terms of the results of the production process; as such, technical progress manifests itself in the form of new or improved products and/or production processes. In the case of investment goods, economic efficiency criteria can be used (e.g. a reduction of the cost for a certain output volume). But in the case of consumer goods a number of difficulties arise. There is the question whether or not "new" consumer goods should incorporate new technologies, or whether or not a new coat of paint for a product should be counted as technical progress. Since there is no unambiguous economic criterion in the case of consumer goods, the literature also uses various output concepts:

1) "Newly fashioned goods". According to Oppenländer, who uses this concept, the cost factor alone is not a sufficient criterion. Rather, the relationship between utility and costs determines whether a "new" consumer good embodies technical progress or not. From this perspective Oppenländer arrives at the conclusion that there are relatively few "new goods", that is, goods which meet a truly new consumer demand. Much more common are "newly fashioned goods" - substitution goods. These "newly fashioned goods" can be evaluated in terms of objective and subjective components of utility.

2) Product life-cycle. This concept is used to help identify indicators for technical progress embodied in new products. Heinen (1970) has noted that goods pass through characteristic "phases of maturity". In the computer industry, for example, the product life-cycle is now less than two years, while during the 1970s it was five years. Thus, this indicator provides information about the acceleration of technical progress in this industry.

3) Technical characteristics. This concept is an attempt to define technical progress only in terms of technical considerations, for example, mechanical versus electronic watches.

Input-output concepts use production functions to measure the contribution of technical progress to total output or to test hypotheses with regard to the acceleration of technical progress (see e.g. Denison on the USA, and Oppenländer on the former FRG). These are usually Cobb-Douglas functions, using labour and capital as production factors and a residual factor which is meant to represent technical progress. A large part of economic growth is not due to changes on the input side of production, but should be attributed to "technical progress". Increases in total productivity, however, may also have other causes, such as changes in output volume (economies of scale) or changes in the utilization rate of the production factors involved. Several authors (e.g. Denison) have, therefore, tried to determine which part of the residual factor is explained by the contribution of actual technical progress.

Even when certain assumptions of the Cobb-Douglas function are dropped (linear homogeneity and a substitution elasticity of 1) technical progress is still seen as unembodied and exogenous. From this perspective technical progress is not due to the introduction of new, better production factors (Gahlen 1972). More realistic models, for instance vintage models, were therefore developed (Solow 1960, Oppenländer 1971 and 1976). In such models, capital stock is not only weighted by age structure, but also by its annual efficiency.

In contrast to total productivity, factor productivities are less suitable for the analysis of technical progress since a change in one factor usually causes changes in all factors of production. Nor can the growth of capital intensity (as an input/input variable) by itself be considered as an indicator of technical progress.

At the firm level and at the level of industries and national economies as a whole, technical progress can be considered as a temporal shift of the production function. Schumpeter already characterized technical progress as the "setting up of a new production function". This allows a conceptual separation of technical progress from pure factor substitution.

The concepts discussed so far treat the production process as a "black box". Process concepts are an attempt to understand technical progress by analyzing production processes, that is, by examining what is in the "black box". This approach, though most frequently used for analyses of industrial activities, has also been used to study developments in the tertiary sector. Within the framework of an approach to analyze technology, Scholz (1977) attempted to identify and characterize changes in four variables: labour processes, automation, complexity of technical organization structures, size of production units. Scholz views this approach as a possible basis for the development of a set of statistics on technical change.

Due to availability limitations of data my study uses the following three indicators to define technical progress: the "share of R&D expenditure in sales" and the "share of R&D employment in total employment" as input indicators, and the "introduction rate of innovations since 1970" as an output indicator. While the first two can be measured empirically, the third cannot be quantified directly. Instead, I used the subjective answers given by R&D experts to related questions in an written survey (Harabi (1988), see below under 3.2).

In addition to the general objections to input concepts mentioned above, the input indicators used here have additional theoretical shortcomings:

- Operational criteria enabling a clear demarcation of the firm activities "R&D" and "Production" are lacking, especially for small and medium-size firms.
- Given the highly stochastic character of R&D results, it seems risky to draw conclusions about the output of the R&D process on the basis of input variables (here: R&D expenditure and R&D employment).
- Not only the level of R&D expenditure and employment are important; the right choice of research projects and their proper integration into the general innovation strategy of a firm are also of key importance.

In spite of such objections, these input indicators have become widely used in research because the statistical data can be easily collected and are generally available. I shall also use them. The third indicator is better from a theoretical point of view because it measures the output of the innovation process. But its direct quantification is very complex, indeed virtually impossible for an individual researcher. I have therefore used a qualitative and indirect method to measure the introduction rate of innovations. (I will return to these indicators in section 3.2, where the empirical model is discussed).

2.3 Determinants of technical progress

Economists increasingly agree that technical progress should not be treated any longer as a "black box", but as an economic phenomenon, which can be explained at the industry level by the following three factors:

1. Technological opportunities;
2. Appropriability conditions (i.e. the ability to appropriate the results of technological innovations);
3. Market demand conditions.

In other words technical progress at the industry level, like many other economic phenomena, is determined both by supply factors (factors 1 and 2) and by demand factors (factor 3). These three determinants are used in evolutionary models (see Nelson and Winter (1982) and Nelson (1987)), as well as in neo-classical models (although not always explicitly) - see Nelson (1959), Arrow (1962), Dasgupta and Stiglitz (1980), Flaherty (1980), Lee and Wilde (1980), Levin (1978), Loury (1979); for a survey of the theoretical literature see Reinganum (1989).

