INTERNATIONAL DISTRIBUTION OF PATENTED INVENTIONS

by

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ABSTRACT

The first objective is to analyze the decision to invent as an economic decision and to apply microeconomic theory to this problem. The second objective is to attempt an empirical analysis of the distribution of patented inventions among the manufacturing industries of six countries in terms suggested by the economic theory of invention.

Inventions were found to be strongly motivated by perceived profit opportunities. Demand and social need for invention, or the cost-reducing effect to scientific knowledge complemented by the institutional environment, are the main economic determinants of inventive activity. The present approach considers expected profit to be a function of demand and supply factors in a framework of imperfect competition. An original formulation of the problem in the framework of activity analysis, completes the theoretical part.

The empirical model suitable for a cross-section regression analysis develops an invention function relating the number of patented inventions by industry to the level of profit maximizing R and D employment and other variables. The model is estimated by the two stage and ordinary least squares methods. Its main conclusions are:

1) The output of patented inventions is a log-linear function of employment in applied research and development.

2) There are significant interindustry differences in employment of R and D; highly concentrated industries employ more labour in development and less in applied research than other industries. Interindustry differences in output of patented inventions are insignificant.

3) The fact that R and D employment in Canadian industries is short of the level predicted by the regression is partially explained by foreign control.

4) The ratio of patents awarded to nationals/patents awarded to foreigners is closely related to export/import performance, and, in Canada, to foreign control as well.

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LIST OF SYMBOLS AND ABBREVIATIONS

R and D Research and development

Subscripts for all variables

j	firm ($j = 1,J$)
i	industry producing product ($i = 1,I$)
t	time
h	country of origin
m	group of R and D labour, or input $m = (1,M)$

Variables (in order of appearance in the text)

π	profit
p, (p)	market price, (vector of prices)
$\bar{c}$	average production cost
e	elasticity of demand
x, (x)	output, quantity produced, (vector of outputs)
RD	cost of R and D activities
D	cost of development activities only
S, $(\bar{S})$	size of the market (sales), (average size of firm-sales)
s	share of the market
k	constant reflecting mark-up pricing
P	patented invention created by a resident (national) of the respective country
P_F	patented invention created by a non-resident of the prospective country
L	license fee

q	negotiating factor
ds*	variation of the market share with respect to the original size of the market, (finite variation)
max	maximum
min	minimum
a,b,c.	coefficients of elasticities
C,/C/	matrix of c-coefficients, /determinant of matrix C/
E( )	expected value of ( )
R	revenue from the use of patented inventions
r	average contribution to revenue
J	number of firms in an industry
M	number of groups of R and D labour inputs
W	the average wage rate paid to R and D personnel
RD1,2,3	R and D labour inputs
log	logarithm
$\alpha,\beta,\gamma,$ δ,ε	mathematical symbols simplifying manipulation of coefficients in equations (3.1) to (3.15)
ω	coefficient of wage adjustment
ψ	coefficient of adjustment of profitability variables
θ	coefficient of adjustment of the industry's sale variable
VA	rate of growth of value added
EX	exports
IM	imports
I	investment in plant and equipment
$\bar{C}$	concentration of total employment in firms with more than 500 employees
STA	supporting staff employed in applied research
MRA	personnel employed in applied research
MRAD	personnel employed in applied research and in development
MD	personnel employed in development

QSEA	number of qualified scientists and engineers employed in applied research
G	patenting ratio (the number of patents granted/the number of patent applications
E	education variable (the number of engineers and technicians employed in the manufacturing sector)
Y, (d)	industry dummy variables (its regression coefficient)
Z	dummy variable indicating "high technology" industries
X(g)	country dummy variable (its regression coefficient)
u,v	random error terms
RES	residual = (log MRAD/S - log MRAD/S)
$\hat{}$	predicted value of the respective variable
FC	foreign control (sales of foreign affiliates of US firms as % of industry'S total sales
DFC	deviation of log foreign control from its mean value
B	matrix of consumption technology
$\bar{b}$	vector of quantities of characteristics
$\bar{z}$	vector of characteristics
U(z)	utility function in terms of characteristics
T	matrix of production technology
$\bar{c}$	vector of primary resources
$\bar{y}$	vector of activities
*	superscript indicating optimum (equilibrium) value
Σ	summation
Π	product
Δ	finite increment
d	derivative

CHAPTER I

INTRODUCTION

The importance of economic effects of technological change has always been recognized by economists. However, the economic determinants of technological change and especially the economic determinants of invention have received much less attention. Technical invention is for most economists today still the exogeneous variable it was to Schumpeter half a century ago when he considered it "... just as relevant as say, climate..."[1]

There is, however, a growing body of literature which explores invention, and technological change in general, as an economic activity. Contributions published before the year 1959 were surveyed in an excellent article by Nelson.[2]

Inventions were found to be strongly motivated by perceived profit opportunities, so that the demand and the cost factors play major roles. The majority of the contributions stressed either the demand and social need for invention or the cost reducing effect of the scientific knowledge prerequisite to invention, as the main economic determinants of inventive activity. This demand or supply orientation served as a good criterion for

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[1] J. Schumpeter, "The Instability of Capitalism", Economic Journal, (1928), reprinted in N. Rosenberg, The Economics of Technological Change, Penguin Modern Economics Readings, (Penguin Books Ltd., 1971), p. 32.

[2] R.R. Nelson, "The Economics of Invention: A Survey of the Literature", The Journal of Business, vol. XXXII, (April, 1959), pp. 101-127.

the organization of the survey [1] although the onesided deterministic character of most of the contributions reviewed was criticized by Nelson, who concluded: "Thus it appears that conditions of cost and demand may be as important in explaining invention as in explaining the rate of output of a firm or an industry." [2]

Part of the literature published after Nelson's article continued the debate along the same lines and can be again labelled as demand or supply oriented. On the other hand, the phenomenal postwar rise of the industrial R and D activity was followed by several attempts to analyze the relationship existing among the economic determinants of the R and D activity and inventive output.

We present first the most important recent contributions to the demand oriented approach, then the contributions to the role of scientific and technological knowledge. The brief survey is concluded by considering studies of inventive activity and its relation to industrial R and D.

1.1 Invention and demand.

According to the demand oriented theory, inventions generally occur through the addition of details rather than as major breakthroughs, and their main cause is social need manifesting itself through perceived opportunities for private profit. The second important factor in the demand oriented approach is "learning through experience" which is believed to be responsible for the bulk of the "improvement" inventions that follow

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1 Th[illegible]rvey also explored other aspects of the inventive process which [illegible] mention because they are outside the scope of our immediate in-

[illegible]d, p. 107.

the breakthrough of the basic invention. In the original form,[1] this theory went as far as to consider inventions to be an automatic and inevitable outcome of social pressure.

The economic theory behind this approach was discussed recently by Schmookler [2] who claims that the expected value of solutions to technical problems guides inventive activity, both in the case of the corporate inventor as well as in the case of the independent inventor.

According to his theory, inventors act as conscious profit maximizers. Given the market share of the firm in monopolistic or oligopolistic competition and given the cost of invention, the number of machines it will pay to invent will vary directly with the expected size of the market. There is, however, no reason to accept Schmookler's assumptions of constant market share and constant, indeed negligible, costs of invention. Oligopolistic competition depends on product differentiation and its main objective is to increase market share. Only in a few oligopolistic industries does the situation correspond to the assumption of a constant market share and even in these cases the firms engage in inventive and innovative activity in order not to lose their share of the market. This remark is not intended to deny Schmookler's claim that profitability is a function of the overall size of the market, but rather it emphasizes the fact that the assumption of a constant market share is unwarranted and therefore it is not useful to concentrate the argument exclusively on the size of the market as does Schmookler.

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[1] S.C. Gilfillan, The Sociology of Invention, (Chicago, Follet Publishing Co., 1935).

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

As for the cost of inventive activity, its importance rises in the case when the market size and share are relatively constant. This seems to be the case of most of the "older" established oligopolistic industries, where the size of the market grows only with the expansion of total economic activity and where the market shares are given, either by the non-competitive climate or by the antitrust regulations. An example that suggests itself is the United States steel industry. We would expect the cost of inventing to be relatively important in such cases. We shall return to the question of the cost of inventions in the next section. Perhaps a still more fundamental problem concerns the general interpretation of the profitability formula. Can we really assume, as Schmookler does, that an inventor has an almost unlimited choice as to what technical problem he decides upon to concentrate his inventive effort? If it is so it would imply that an inventor is free to choose the industry of his interest as a function of its profit expectations. This assertion seems to be simply too strong to be acceptable in today's highly specialized industrial society.

Schmookler presents his theory as an explanation of the time series data on United States investment and patents in the railroad industry. The data indicate a close association of the two variables, and according to Schmookler's interpretation, the peaks in the investment series tend to precede those in the patent series. Further analysis includes other economic variables such as stock prices and the output of the railroad industry. Schmookler concludes from a visual comparison of the relevant time series:

> Thus, from these long swing comparisons three dominant impressions emerge: a) as with their trend behaviour, patents in the field tend to oscillate synchronously with the two economic variables; but b) at the same time patents tend to lag behind the economic variables at turning

> points. Moreover, c) these relations between railroad patents and economic variables seem to have been relatively invariant during a century in which drastic changes occured in the American society generally, in inventive activity itself, and in the railroad industry, which moved from an unregulated to a regulated status and from growth to decline.[1]

However, the evidence on which these generalizations are based is less than convincing. As Sanders[2] pointed out, the economic variables series lead the patent series only nine times out of nineteen: five times they are the same and five times they lag the patent series. However, when the series are adjusted to take into account the average time lapse from conception to development of a patent, as presented by Sanders, the situation changes drastically. The patent series lead 16 times, they are the same in two instances and the economic series leads in only one instance. A similar criticism applies to other tables presented by Schmookler in support of his theory. According to this criticism the time series results can not be accepted as valid, unquestionable evidence of the theory considering invention to be caused solely by demand or by the extent of the market.

As for the empirical evidence of the cross-section data, Schmookler found a high degree of correlation in most cases ($r^2 > 0.9$) between patents and investment in different industries and concluded from this that the direction of causality is the same as in the time series, that is that a one percentage increase in investment leads to one percent increase in in-

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[1] J. Schmookler, op. cit., p. 120.

[2] B.S. Sanders, Commentary on "Invention and Economic Growth", IDEA, vol. 10, no. 4, (Winter, 1966-7), pp. 487-508.

vention.[1]

The very high correlation coefficients would imply that the inventors have been able to react instantaneously and very accurately to the variations in investment. In many cases where the actual time lag between patenting and investment exceeds a period of three years, the inventors must have had almost perfect foresignt as far as future investment or future market conditions in the industry were concerned. Can we accept this unlikely degree of economic intuition on the part of inventors and their employers or should we question the validity of the findings and their interpretation?