According to both evolutionary and neo-classical models, technical progress (TP) depends, first, on the volume (VRD) and secondly on the productivity (PRD) of R&D expenditures. R&D expenditures are again determined by the size of the market (MARKET), by technological opportunities (the opportunities for access to technologically useful knowledge - OPPORTUNITIES) and by the ability of the economic system to appropriate the results of innovations (APPROPRIABILITY). The productivity of R&D expenditures is also dependent on the last two factors. These overall theoretical relationships can be summarized in the following equations:

TP = f (VRD, PRD)
VRD = f (MARKET, OPPORTUNITIES, APPROPRIABILITY)
PRD = f (OPPORTUNITIES, APPROPRIABILITY)

It then follows that

TP = f (MARKET, OPPORTUNITIES, APPROPRIABILITY)

Relevant surveys, especially of the empirical literature on the subject, have been provided by a.o. Dosi (1988) and Cohen/Levin (1989). From this literature, I selected a very useful theoretical model for a systematic analysis of the industry-level determinants of technical progress which are postulated in very general terms above. This model, known as the "R&D capital stock model", was formulated by a.o. Nelson and will be presented here in detail (see Nelson/Wolff 1988 and Baumol/Wolff 1983). The basic idea is that the technical progress or - to use the input-output concepts formulated on the basis of production theory (see above) - the total factor productivity A_t of an industry is dependent on the cumulative R&D capital stock R_t and on other exogenous factors (especially external technological opportunities), which are represented here by a time factor t. The equation is then as follows:

$$A_t = R_t^b e^{at}, \quad d^2A/dR^2 < 0; \; d^2A/dRdt > 0. \qquad (1)$$

It is assumed (and this is characteristic of this type of R&D capital stock models) that the marginal productivity of increasing amounts of R&D capital decreases, but that there are external factors which compensate for these decreasing marginal returns. Parameter a is the rate at which these external factors compensate for decreasing marginal returns of increases in R; b is the elasticity of A in relation to R. It is, moreover assumed, that an increase in A, i.e. in total factor productivity or the in level of technical change, equals a reduction of production unit costs.

For an examination of the dynamics of this system, the relationship between the growth rate of A and that of R can be derived from equation (1) as follows:

$$(2) \qquad \dot{A}/A = a + b\,\dot{R}/R$$

The next step is to specify $\dot{R}/R$. To keep things simple, it is assumed that the R&D capital stock does not depreciate and that r signifies the proportion of R&D expenditures in sales. The latter is also called R&D-intensity. In this case, an increase in R equals r multiplied by total sales (P.Q):

$$(3) \qquad \dot{R} = rPQ$$

where P represents unit price and Q represents output. If both sides of equation (3) are divided by R, one arrives at equation (4):

$$(4) \qquad \dot{R}/R = rPQ/R$$

If, furthermore, we assume (a) that an increase in total factor productivity will be fully expressed in lower prices (through lower unit production costs) - i.e. $A/A = -P/P$ - and (b) that the price elasticity of demand (-E) is constant, then we arrive via equation (2) at:

$$(5) \qquad -\dot{P}/P = a + b\,\dot{R}/R$$

and

$$(6) \qquad \dot{Q}/Q = E\,(a + b\,\dot{R}/R)$$

If an exogenously given equilibrium growth rate of R&D capital stock is termed G (i.e. $G = \dot{R}/R$), then the result is equation (7a). This is because R and QP must grow in the same rate in an equilibrium situation:

(7a) $$G = \dot{P}/P + \dot{Q}/Q$$

and (5) and (6) lead to:

(7b) $$G = - (a + bG) + E (a + bG)$$

or, by a slight manipulation of (7b):

(7c) $$G = a (E-1)/1- b (E-1)$$

Furthermore, (2) and (7c) result in:

(8) $$\dot{A}/A (G) = a + b a (E-1)/1- b (E-1)$$

Equation (8) is of key importance because it determines the equilibrium growth rate of the total factor productivity and of technical progress $\dot{A}/A$ (G). This depends on the three parameters a, b and E, which embody two of the three determinants of technical progress mentioned above: a and b standing for technological opportunities and E for demand conditions. This equation also indicates the order of magnitude of these relationships: for an equilibrium with a positive G-value to exist, a must be positive; E must be larger than 1; and b (E-1) must be positive, but smaller than 1, while b must be larger than 0 and smaller than 1.

It should, however, be noted that the R&D intensity r is not included in equation (8), and therefore has not played a role in determining the equilibrium growth rate of total factor productivity or of technical progress so far. In other words, the rate at which unit production costs would fall is independent of R&D intensity. The questions now are how this important factor r can be integrated into the system and which role it plays. To answer these questions, equation (4) must be slightly rearranged and $G = \dot{R}/R$ must be introduced. This results in equation (9):

$$(9) \qquad R/QP = r/G$$

While equations (7) and (8) determine the equilibrium growth rates of R&D capital stock and of total factor productivity, thus allowing "steady state" conclusions to be drawn, equation (9) allows the following statement to be made: independent of the sales level QP, an exogenous increase in R&D intensity r leads to an increase in R&D capital stock and - through further equations in the model, such as (3) - therefore to a higher level of total factor productivity as well; this in turn leads to lower unit production costs. The rate at which these unit costs decrease, is, however, independent of r (see equation 8).

Since r is one of the main variables in models of total factor productivity and technical progress, it should also be endogenized by these models, i.e. it should be explained by the system's equations and not be considered an exogenous variable, as has been the case. To achieve this, we must make additional assumptions. In the model discussed here, Nelson makes the common theoretical assumption of a profit-maximizing equilibrium: adjustment in R&D capital stock should only be undertaken when marginal benefits from new R&D investments are equal to marginal costs. Marginal benefits in this case are the equivalent of additional reductions in cost (-dc.Q) made possible by those new R&D expenditures whose results can be appropriated by the investing economic unit.