We used Schmookler's data for an additional analysis with the aim of ascertaining whether or not they lead unambiguously to his conclusions. The evidence of his cross-section data does not exclude the possibility that the high correlation between investment and patents reflects rather

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1 Schmookler's regression equation exhibited in both cases a regression coefficient close to unity.

$$\underset{1940\text{-}42}{\log \text{Patent}} = \underset{(0.080)}{1.174} + \underset{(0.070)}{0.927} \underset{1939}{\log \text{Invest.}} \qquad r^2 = .918$$

$$\underset{1948\text{-}50}{\log \text{Patent}} = \underset{(0.116)}{0.598} + \underset{(0.070)}{0.940} \underset{1947}{\log \text{Invest.}} \qquad r^2 = .905$$

J. Schmookler, op. cit. p. 144.

the relationship between the size of industries and their patent output.[1]

The influence of the size of an industry on the value of the regression coefficient of the investment variable was also reported by Scherer.[2] Although Schmookler found that there is a high level of association between the number of patented inventions in the given year t, and in the previous years, he rejects the possibility that the present investment may be result of inventive activity in the recent past. It is worth noting that this claim is in contrast with the largely accepted Schumpeterian theory of business cycles dependent on major innovations.

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1 Investment and size (in terms of employment) are strongly intercorrelated

$$\text{Invest.}_{39} = 10.2 + 2.06 \text{ Empl.}_{39} \qquad R^2 = 0.76$$
$$(7.95)$$

It is therefore difficult to accept the claim that the patents are functions of investment and not of the size of the industry. When the patents are regressed on employment, the regression coefficient for the employment variable has basically the same value as the one for the investment variable. Both are equally significant.

$$\text{Lg Patent} = 1.1 + 0.927 \text{ Lg Empl.} \qquad R^2 = 0.73$$
$$(7.11)$$

The Goldfeld - Quandt test for heteroscedascity was inconclusive. It revealed that the regression coefficient for the investment variable in Schmookler's equation was only 0.63 for the big industries (first ten industries ordered according to employment size) but increased to 1.25 for the small ones. This shows that the alleged one to one correspondence between an increase in investment and in patents for capital goods can not be taken very seriously. It seems that the numerical value is rather a result of the particular mix of industries and may also be attributed to the influence of size of employment as well as to investment. The data used for these calculations are from: J. Schmookler, op. cit. p. 142.

2 Scherer also found that the smaller industries have higher values for the regression coefficient of the investment variable than the larger ones. F.M. Scherer, "Firm Size, Market Structure, Opportunity and the Output of Patented Inventions", A.E.R., (December, 1965), p. 1121.

According to Schumpeter

> The kind of wave - like movement, which we call the business cycle, is incident to industrial change and would be impossible in an economic world displaying nothing except unchanging repetition of the productive and consumptive process. Industrial change is due to the effect of outside factors, to the non-cyclical element of growth, and to innovation. [1]

What are the implications of our findings? The first is that we cannot reject the possibility that the number of patents granted is simply a function of the industry size, which may be measured by investment, employment, value added or shipments. This does not exclude the possibility that the underlying cause is demand; at the same time, it is also compatible with the hypothesis that the number of patented inventions is a function of the number of workers dealing with the problems connected with production in the given industry.

Thus we cannot accept without reservation Schmookler's claim that his empirical evidence is "..fundamentally consistent with the spirit of the theory advanced here, namely, that industrial distribution of investment substantially determines the industrial distribution of capital goods invention."[2]

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1 J.A. Schumpeter, "The Analysis of Economic Change", The Review of Economic Statistics, (May, 1935), p. 5.

2 J. Schmookler, op. cit., p. 149.
We have concentrated our discussion on Schmookler's last major publication, i.e. his book Invention and Economic Growth, which represents his own synthesis of his numerous previous contributions to the theory and empirical analysis of invention. We do not review, therefore, these previous contributions. Most of the previous studies and a wealth of previously unpublished empirical data on patenting were posthumously edited by Griliches and Hurwicz and published as:
J. Schmookler, Patents, Invention and Economic Growth, (Cambridge, Mass., Harvard University Press, 1972).

In a recent critique and analysis of Schmookler's demand oriented thesis, Rosenberg pointed out the essential problem in Schmookler's argument: "The role of demand side forces is of limited explanatory value unless one is capable of defining and identifying them independently of the evidence that the demand was satisfied."[1] Rosenberg stressed that inventions are not equally possible in all industries and that they depend also on the state of science which determines the cost of inventive activity.

1.2 Invention as a function of scientific and technological knowledge.

This school of thought, widely accepted, considers invention as being determined by autonomous development of scientific and technological knowledge. According to one of its best known proponents Ogburn,[2] social heritage is the real mother of invention. In his view, the current breakthroughs in knowledge make particular inventions, previously impossible or extremely difficult, easy and natural.

A more penetrating assessment of the role played by scientific and technological knowledge in the inventive process is given by Usher,[3] who presented an integrated theory of inventive activity. Invention is to him a process rather than an act, the stages of the process being:

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1 N. Rosenberg, "Science, Invention and Economic Growth", The Economic Journal, (March, 1974), p. 97.
As the data of publication indicates, I was not aware of Rosenberg's article at the time when I wrote first version of this thesis. His arguments support with historical evidence my critique of Schmookler's approach.

2 W.F. Ogburn, Social Change, (N.Y., Viking Press, 1933).

3 A.P. Usher, "Technical Change and Capital Formation", in Capital Formation and Economic Growth, (National Bureau of Economic Research, 1955), pp. 523-50.

1) the perception of an unsatisfactory pattern

2) the setting of the stage

3) the primary act of insight

4) the critical revision and development.