The level of these marginal benefits is therefore dependent, as well, on the time period (T) during which new R&D expenditures can be economically exploited before competitors begin to imitate. This variable T represents the "appropriability conditions" mentioned above. Investment in R&D capital stock takes place until the profit-maximizing equilibrium condition "marginal benefits = marginal costs" (equation 10a) is fulfilled.

$$(10a) \qquad -\, dc.Q.T = dR$$

If, instead we take the difference between marginal costs and marginal benefits (which represents additional profit), then in a state of equilibrium the following obtains :

$$(10b) \qquad d\pi = -\, dc.Q.T - dR = 0$$

where π represents profit and $d\pi$ changes in profit. If the additional savings ($-$ dc.Q.T) are divided by total costs (c.Q), and the additional R&D (dR) investments are divided by total sales (P.Q), then the result is:

$$(11a) \qquad (-\, dc/c)T = dR/QP$$

Since $(-\, dc/c)T = \dot{A}/A$ and $dR/QP = r$, R&D-intensity r can be written as follows:

$$(11b) \qquad r = T.\ \dot{A}/A$$

Together with equation (8), which indicates the factors determining A/A in equilibrium, equation (11b) shows that a profit-maximizing R&D intensity at the industry level is positively determined by the following three factors:

- market conditions, represented by the price elasticity of demand, E, in this model;
- technological opportunities, represented here by parameters a and b; and finally
- the ability of the system to appropriate R&D results (appropriability conditions), represented here by variable T.

These three factors represent the theoretical specifications of the variables MARKET, OPPORTUNITIES and APPROPRIABILITY, postulated at the beginning of Section 2.3. These three factors are the driving forces behind inter-industrial differences in technical progress.

3. EMPIRICAL ANALYSIS

3.1 Data

In this section the theoretical implications of the model will be tested. For a general overview of the empirical literature in this field see Cohen/Levin (1989), especially the papers of Cohen/Levinthal (1989) and Levin et al (1985).

For the empirical analysis I will be using two sets of Swiss data. One set was made available by the Swiss Federal Office of Statistics, the other is the result of my own data collection. The former data set was produced in 1987 in the context of the regular bi-annual collection of R&D data by the Federal Office of Statistics. It consists of data from 1986 on R&D expenditures, R&D personnel, sales and total employment in 124 (4-digit SIC) industries. The second data set is the result of a survey among Swiss industry experts carried out in the summer of 1988; it contains quantified information on the supply-side determinants of technical change. This data has also been aggregated at the level of (4-digit SIC) industries. (For an extensive description of the questionnaire and of the preliminary results see Harabi (1991).)

The sample frame for the survey was formed by industry experts working in 1157 firms which were characterized as "firms actively engaged in R&D" (in a publication of the head office of the Swiss Federation for Trade and Industry, see Schweizerischer Handels- und Industrieverein 1987:11). Experts in 217 firms located in the French and Italian-speaking parts of the country could not complete the German version of the questionnaire and were dropped from the survey. Nonetheless, experts in the larger firms in these regions did take part.

Of the 940 experts who participated, 358, or 38% completed the questionnaire. These experts were active in 127 (4-digit SIC) industries. Taking the industrial structure of their activities at the 2-digit level, 38% of the respondents worked in the machinery and metals industry, 23% in the chemicals industry, 2% in the watch-making industry, 3% in the textile and clothing industry, 6% in the food industry and 5% in the plastics and paper industry; additionally, 4% of the responses came from the construction industry, 7% from technical services and 3% from private research laboratories.

An additional important piece of information about the participating experts is the structure of the R&D expenditures in their firms which, in 1986, was as follows: less than 1 million Swiss Francs was spent by 55% of the firms, 1 to 2 million by 10.5%, 2 to 5 million by 10.5%, 7 to 10 million by 7%, 10 to 50 million by 9%, and more than 50 million by 8%.

3.2 Econometric specification

Three models will be tested in this section. In combination, they represent an empirical approximation for the theoretical model discussed above. The only difference among them is in the choice of the dependent variables. These are the "introduction rate of innovation" in the first model, the "intensity of R&D expenditures" in the second model and the "intensity of R&D employment" in the third model. Operationally, these variables are defined as follows (see Annex Table 1 for the explanation of all the variables to be discussed below).

The introduction rate of innovations (INNOV) is the sum of values given in answer to questions IV.A and IV.B of the questionnaire: "How would you characterize the speed at which new or improved production processes were introduced in your industry since 1970?" and: "How would you characterize the speed at which new or improved products were introduced in your industry since 1970?". The responses varied from 1 (very slow) to 7 (very rapid). R&D intensity

(RDINTE) is defined as the share of R&D expenditures in sales per industry, and the R&D employment intensity (PERINTE) as the share of R&D personnel in total employment per industry in 1986. In sum, technical progress, as the dependent variable, is measured by three indicators: an output indicator INNOV and two input indicators, RDINTE and PERINTE.

As described above, there are three groups of independent variables: appropriability conditions of R&D results (APPROPRIABILITY), technological opportunities (OPPORTUNITIES) and market demand conditions (MARKET).

APPROPRIABILITY: In the theoretical model, appropriability is represented by T; it is operationalized empirically here by three variables: APPROPRIA1, APPROPRIA2 and IMITATE. APPROPRIA1 and APPROPRIA2 are the two principal components, summarizing through factor analysis the items 1 to 6 of question I.B in the questionnaire. This question focuses on the effectiveness of six different means of capturing and securing competitive advantages from product innovations. APPROPRIA1 represents the effectiveness of two means: "patents to protect against imitation of new or improved products" and "patents to secure royalty income". APPROPRIA2 represents the effectiveness of the remaining four means of appropriability not related to patents: "secrecy", "lead time", "moving downward on the learning curve" and "superior sales and service efforts". Theoretically, it is to be expected that effective protection of R&D results and the ensuing innovations will exert a positive influence on technical progress in an industry.

If competitors are unable to imitate innovations rapidly, or to imitate them at all, the results of innovations are protected indirectly. In other words: the longer the imitation time lag, the longer the monopoly on economic exploitation by the innovating firms within a specific industry, which again improves their financial situation and will increase their R&D investments. According to theoretical considerations, the result must be a greater capacity to innovate. All this is taken into account by the variable IMITATE, which represents the time required for successful imitation of major, patented product and process innovations.

OPPORTUNITIES: Technological opportunities are operationalized by two groups of variables. The first group pertains to the contribution of external sources of technological opportunities, the second to the special relevance of science - represented by the relevance of education and training in specific fields of science - for the technical progress in a specific industry.