In his own words:

> New problems emerge because some inadequacy of existing knowledge or of current modes of action is perceived. Existing skills are seen to be inadequate. Some measure of failure in the performance of an act of skill touches off a sequence of invention. If stage-setting is deliberately undertaken by systematic experimentation, acts of skill enter at this act too, but not too clearly. After the major act of insight has occured, critical revision and development involve a very intimate interweaving of minor acts of insight and acts of skills performed at high levels by persons of special training.[1]

Usher's perception of inadequacy cannot be interpreted as the unique cause of invention as in the "mechanistic" theories of Gilfillan or Ogburn. According to Usher, "inadequacy" is only the first step in a cumulative process, which is not reducible to a single identifiable cause. Invention itself ceases to be a separate element as it is in the Schumpeterian sequence of invention, innovation, imitation, for Usher integrates invention into the social process by which new things are created. The roles of various actors in the inventive process are no longer independent. The scientists, inventors and enterpreneurs are interacting in this model in a way which is very close to the reality of today's science oriented industries where it is virtually impossible to distinguish the inventive activity from the Schumpeterian innovative activity. Knowledge, applied science and technological research play a very important and explicit role in what Usher

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1 Ibid, p. 528.

calls "the setting of the stage" and in "the critical revision and development". Although his theory of cumulative synthesis leading to inventions is not operational in the sense that it does not permit one to predict the course of technical progress as the mechanistic theories pretend to do, it appears to be more realistic because it indicates that the sources of invention are many and various, that inventions are necessarily of different orders of importance and that particular inventions are to a great extent uncertain.

There are several elements in Usher's theory that can be useful in an analysis of economic determinants of inventive activity. The R and D effort is essential for "setting the stage" and in the "critical revision" stage. The integration of inventive activity with production and entrepreneurial activity explains well the creation of second and third order inventions which constitute the bulk of patented inventions. Economic demand is present throughout the process but it is no longer the prime and sole cause as it was in the deterministic demand oriented approach.

Another attempt to replace the deterministic theory of technical change and invention by a more synthetic approach was made by Siegel,[1] who also rejected the Schumpeterian linear sequence from invention to innovation and imitation. He replaced it by a broad spectrum of information-creating processes ranging from scientific discovery to the application of new technology in production processes. He admitted that the economic and social factors play an important role but he rejected the single factor theories of invention.

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1 I.H. Siegel, "Scientific Discovery and the Rate of Invention", The Rate and Direction of Inventive Activity, National Bureau of Economic Research, (Princeton University Press, 1962), pp. 441-450.

Siegel's critique of theories which simplified technical change was praised by another historian of science, Kuhn,[1] who also joined Siegel in rejecting the Schumpeterian sequence. However, he criticized Siegel for not differentiating between science and technology. According to Kuhn, science and technology in history flourished at different times in the same places and in different places at a same time. Although both science and technology depend on a common pool of existing knowledge and in turn feed back into this pool, there are important distinctions between the two. There is also direct interaction between them as in today's science based industries.

The welfare implications of basic scientific research were studied by Nelson,[2] who claimed that owing to the free access to scientific information the marginal value of scientific research to society is greater than its marginal value to the individual who pays for it. Therefore, according to Nelson, the private sector is likely to underinvest in basic scientific research. To the extent that inventive activity depends upon scientific and technological knowledge triggered off by basic research, the underinvestment in basic research by the private sector will be prejudicial to inventive activity. Arrow[3] came to a similar conclusion from an analysis of resource allocation under the conditions of indivisibility, inappropriability and uncertainty that are characteristic of inventive activity. In addition, he demonstrated that the incentive to invent will be

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1 T. Kuhn, "Comment", The Rate and Direction of Inventive Activity, National Bureau of Economic Research, (Princeton University Press, 1962), pp. 450-57.

2 R. Nelson, "The Simple Economics of Basic Scientific Research", J.P.E., (June, 1959), pp. 297-306.

3 K. Arrow, "Economic Welfare and the Allocation of Resources for Invention", in The Rate and Direction of Inventive Activity, (Princeton University Press, 1962), pp. 609-25.

smaller under monopolistic conditions than under competitive ones.

The relationship between basic and applied research is one of decreasing uncertainty. The objectives of applied research are closely constrained and applied research is undertaken only in cases where there is at least some underlying scientific knowledge that indicates the attainability of the objectives. Nelson argues that:

> Applied research is relatively unlikely to result in significant breakthroughs in scientific knowledge save by accident, for, if significant breakthroughs in scientific knowledge are needed before a particular practice problem can be solved, the expected cost of achieving these breakthroughs by a direct research effort are likely to be extremely high; hence applied research on the problem will not be undertaken, and invention will not be attempted.[1]

Nelson does not attempt to predict the relationship between basic and applied research, except that there should be a positive correlation between basic and applied research in the firms and industries engaged intensively in basic research. Brozen [2] went further than Nelson and suggested that in general: "we may expect that an industry having today higher average basic research will have in the future more of applied research". According to his analysis, the interindustry differences in R and D and consequently in inventive output are chiefly outcomes of differences in the underlying scientific base and resulting costs of inventive activity.

The complex interaction existing between science and technology in modern industry is best illustrated in case studies of recent important

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[1] R. Nelson, op. cit., p. 154.

[2] Y. Brozen, "Trends in Industrial R and D", Journal of Business, (July, 1960).

inventions. In this respect a very rich source of references is the work by Jewkes.[1] Nelson's case study of the discovery of the trasistor effect and of the invention of the transistor[2] illustrates very well the interaction of economic factors with the direction of scientific research. He concludes that the direction of science is not independent of economic and social factors but the interaction is of different intensity, stronger in some fields, weaker in others. Economic factors affect the development of science to the extent that the industrial institutions of R and D concentrate their research effort in areas where the importance of practical advances is great. The case of the transistor shows that there was no question of a preexisting demand for the new product in the narrow sense. It was the scientific and technological progress that created the new devices based on the transistor effect that became essential products of the modern electronic industry.