The first group consists of the contributions of suppliers of material inputs (SUPPLIER1), of suppliers of equipment for production and for R&D (SUPPLIER2), of product users (USER), of domestic and foreign academic research (UNIVERSITY) and of other public research institutions, enterprises and agencies (STATE). The term "contribution" refers explicitly in the questionnaire to such items as finance, personnel, information, etc.

The second group of variables "relevance of science for technical progress" is defined by two indicators. One indicator is the relevance of education and training in fourteen selected fields of basic and applied science. The six fields of basic science are biology, theoretical chemistry, geology, mathematics, theoretical physics, theoretical computer science. The fields of applied science are agronomy, applied mathematics and operations research, applied computer science, materials science, medical science, applied chemistry, electronics and mechanical engineering. The other indicator (SCIBASE), defined as the cumulative relevance of all fourteen fields for technical progress, measures the relationship between science as a whole and technical progress in a specific industry. Theoretically, a positive effect of technological opportunities on technical progress is to be expected (see the positive sign preceding parameters a and b in the theoretical model). Since, however, the empirical operationalization also includes institutional factors which are country-specific, it cannot be determined ex-ante which variable influences technical progress and whether its influence is positive or negative. The "+" or "-" sign can therefore only be determined empirically, ex-post.

MARKET: According to economic theory, the MARKET variable should be represented by the price elasticity of demand. Since this type of information is not available in Switzerland for all the 127 industries analyzed here, the market conditions are operationalized by the following two indicators: first, by sales (SALES) as an indicator for market volume or market demand; second, by a measure for market competition (COMPETITION), defined as the number of firms which are capable of imitating a major innovation made by a competitor in a particular industry. It is an indicator for technological competition and not for sales-market competition. In the case of sales a positive sign should be expected, whereas in the case of the second variable it is theoretically difficult to predict a sign ex-ante for the following reason. On the one hand, economic theory postulates a positive effect of competition on innovative activity. On the other hand, technological competition in a certain market can be seen as an indicator for this market's ability to protect an innovation which it has made and to appropriate its results (see the group of variables APPROPRIABILITY above). The smaller the number of those capable of imitating a certain innovation in a certain market, the greater the ability of this market to protect its innovation, and therefore the more positive the effect on technical progress. Therefore a positive or negative sign of the variable COMPETITION cannot be determined ex-ante. It depends on the net effect of competition, which can only be determined ex-post.

In sum, I will estimate the following three equations:

INNOV = a0 + a1.APPROPRIA1 + a2.APPROPRIA2 + a3.IMITATE + a4.SUPPLIER1 + a5.SUPPLIER2 + a6.USER + a7.UNIVERSITY + a8.STATE + a9.BIOLOGY + a10.CHEMISTRY1 + a11.GEOLOGY + a12.MATHS1 + a13.PHYSICS

+ a14.INFORMATICS1 + a15.AGRONOMY + a16.MATHS2 + a17.INFORMATICS2 + a18. MATERIALS + a19.MEDICAL + a20.CHEMISTRY2 + a21.ELECTRO + a22.MACHINES + a23.SCIBASE + a24.SALES + a25.COMPETITION + μ_i.

RDINTE = a0 + a1.APPROPRIA1 + a2.APPROPRIA2 + a3.IMITATE + a4.SUPPLIER1 + a5.SUPPLIER2 + a6.USER + a7.UNIVERSITY + a8.STATE + a9.BIOLOGY + a10.CHEMISTRY1 + a11.GEOLOGY + a12.MATHS1 + a13.PHYSICS + a14.INFORMATICS1 + a15.AGRONOMY + a16.MATHS2 + a17.INFORMATICS2 + a18. MATERIALS + a19.MEDICAL + a20.CHEMISTRY2 + a21.ELECTRO + a22.MACHINES + a23.SCIBASE + a24.SALES + a25.COMPETITION + μ_i.

PERINTE = a0 + a1.APPROPRIA1 + a2.APPROPRIA2 + a3.IMITATE + a4.SUPPLIER1 + a5.SUPPLIER2 + a6.USER + a7.UNIVERSITY + a8.STATE + a9.BIOLOGY + a10.CHEMISTRY1 + a11.GEOLOGY + a12.MATHS1 + a13.PHYSICS + a14.INFORMATICS1 + a15.AGRONOMY + a16.MATHS2 + a17.INFORMATICS2 + a18. MATERIALS + a19.MEDICAL + a20.CHEMISTRY2 + a21.ELECTRO + a22.MACHINES + a23.SCIBASE + a24.SALES + a25.COMPETITION + μ_i.

3.3 Econometric issues

A significant problem, which has been discussed in some detail in Harabi (1991), is related to the "noise" in the data used. A major reason for this "noise" is that almost all variables - the exceptions are: RDINTE, PERINTE, SALES and COMPETITION - are originally semantic responses to qualitative questions on the basis of a 7-point semantic Likert scale. These variables have the measurement properties of ordinal categorial data. To be useful in our econometric analysis, these semantic responses have to be converted into numerical responses. For this purpose and in order to maintain consistency with the theoretical framework, the original responses of individual firms have been grouped into average responses for industries. Industry means have been computed and then used in the regression analysis. This data transformation justifies the use of OLS and GLS procedures. In addition, the Tobit-method is also used in order to take full advantage of the data available.

A second econometric problem is the presence of heteroscedasticity in the error terms: the assumption of an equally large variance for all error terms cannot hold. In the following paragraphs, I briefly discuss the diagnosis and treatment of this problem in the context of the present study.

Heteroscedasticity can a.o. arise when data are arranged in groups of unequal size. In this case the variance in the different groups (observations) will differ. This is the case here, since the collected data were aggregated at the level of the 4-digit industrial classification. As a consequence, groups of unequal size not only show unequal average values, which is desirable, but unequal variances as well. This fact has been confirmed by two tests. One was purely visual: the residual values vary with group size. The second test was formal and followed the suggestion made by Goldfeld and Quandt (1965). It consists of testing the null hypothesis

$$Ho: \sigma^2_{\mu_i} = \sigma^2 \text{ for all } i$$

against the alternative hypothesis (heteroscedasticity)

$$Ha: \sigma^2_{\mu_i} \neq \sigma^2 \text{ for at least one } i$$

using a test function which these authors developed (see below). To carry out this test the number of observations (N) which is available for testing the model is divided into two sub-groups, each with (N-t)/2 observations; t observations in the middle of the original sample are dropped. Since it has not been theoretically possible so far to specify a general "optimal value" for t, a value in the order of magnitude of N/5 is often chosen (Schips 1990:146). As in any other regression analysis, the number of observations must at least equal the number of independent variables (K). In other words, (N-t)/2 must be larger or at least equal to K. In my example, N = 103, t = N/5 = 103/5 = 21, K = 25. Both sub-groups contain 41 observations: the first sub-group ends with observation no. 41, and the second starts with no. 63. The test function suggested by Goldfeld and Quandt is defined as follows:

$$R_2'R_2 / R_1'R_1$$

R_1 and R_2 are the vectors of the residuals of the OLS-estimate. If the null-hypothesis is valid, then the test function is F-distributed and characterized by (((N-t-2K)/2), ((N-t-2K)/2)) degrees of freedom. In this case we can expect a test value of 1. In my example this value is .89 for the first model, 5.63 for the second, and 4.22 for the third. Thus, the alternative hypothesis is true: there is heteroscedasticity in all three models, but especially in the second and third. The OLS-estimates are no longer optimal, that is, they are still unbiased but not efficient. Therefore I chose the GLS procedure, which is BLUE (Best Linear Unbiased Estimator). According to this method not the sum of the squared residuals but a weighted sum of the squared residuals is minimized. A smaller weight is given to variables whose error term shows a larger variance. (For a detailed description of GLS procedure see Judge, et al 1985.)

In the present example, the following variables show relatively large variances in the error term: APPROPRIA1, APPROPRIA2, SUPPLIER1, SUPPLIER2, SCIBASE, SALES and GEOLOGY in model no.1; APPROPRIA1, STATE and SALES in model no.2; and APPROPRIA1, SCIBASE, SALES, COMPETITION and MACHINES in model no.3.

4. RESULTS

In this section I will present the results of the estimation of the three models, using OLS, GLS and Tobit methods. These results are summarized in Tables 2, 3 and 4. The overall econometric results can be stated as follows; the first two results are related to the OLS and GLS estimates only:

- All three models are statistically significant at the 5% level.
- The determination coefficient R^2 is approximately 40%.
- There is a low level of multicollinearity between the independent variables: the condition index is only 7.74 in all three models, while the cut-off point for critical multicollinearity is 30.

To interpret the test results of the individual variables these are grouped under APPROPRIABILITY, OPPORTUNITIES and MARKET.

APPROPRIABILITY: The ability to capture and protect the results of innovations has a positive influence on technical progress in all three models. The non-patent related means of appropriability - "secrecy", "lead time", "moving downward on the learning curve" and "superior sales and service efforts" - prove to be more important for the innovation process than "patents to protect against imitation" and "patents to secure royalty income". In two of the three models tested (see Tables 3 and 4), the coefficient of the variable APPROPRIA1 is higher than that of the variable APPROPRIA2 and is statistically significant. In the other model, however, the coefficient of variable APPROPRIA1 is smaller than that of APPROPRIA2. The value of this result is restricted by the fact that neither of the variables is statistically significant (Table 2).

The relationship between imitation time and technical progress is positive at the R&D level, as could be expected: the greater the time lag for imitation, the higher the R&D intensity will become and the more employment in R&D laboratories of the industries in question will be increased (see Tables 3 and 4). The coefficient of the variable IMITATE is positive in the second and third model, though only weakly positive and not statistically significant. This ambivalence, represented by the low values and the statistical insignificance of the coefficients, allows us to conclude that the imitation time - as defined here - does not have a clear-cut impact on technical progress.

OPPORTUNITIES: Technological opportunities, the second determinant of technical progress, were divided into external sources of technological opportunities and the special contribution of science. For the first sub-group, the following conclusions can be drawn:

- In all three models the suppliers of material inputs make a positive contribution to technical progress. This contribution is appreciably higher in the innovation phase (Table 2) than in that of R&D (Tables 3 and 4).
- In contrast, the suppliers of equipment for production and for R&D either do not contribute to technical progress or contribute negatively.
- The same is true for the contribution of users for R&D . However, a positive contribution is made by users when product or process innovations are introduced, even if this contribution is not statistically significant. (See the result of the GLS procedure in Table 2.)
- The contribution of domestic and foreign university research to technical progress seems to be particularly positive and relevant at the innovation phase (Table 2). For this phase it has the highest score of all other external sources. It is insignificant for the R&D phase, however (Tables 3 and 4).
- The contribution of other public research institutions, enterprises and agencies is negative at the innovation phase, but positive at the R&D phase. But in both cases its contribution is not statistically significant. In other words the assumption that in a market-oriented country the state - university research excepted - contributes to R&D but not to the actual introduction of innovations into the market is confirmed.

With regard to the contribution of science to technical progress, the following results are interesting:

- Science in general, defined here as the cumulative relevance of all 14 fields of basic and applied science (variable SCIBASE), is relevant for technical progress in the innovation phase, even if the relevance is low and statistically insignificant. On the other hand, the result for science is negative, as well as statistically significant, at the R&D level (second and third model). These results can be interpreted as follows: science as a whole is relevant for the innovation process, but at the R&D level its application requires specialization and targeting.

- Of the six fields of basic science studied, only in mathematics and theoretical computer science do education and training contribute positively to technical progress. In the case of mathematics and computer science the contribution is also statistically significant. It is negative or nil in the fields of biology, geology and physics.
- The relevance of education and training in the applied sciences for technical progress is high and significant in the fields of medical science (first and second model) and electronics (third model). The relevance of applied mathematics is high, but not statistically significant.
- On the contrary, the fields of applied computer science, materials science and mechanical engineering do not contribute to technical progress. In the case of applied chemistry the result is ambivalent: while its contribution is negative at the innovation phase, it is positive at the R&D phase; but in neither case is it statistically significant.