One limit in the range of opinions on this subject is the one-sided "demand oriented interpretation of scientific and technological progress" of Schmookler.[3] According to his view the development of basic science during recent centuries was distributed among fields roughly in accordance with demand. This interpretation of the role of science has

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1 Although this book was included in Nelson's survey of literature, it is worth mentionning here because its latest edition is enlarged by recent case studies.
J. Jewkes, D. Sawers and R. Stillerman, The Sources of Invention, 2nd edition, (New York, W.W. Norton & Co. Inc., 1969).

2 R. Nelson, "The Link between Science and Invention: The Case of the Transistor", in the Rate and Direction of Inventive Activity, op. cit.

3 J. Schmookler, "Catastrophe and Utilitarism in the Development of Basic Science", in R. Tybout, Economics of R and D, (Ohio State University Press, 1965).

met criticism from Mendelsohn[1] and Kranzberg[2] among others. The opposite limit is the belief that the path of basic science is completely independent of economic, political and social influences.

1.3 Industrial R and D and inventive activity.

The organization of inventive activity during the last one hundred years underwent a change not less spectacular then changes in other spheres of economic life. The independent inventor who was by far the most important creator of inventions even at the beginning of this century, has been replaced today, to an important extent, by organized research and development activity employing teams of scientists and engineers. However, the quantitative importance of the independent inventor is still far from negligible. Estimates for the United States indicate that in 1958 about 40 percent[3] of all inventions were created by the independent inventor, compared to 82 percent at the beginning of the century.[4] Beside their continuing presence in the inventive field, independent inventors are believed to be still responsible for a majority of the technically and economically most important inventions.[5] Industrial R and D appears to be mainly responsible for the "run of the mill" or improvement inventions. Although the importance of

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1 E. Mendelsohn, "Comment on Bahrdt and Schmookler", idem.

2 M. Kranzberg, "Comment on Bahrdt and Schmookler", idem.

3 R.R. Nelson, M.J. Peck and E.D. Kalachek, Technology Economic Growth and Public Policy, (Washington, D.C., Brookings Institution, 1967).

4 J. Jewkes, D. Sawers and R. Stillerman, op. cit., p. 103.

5 D. Hamberg, "Invention in the Industrial Research Laboratory", J.P.E., vol. LXXI, (April 1963), pp. 96-115.

basic inventions for the course of technical change is incontestable, it is difficult to assess correctly the qualitative contribution of the improvement inventions which in their cumulative effect may be of substantial importance to society. Hamberg identifies three main causes of the relative inefficiency of organized R and D: (1) Firms have short term objectives for their R and D and try to minimize risk by concentrating on less revolutionary and therefore less uncertain R and D projects. (2) The sources of ideas for the R and D are mostly outside the R and D laboratories,[1] often coming from the sales department and this is believed to lead to the improvement of existing products rather than to experimenting with new ideas. (3) The influence of vested positions and in general the dubious efficiency of teamwork in a creative activity reduces productivity.

The alleged sources of reduced productivity of organized R and D support the view that there are also likely to be diminishing returns associated with an increase of the R and D staff as far as the numerical output of inventions is concerned.[2]

Organized inventive activity is performed by three types of institutions: the R and D activity of the business sector, the government

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1 There seems to exist important interindustry differences in the importance of the R and D staff in the role of originator of ideas for further R and D. In the science oriented industries, the proportion of ideas coming from R and D staff is relatively more important than in the more traditional industries.

2 Empirical evidence of decreasing returns to scale was found by F.M. Scherer, op. cit., pp. 1112-1113.

research institutes, and the non-profit research institutes such as foundations and universities. We limit our discussion to industrial R and D because it is the most important source of inventions and because it is the main preoccupation of our research.

The objectives of a typical R and D program are broader than the creation of inventions. They range from pure scientific research undertaken primarly for the advancement of scientific knowledge, to the development of improved or new products or processes. The wide scope of objectives of R and D activity lead to an attempt to distinguish three different components:

1. Basic research: Work undertaken primarly for the advancement of scientific knowledge, without a specific application in view.

2. Applied research: The same, but with a specific practical aims in view.

3. Development: The use of the results of basic and applied research directed to the introduction of useful materials, devices, products, systems and processes, or the improvement of existing ones.[1]

It is, however, impossible to identify unambiguously inventive activity with any one of the three main components of R and D. The bulk of inventions comes from applied research and from development but there are important differences between industries and firms so that any generalization or attempt to identify inventive activity with one of the components

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[1] These are the definitions used by the OECD.
OECD, The Overall Level and Structure of R and D effort in OECD countries, (OECD, Paris, 1967), p. 32.

of R and D is not very satisfactory.[1]

The problem of definition and measurement of inventive inputs and output has not prevented several attempts to quantify the relationship existing between R and D and the output of inventions. Mansfield [2] constructed a model which predicted the level of a firm's R and D expenditures as a probabilistic function of the expected rate of return of the proposed R and D projects, the level of sales, past profitability, and the past R and D expenditures. The model was tested for a limited sample of big firms in the U.S. Steel, chemical and petroleum industries and performed very well. When the number of significant inventions created by the firms was regressed on the R and D expenditures and the size of the firm's sales, the R and D and sales explained significantly a very high proportion of the total variance. The largest firms exhibited lower inventive output per dollar of R and D and only in chemical industry did an increase in R and D expenditures result in more than proportional increases in inventive output, in the remaining industries there being no evidence of economies or diseconomies of scale.

Scherer tested Schmookler's demand pull theory by regressing the number of patents awarded to 352 firms on the level of sales. He found

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1 According to Kuznets, the inventive input is the applied research. This view was criticized by Schmookler, who identifies the inventive activity rather with development.
S. Kuznets, "Inventive Activity: Problems of Definition and Measurement", in The Rate Direction of Inventive Activity, National Bureau of Economic Research, (Princeton University Press, 1962).
J. Schmookler, "Comments", in The Rate and Direction of Economic Activity, (Princeton University Press, 1962).