MARKET: As an indicator for market conditions, sales exert a statistically significant negative impact - in contrast to what theory has predicted (model 1). This means that the innovative ability of the industries studied decreases with growing sales. Technological competition, however, plays a stimulating role in technical progress (positive sign for the variable COMPETITION, but not statistically significant).

5. SUMMARY AND CONCLUSIONS

The aim of this study was to identify theoretically the determinants of technical progress at the industry-level and then to estimate their respective contributions empirically. In other words the purpose was to understand both theoretically and empirically those factors which underlie the - empirically observable - inter-industry differences in technical progress. At the theoretical level economists agree more and more that technical progress can be explained at the industry level by the following three factors: (1) the technological opportunities; (2) the ability of the economic system to appropriate the results of technical innovations (appropriability conditions); and (3) the demand conditions.

The basic theoretical model was tested with the help of two sets of Swiss data. One set was made available by the Federal Office of Statistics and consisted of quantitative information on R&D expenditures, R&D personnel, total employment and sales figures for 124 (4-digit SIC) industries for the year 1986. The second set was derived from a survey I carried out in the summer of 1988. 940 industry experts were approached; 358 of them, or 38%, covering 127 industries, completed the questionnaire. The items on the questionnaire were related to the two supply-side determinants of technical progress - items (1) and (2) above.

For the empirical specification of the theoretical model, technical progress (as the dependent variable) was measured by three indicators: an output indicator, representing the introduction rate of innovations since 1970; two input indicators, "share of R&D expenditures in sales" and "share of R&D personnel in total employment". All data were aggregated at the level of the industry (4-digit SIC). Therefore, three equations were estimated individually, using the OLS, GLS and Tobit methods.

The most important results of the empirical analysis can be summarized as follows:

- The ability to appropriate the results of innovations exerts a positive impact on technical progress in all three models. In this context, the non-patent related means of appropriability "secrecy", "lead time", "moving downward on the learning curve" and "superior sales and service efforts" prove to be more important for the innovation process than the means "patents to protect against imitation" and "patents to secure royalty income".

- Of all external sources of technological opportunities , domestic and foreign university research makes the largest quantitative and statistically most significant contribution to technical progress.
- Science (i.e. education in 14 fields) is on the whole relevant for technical progress. But its contribution to technical progress would increase if at the R&D level its application could be better targeted.
- Of the six fields of basic science, only in mathematics and in theoretical computer science is education relevant for technical progress (the coefficient of both variables is positive and statistically significant, especially in the second and third model). The results were negative or statistically insignificant for the other fields of basic science.
- The relevance of education and training in the applied sciences for technical progress is very high and significant in the fields of medical science and electronics.
- The impact of sales as an indicator for demand is negative - in contrast to what theory has predicted. Industries with relatively low sales are relatively more innovative than those with a higher level of sales.

The results are relevant for government, as well as for firms. In an market-oriented country government has a responsibility for university research and education, especially in those fields which have proved to be relevant for the innovation process as a whole. Both university research and education were shown to be important determinants of technical progress.

The main actors in the process of innovation, the firms, should take note of the following:

- A well-designed firm-level strategy in the areas of "lead time", "learning curve advantages" and "superior sales and service efforts" is essential, these being of key importance for the appropriability of the results of innovations and therefore for the innovation process.(For suggestions see Teece 1986).

- Because of the significance of university research for technical progress, systematic access to and continuous utilization of this source is of great importance for the innovative ability of firms. But the utilization of scientific R&D results should be selective and properly targeted.

Table 1: LIST OF VARIABLES

Notation	Short Description	Expected Sign
Dependent Variables		
INNOV	Introduction rate of innovations since 1970 (1=very slow, 7=very rapid. Sum of the responses to two questions IV.A and IV.B. in the questionnaire)	
RDINTE	Share of R&D expenditures in sales per industry (4-digit SIC), 1986, in %. (data of the Swiss Federal Office of Statistics)	
PERINTE	Share of R&D personnel in total employment per industry (4-digit SIC), 1986, in %. (data of the Swiss Federal Office of Statistics)	
Independent Variables		
APPROPRIA1	Effectiveness of the two means "patents to protect against imitation of product innovation" and and "patents to secure royalty income". (1=not all effective, 7= very effective; value obtained through principal components analysis of the six items of question I.B).	(+)
APPROPRIA2	Effectiveness of the means "secrecy", "lead time" "learning curve advantages", and "superior sales and services efforts" (1=not all effective, 7= very effective, value obtained through principal components analysis of the six items of question I.B).	(+)
IMITATE	Time required for imitating major and patented product and process innovations (1=less than 6 Months, 6=timely duplication	(+)

	not possible; sum of the responses to questions II.E.1 and II.F.2)	
SUPPlIER1	Contribution of all kinds (finance, personnel, information, etc) of material suppliers to technical progress in industry (4-digit SIC) (1=no contribution, 7=very important contributions; question III.E.2)	(+)
SUPPlIER2	Contribution of all kinds (finance, personnel, information, etc) of suppliers of equipment for production and for R&D to technical progress in industry (4-digit SIC) (1=no contribution, 7=very important contributions; sum of the responses to questions III.E.3 and III.E.4)	(+)
USER	Contribution of all kinds (finance, personnel, information, etc) of product users to technical progress in industry (4-digit SIC) (1=no contribution, 7=very important contributions; question III.E.5)	(+)
UNIVERSITY	Contribution of all kinds (finance, personnel, information, etc) of domestic and foreign academic research to technical progress in industry (4-digit SIC) (1=no contribution, 7=very important contributions; question III.E.6)	(+)
STATE	Contribution of all kinds (finance, personnel, information, etc) of other public research institutions, enterprises and agencies to technical progress in industry (4-digit SIC) (1=no contribution, 7=very important contributions; sum of responses to questions III.E.7 and III.E.8)	(+)
BIOLOGY	Relevance of biology to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.a)	(+)
CHEMISTRY1	Relevance of theoretical chemistry to technical	(+)

	progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.b)	
GEOLOGY	Relevance of geology to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.c)	(+)
MATHS1	Relevance of mathematics to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.d)	(+)
PHYSICS	Relevance of physics to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.e)	(+)
INFORMATICS1	Relevance of theoretical computer science to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.f)	(+)
AGRONOMY	Relevance of agronomy to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.2.a)	(+)
MATHS2	Relevance of applied mathematics and Operations research to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.2.b)	(+)
INFORMATICS2	Relevance of applied computer science to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.2.c)	(+)
MATERIALS	Relevance of materials science to	(+)

	technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.2.d)	
MEDICAL	Relevance of medical science to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.2.e)	(+)
CHEMISTRY2	Relevance of applied chemistry to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.2.f)	(+)
ELECTRO	Relevance of electronics to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.g)	(+)
MACHINES	Relevance of mechanical engineering to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; question III.A.1.h)	(+)
SCIBASE	Relevance of science as a whole to technical progress in industry (4-digit SIC) in the past 10-15 years. (1=not relevant, 7=very relevant; Sum of responses to the 14 sub-questions of question III.A).	(+)
SALES	Sales per industry (4-digit SIC), 1986, in Mio SFr. (data of the Swiss Federal Office of Statistics)	(+)
COMPETITION	Number of firms which are capable of imitating a major innovation developed by competitors sum of responses to questions II.B.1 and II.B.2).	(?)

Table 2: Determinants of introduction rate of innovation (INNOV)

		Regression coefficient (standard error)		
Parameter	Variable	OLS	GLS	Tobit
a0	INTERCEPT	8.0773**	7.8887**	8.0773**
		(1.6716)	(1.6419)	(1.4453)
a1	APPROPRIA1	0.2730	0.2222	0.2730
		(0.2061)	(0.2051)	(0.1782)
a2	APPROPRIA2	0.1110	0.0812	0.1110
		(0.2141)	(0.2096)	(0.1851)
a3	IMITATE	-0.0207	-0.0162	-0.0207
		(0.0810)	(0.0825)	(0.0700)
a4	SUPPlIER1	0.1415	0.1883	0.1415
		(0.1742)	(0.1800)	(0.1506)
a5	SUPPlIER2	-0.1157	-0.1744	-0.1157
		(0.1241)	(0.1250)	(0.1073)
a6	USER	-0.0241	0.0446	-0.0241
		(0.1476)	(0.1505)	(0.1276)
a7	UNIVERSITY	0.3475*	0.3316*	0.3475*
		(0.1645)	(0.1660)	(0.1423)
a8	STATE	-0.0076	0.0439	-0.0076
		(0.1075)	(0.1010)	(0.0930)
a9	BIOLOGY	-0.3277	-0.3167	-0.3277*
		(0.1930)	(0.2004)	(0.1669)
a10	CHEMISTRY1	0.1336	0.0764	0.1336
		(0.2044)	(0.2091)	(0.1767)
a11	GEOLOGY	-0.5672**	-0.6105**	-0.5672**
		(0.1900)	(0.1923)	(0.1642)
a12	MATHS1	0.4267*	0.4105*	0.4267*
		(0.2324)	(0.2411)	(0.2000)
a13	PHYSICS	-0.2930	-0.1983	-0.2930
		(0.1976)	(0.2062)	(0.1708)
a14	INFORMATICS1	0.2861	0.2944	0.2861

		(0.1817)	(0.1865)	(0.1571)
a15	AGRONOMY	0.1650	0.1510	0.1650
		(0.1913)	(0.1942)	(0.1654)
a16	MATHS2	0.2012	0.1332	0.2012
		(0.2218)	(0.2251)	(0.1917)
a17	INFORMATICS2	-0.1332	-0.1128	-0.1332
		(0.2021)	(0.2058)	(0.1747)
a18	MATERIALS	-0.2056	-0.1952	-0.2056
		(0.1456)	(0.1452)	(0.1260)
a19	MEDICAL	0.3216*	0.3406*	0.3216*
		(0.1632)	(0.1660)	(0.1411)
a20	CHEMISTRY2	-0.0350	-0.0207	-0.0350
		(0.2051)	(0.2120)	(0.1773)
a21	ELECTRO	-0.1054	-0.1458	-0.1054
		(0.1611)	(0.1613)	(0.1394)
a22	MACHINES	-0.0306	-0.0040	-0.0306
		(0.1654)	(0.1694)	(0.1430)
a23	SCIBASE	0.0090	0.0085	0.0090
		(0.0360)	(0.0351)	(0.0309)
a24	SALES	-0.0028**	-0.0030**	-0.0028**
		(0.0008)	(0.0008)	(0.0007)
a25	COMPETITION	0.1952	0.2471	0.1952
		(0.1382)	(0.1384)	(0.1194)

R^2	0.4350
F-WERT	2.3710
PROB >F	0.0021

* Significant at 0.05 level, ** significant at 0.01 level

Table 3: Determinants of R&D Intensity (RDINTE)

		Regression coefficient (standard error)		
Parameter	Variable	OLS	GLS	Tobit
a0	INTERCEPT	0.0836	0.0989	0.0836
		(0.0853)	(0.0812)	(0.0737)
a1	APPROPRIA1	0.0103	0.0076	0.0103
		(0.0105)	(0.0107)	(0.0090)
a2	APPROPRIA2	0.0257*	0.0258*	0.0257**
		(0.0109)	(0.0102)	(0.0094)
a3	IMITATE	0.0026	0.0019	0.0026
		(0.0041)	(0.0040)	(0.0036)
a4	SUPPlIER1	0.0006	0.0024	0.0006
		(0.0089)	(0.0086)	(0.0076)
a5	SUPPlIER2	-0.0053	-0.0071	-0.0053
		(0.0075)	(0.0061)	(0.0054)
a6	USER	-0.0059	-0.0046	-0.0059
		(0.0075)	(0.0070)	(0.0065)
a7	UNIVERSITY	0.0006	-0.0005	0.0006
		(0.0084)	(0.0080)	(0.0072)
a8	STATE	-0.0007	0.0010	-0.0007
		(0.0055)	(0.0051)	(0.0047)
a9	BIOLOGY	-0.0000	-0.0055	-0.0000
		(0.0098)	(0.0089)	(0.0085)
a10	CHEMISTRY1	0.0129	0.0083	0.0129
		(0.0104)	(0.0097)	(0.0090)
a11	GEOLOGY	-0.0120	-0.0141	-0.0120
		(0.0097)	(0.0093)	(0.0083)
a12	MATHS1	0.0211	0.0168	0.0211*
		(0.0118)	(0.0109)	(0.0102)