2 E. Mansfield, "Industrial Research and Development Expenditures Determinants, Prospects, and Relation to Size of Firm and Inventive Output", J.P.E., (August, 1964).

the expected positive association accompanied, however, by important interindustry differences, which he associated with "dynamic supply conditions dependent in turn upon the broad advance of scientific and technological knowledge."[1] When he introduced R and D employment in his model, inventive output increased with sales and R and D employment per unit of sales but at a decreasing rate. Mueller[2] found a persistent high correlation between the number of patented inventions and the level of R and D expenditures for U.S. firms in several industries. His objective was to find whether R and D or any of its components may be used as a measure of inventive activity. Referring to Kuznet's and Schmookler's debate on the measure of inventive activity, he found that neither of the two conflicting definitions of inventive activity - applied research and development - was able consistently to outperform the other as a predictor of patenting. Together, however, they performed well.

The studies discussed so far were microeconomic in focus and empirical in character. None of them pretended to be at the same time a general theoretical formulation of the economic theory of invention[3] created by the R and D of a business firm.

Various theoretical aspects of inventive activity were analyzed by Arrow,[4] Nelson[5] and others, but the first attempt to formalize the

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1 F.M. Scherer, op. cit., p. 1100.

2 D. Mueller, "Patents, R and D and the Measurement of Inventive Activity", Journal of Ind. Ec., (November, 1966), pp. 26-37.

3 Although Mansfield presented an explicit theoretical model leading to the econometric relationships he estimated and Scherer referred to Schmookler's demand pull theory.

4 R. Arrow, op. cit., discussed the welfare implications of inventions.

5 R.R. Nelson, op. cit., analyzed the role of basic science in inventive activity.

economic theory of inventive activity of an R and D performing firm was made by Nordhaus.[1] He includes R and D as one of the regular inputs (besides capital and labour) of a profit maximizing firm in a perfectly competitive market. The firm is supposed to optimize the use of R and D inputs by maximizing the present value of the firm with respect to the research inputs. The optimum level of R and D input is determined by the size of the firm, the marginal productivity of inventive inputs, the price of output, the cost of research inputs and by the discount rate. The model is then extended for the conditions of an imperfect market for inventions, the criteria for the optimal life of a patent are derived and eventually the model is integrated into the theory of economic growth. The very generality of this model makes it rather impractical not only for empirical tests but also for the explanation of invention created in the context of non-perfect competition, especially for inventions creating new or differentiated products.

On still a higher level of generality is a very interesting model of invention in the context of a linear activity analysis elaborated in geometrical terms by Lancaster.[2] I have extended and reformulated algebraically his model to give rise to a set of criteria that have to be satisfied before an invention is considered by a firm for commercial exploitation. In the context of the second chapter of this thesis, these criteria serve to distinguish the main categories of invention.[3]

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1 W.D. Nordhaus , Invention, Growth and Welfare, the MIT Press, 1969.

2 R. Lancaster, "Change and Innovation in the Technology of Consumption", A.E.R., Papers & Proceedings, (May, 1966), pp. 14-23.

3 See Appendix A to chapter 2.

1.4 Market structure and invention

We have so far abstracted from the effects of institutional environment on the inventive process. Market structure affects the conduct and performance of firms in general and their technological competition, of which invention is the first link, in particular. Arguments about which institutional environment is the most favourable to invention are polarized between the Schumpeterian defense of monopoly power, and its opponents who claim that monopoly power retards technical change. This almost century-long controversy was recently evaluated in two review articles.[1] Because the discussion covers the whole process of technical change, we concentrate only on the conclusions concerning invention.

Each of the two opposing views is undebatable within its own set of assumptions. Schumpeter and his followers claim that market power is necessary to innovation and that innovation is the core of effective competition.[2] Partisans of the competitive view believe that "where profits on old methods and old products are melted away by competition, the urge is greatest to seek the profits of new products and methods. Conversely, where profits can be maintained by monopolies and cartels, the urge is less".[3]

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[1] M.L. Kamien and N.L. Schwartz, "Market Structure and Innovation:A Survey", Journal of Econ. Lit., vol. XIII, (1), (March 1975), pp. 1-37. J.W. Markham, "Concentration:A stimulus or Retardant to Innovation?" in H.J. Goldschmid, H.M. Mann, J.F. Weston, editors, Industrial Concentration:The New Learning, (Boston, Toronto Little, Brown & Co., 1974).

[2] E.J. Mason, cited by J.W. Markham, idem., p. 249.

[3] M.A. Adelman, cited in J.W. Markham, op. cit., p. 249.

The empirical evidence is rich in quantity but rather poor in clear-cut conclusions. The difficulty underlying all empirical tests is that there is no perfect measure either for invention or for market power.

When inventive and innovative inputs in the form of R and D per sales were related to industrial concentration a weak positive association[1] was found. Scherer[2] found a positive and significant relationship between technical employment and concentration; however, when interindustry differences were accounted for by dummy variables, the explanatory power of concentration was far smaller and less significant. The fact that the industry dummy variables took away a significant portion of concentration's explanatory power and significance was attributed to the positive correlation between concentration and technological intensity of industry. Scherer suggested that this might imply that innovation resulting from technological opportunity has increased concentration. According to Scherer and others, there is a threshold at about 50 percent to 60 percent concentration ratio at which maximum research intensity appears, but it tends to decrease at higher levels of concentration. The above mentioned studies focused on U.S. data. French data[3] indicated that differences in research intensity among French firms

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1 D. Hamberg, "Size of Firm, Oligopoly, and Research: The Evidence," Canad. Jour. of Economics and Polit. Science, 30 (February 1964), p. 75.