a13	PHYSICS	-0.0010	-0.0003	-0.0010
		(0.0100)	(0.0095)	(0.0087)
a14	INFORMATICS1	0.0216*	0.0189*	0.0216**
		(0.0092)	(0.0087)	0.0080)
a15	AGRONOMY	-0.0013	0.0006	-0.0013
		(0.0098)	(0.0083)	(0.0084)
a16	MATHS2	0.0168	0.0190	0.0168
		(0.0113)	(0.0107)	(0.0098)
a17	INFORMATICS2	-0.0123	-0.0137	-0.0123
		(0.0103)	(0.0094)	(0.0090)
a18	MATERIALS	-0.0080	-0.0093	-0.0080
		(0.0074)	(0.0068)	(0.0064)
a19	MEDICAL	0.0180*	0.0163*	0.0180*
		(0.0083)	(0.0079)	(0.0072)
a20	CHEMISTRY2	0.0033	0.0025	0.0033
		(0.0105)	(0.0094)	(0.0090)
a21	ELECTRO	0.0157	0.0115	0.0157*
		(0.0082)	(0.0074)	(0.0071)
a22	MACHINES	-0.0003	-0.0014	-0.0003
		(0.0082)	(0.0077)	(0.0072)
a23	SCIBASE	-0.0055**	-0.0038**	-0.0055**
		(0.0018)	(0.0017)	(0.0016)
a24	SALES	-0.0000	0.0000	-0.0000
		(0.0000)	(0.0000)	(0.0000)
a25	COMPETITION	0.0057	0.0053	0.0057
		(0.0041)	(0.0065)	(0.0061)

R^2	0.4156
F-WERT	2.1900
PROB >F	0.0048

* Significant at 0.05 level, ** Significant at 0.01 level

Table 4: Determinants of R&D Personnel Intensity (PERINTE)

		Regression coefficient (standard error)		
Parameter	Variable	OLS	GLS	Tobit
a0	INTERCEPT	0.1419	0.1806	0.1419
		(0.0858)	(0.0963)	(0.0742)
a1	APPROPRIA1	0.0076	0.0122	0.0076
		(0.0106)	(0.0124)	(0.0091)
a2	APPROPRIA2	0.0260*	0.0252*	0.0260**
		(0.0110)	(0.0123)	(0.0095)
a3	IMITATE	0.0009	0.0025	0.0009
		(0.0041)	(0.0049)	(0.0035)
a4	SUPPlIER1	0.0010	0.0111	0.0010
		(0.0089)	(0.0097)	(0.0055)
a5	SUPPlIER2	-0.0090	-0.0175	-0.0090
		(0.0063)	(0.0079)	(0.0055)
a6	USER	-0.0096	-0.0190	-0.0096
		(0.0076)	(0.0081)	(0.0065)
a7	UNIVERSITY	-0.0039	-0.0026	-0.0039
		(0.0084)	(0.0090)	(0.0073)
a8	STATE	0.0046	0.0108	0.0046
		(0.0055)	(0.0062)	(0.0047)
a9	BIOLOGY	-0.0005	-0.0023	-0.0005
		(0.0099)	(0.0115)	(0.0085)
a10	CHEMISTRY1	0.0033	-0.0089	0.0033
		(0.0105)	(0.0113)	(0.0090)
a11	GEOLOGY	-0.0152	-0.0226	-0.0152
		(0.0097)	(0.0106)	(0.0084)
a12	MATHS1	0.0244*	0.0391*	0.0244*
		(0.0119)	(0.0128)	(0.0103)

a13	PHYSICS	-0.0033	-0.0069	-0.0033
		(0.0101)	(0.0111)	(0.0088)
a14	INFORMATICS1	0.0164*	0.0095*	0.0164*
		(0.0093)	(0.0099)	(0.0080)
a15	AGRONOMY	0.0008	-0.0027	0.0008
		(0.0098)	(0.0113)	(0.0084)
a16	MATHS2	0.0131	0.0061	0.0131
		(0.0113)	(0.0127)	(0.0098)
a17	INFORMATICS2	-0.0068	-0.0079	-0.0068
		(0.0103)	(0.0112)	(0.0089)
a18	MATERIALS	-0.0102	-0.0077	-0.0102
		(0.0084)	(0.0083)	(0.0065)
a19	MEDICAL	0.0125	0.0043	0.0125
		(0.0084)	(0.0091)	(0.0072)
a20	CHEMISTRY2	0.0125	0.0188	0.0125
		(0.0105)	(0.0123)	(0.0091)
a21	ELECTRO	0.0196*	0.0150*	0.0196**
		(0.0082)	(0.0095)	(0.0071)
a22	MACHINES	-0.0102	-0.0096	-0.0102
		(0.0085)	(0.0098)	(0.0073)
a23	SCIBASE	-0.0039*	-0.0024*	-0.0039*
		(0.0018)	(0.0020)	(0.0016)
a24	SALES	-0.0000	0.0000	-0.0000
		(0.0000)	(0.0000)	(0.0000)
a25	COMPETITION	-0.0034	0.0041	-0.0034
		(0.0000)	(0.0075)	(0.0061)
R^2	0.4327			
F-WERT	2.3500			
PROB >F	0.0023			

* Significant at 0.05 level, ** Significant at 0.01 level

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