2 F.M. Scherer, "Market Structure and the Employment of Scientists and Engineers," American Econ. Review, 57, (3), (June 1967) pp. 524-31.

3 W.J. Adams, "Firm Size and Research Activity:France and the United States," Quart. Journal of Econ., 84 (3), (August 1970), pp. 386-409.

were unrelated to differences in concentration. Similar analysis for Belgium[1] revealed that only in chemical and possibly in the electrical equipment industries, was research intensity related positively to concentration. Globerman's[2] study of Canadian industries found that, for technologically intensive industries, research intensity varied inversely with concentration but directly with foreign ownership. Some of the diversity found in the studies cited above is certainly due to the fact that the measures of R and D intensity, as well as of concentration, were not uniform for all studies.

The evidence on the relationship between inventive output and concentration is meager. Scherer found no correlation between the number of industry related patents issued in 1954 to the leading four firms in the industry, and the four firms concentration ratio and their sales.[3] Similarly, Mansfield's work suggests that the relationship between concentration and innovation was not positive.[4]

Thus it is possible to conclude that there is some weak evidence that R and D increases with industrial concentration but only up to

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1 L. Phillips, "Research," Chapter 5 in, Effects of Industrial Concentration A Cross-Section Analysis for the Common Market, (Amsterdam, North-Holland Publ. Co., 1971), pp. 119-42.

2 S. Globerman, "Market Structure and R and D in Canadian Manufacturing Industries", Quart. Rev. Econ. Bus., (Summer 1973), pp. 59-67.

3 F.M. Scherer, (1965), op. cit., p. 1121.

4 E. Mansfield, Industrial Research and Technological Innovation - An Econometric Analysis, (New York, Norton, 1968).

a certain threshold, not indefinitely. Inventive output appears to be unrelated to concentration.

In this review of previous research emphasis has been placed on studies which are relevant to the empirical framework presented below: a cross-sectional analysis of highly aggregated manufacturing industries. There is of course literature on a variety of aspects of inventive process which lie outside this framework. For example relationships among industry age, structure, competitive rivalry on the one hand and on the other hand intensity and timing of R & D and patenting have been examined. Correspondingly, the relationship between firm size and innovation has generated considerable conflicting evidence.

The reviewed theoretical contributions place the inventive activity in the context of the theory of production and point out the economic determinants of invention. The empiricaly oriented ones provide some evidence and many unanswered questions related to the empirical framework of this study.

The next chapter outlines a microeconomic model of inventive activity, the empirical model is presented in chapter three.

CHAPTER II

A MICROECONOMIC ANALYSIS OF INVENTION

In the first section, we analyze the economic contribution of an invention to the innovating firm. We assume that the firm maximizes profit and we will first study the profit functions of the firm performing R & D activity leading to new inventions. The situation of a firm buying or licensing an invention from outside is discussed in the second part of this chapter.

Owing to the fact that inventive and innovative activity is mostly concentrated in industries characterized by imperfect competition, we also analyze the profit function under the assumption that firms are using the markup pricing technique. Their profit is a function of the market size of the industry, their share of this market and the R & D expenses.

2.1 Profit function of a firm.

The profit of the j-th firm Π_{ij}, producing a product i, is a function of the price of i,p_{ij}, the total output x_{ij}, the total average production cost $\bar{c}_{ij}$ and the present value of the past and current cost of R and D activities attributed to the product i, RD_{ij}:

$$(2.1) \qquad \Pi_{ij} = p_{ij} \cdot x_{ij} - \bar{c}_{ij} \cdot x_{ij} - RD_{ij}$$

or defining the size of the market for i, S_i,

$$S_i = \sum_{j=1}^{n} p_{ij} \cdot x_{ij} \; (j = 1, 2 \ldots n)$$

and the share of the market controlled by the j-th firm s_{ij},

$s_{ij} = p_{ij} \cdot x_{ij}/S_i$; and a constant k_{ij} reflecting the conventional pricing practice of imperfectly competitive industries, based on a fixed markup over the average cost;

$$k_{ij} = (1 - \bar{c}_{ij}/p_{ij}),$$

the profit then can be expressed[1] as:

$$(2.1a) \quad \Pi_{ij} = s_{ij} \cdot S_i \cdot k_{ij} - RD_{ij}$$

2.2 Expected change of profit due to the use of an invention.

We shall now extend this basic model and assume that the firm envisages the possibility of innovating with respect to its production of the product i, through use of an invention improving either the product i itself or its production, or both.

The main categories of technical change that can be considered are three:

1) Invention represents a new commodity, which is associated with preexisting characteristics in different proportions.
2) - Invention adds new characteristics to the preexisting ones. The two cases are examples of product differentiation.
3) - Invention reduces the cost of production, leaving the other characteristics unchanged.

Referring to Appendix A for a detailed analysis of these different cases of technical change, we shall discuss here their possible impact on the profitability of production of the "improved" product i.

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1 This formulation is due to J. Schmookler, Invention and Economic Growth, (Cambridge, Mass., Harvard University Press, 1966), p. 114.

In order to assess the advisability of adopting an existing invention for commercial production or of devoting its own R & D resources to inventive activity in the improvement of product i, the firm in our hypothetical optimally behaving world has to compare the present value of the expected revenue flow with the present value of the expected cost likely to result from the acquiring or creating and working of the invention. We assume that the decision to go ahead and to adopt or create the invention, whatever the alternative may be, will be positive only if the present value of expected future revenues is greater than the present value of expected costs of the venture.[1]

2.2.1 Expected profitability of an inventive effort within the innovating firm.

We assume that the firm will decide to go ahead and try to invent the improvement if the present value of the expected profit change due to the invention will be positive. The firm will devote its R & D resources to the inventive activity if the total derivative of the profit function (2.1) with respect to the differential dP is positive:

$$(2.2) \quad \frac{d\Pi_{ij}}{dP} = (p_{ij} - \bar{c}_{ij}) \frac{dx_{ij}}{dP} + x_{ij} \left(\frac{dp_{ij}}{dP} - \frac{d\bar{c}_{ij}}{dP}\right) - \frac{dRD_{ij}}{dP} > 0$$

where dP refers a change in number of inventions patented. The differentials are all supposed to measure the expected variation of the present value of the respective variables with respect to their initial levels, due to the new invention dP.

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1 If there is a choice among several inventions, the one promising the highest value of the expected profit is supposed to be chosen.

In the case of monopolistic[1] or oligopolistic industries the technical change may increase profit of the innovating firm leaving its output unchanged $dx_{ij} = 0$ (cost reduction and/or higher priced differentiated product). The present value of expected profit increment is simplified:

$$(2.2a) \quad \frac{d\Pi_{ij}}{dP} = x_{ij} \cdot (\frac{dp_{ij}}{dP} - \frac{d\bar{c}_{ij}}{dP} - \frac{dRD_{ij}}{dP} > 0$$

2) In oligopolistic industries using markup pricing, technical change results in changes in market share and market size. We can write the total derivative[2] of the profit function with respect to the new invention dP in terms of the market size S_i, the variation of the market share of the j-th firm with respect to the original size of the market ds_{ij}^*, the variation of the R & D expenses dRD_{ij} and the constant markup coefficient, k_{ij} = const., as follows:

$$(2.2b) \quad \frac{d\Pi_{ij}}{dP} = S_i \cdot \frac{ds_{ij}^*}{dP} \cdot k_{ij} - \frac{dRD_{ij}}{dP} > 0$$

where: $ds_{ij}^* = ds_{ij} + s_{ij} \dfrac{dS_j}{S_i}$

Technical change, specially in the form of strategic inventions, may be used to create or maintain a monopoly position by erecting a barrier to the entry of new competitors, for example by means of patents. Thus the

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1 In monopolistic industries the number of sellers is sufficiently large so that the actions of an individual seller have no perceptible influence upon his competitors. Both oligopolistic and monopolistic industries are assumed to produce differentiated products.

2 For the derivation of the $d\Pi_{ij}$ and discussion, see appendix (B).

firms in imperfect competition are motivated to invest not only in order to increase their market share and market size but also in order to defend their existing monopolistic or oligopolistic position and profits.

In such a case a firm decides to invest in order not to lose the prospective increment of profit that otherwise could be appropriated by its competitors.

We can relate two categories of technical change to the variation of the market share of a firm. The first one covers the cases of various forms of product differentiation, the second one refers to the increase of market share due to a cost reducing invention.

2.2.1.1 <u>Product differentiation leading to an increase of the market share of the innovating firm.</u>

Product differentiation may affect the market share of an innovating firm in three ways:

a) The overall size of the market remains unchanged ($dS_i = 0$) but the invention adopted by the firm producing the improved product is expected to redistribute the market in its favour.

b) The increase of the firm's market share is due solely to the increase of the market size dS_i of the industry i.

c) The combination of the two preceding cases; the innovating firm increases its market size at the expense of its competitors and at the same time expands the overall size of the market.

2.2.1.2 <u>An increase of the market share owing to a cost reducing invention.</u>

In an oligopolistic market the effect of the cost reducing invention is undetermined without further assumptions about the nature of the product and the pricing policy of the competitors. One limit in the range of possible situations is an innovating firm producing a homogeneous product subject to the kinked demand curve. The firm will not increase its output at all unless the cost reduction due to innovation is sufficiently large to jump the marginal revenue function's gap.[1] Even if the cost reduction is sufficiently large, the specific conditions in the industry and in the economy can delay for long time price and market share adjustment.[2] The opposite limit is the cost reducing innovation by a firm producing a differentiated product. The reduction of the production cost by a differential $d\bar{c}_{ij}$ will enable the firm profitably to expand its sales by dx_{ij}, given elastic demand $(-e_{ij} > 1)$.

Assuming that the innovating firm will be the unique user of the invention, the resulting changes in the innovating firm's sales represent the change for the whole industry i.

$$dS_i = d\left(\sum_{j=1}^{n} p_{ij}\, x_{ij}\right)$$

$$= x_{ij}\, d\bar{c}_{ij}\, (1 + e_{ij}) \,/\, (1 - k_{ij})$$

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1 See O. Lange, "A Note on Innovations", Review of Economic Statistics, (1943), pp. 23-24. This case is covered by equation (2.2a).

2 This complex and so far unsufficiently theoretically explained situation is in detail discussed by F.M. Scherer, Industrial Market Structure and Economic Performance, (Rand McNally & Co., 1971), pp. 145-157.

Substituting into the expression for ds^*_{ij}, the change of the market share is a function of the cost reduction $d\bar{c}_{ij}$.

$$ds^*_{ij} = ds_{ij} + (1 + e_{ij}) \; s_{ij}^2 \; d\bar{c}_{ij}/\bar{c}_{ij} \; .$$

Substitution of ds^*_{ij} into equation (2.2b) would yield the expected profit change.

According to Scherer,[1] 20 to 40 per cent of all concentrated industries supply products moderately heterogeneous so that their situation is likely to fit between the two limits discussed above.

2.3 Determination of the licence fee.

All inventions are not created by the R and D effort of firms inventing for their own needs. Some are created by independent inventors[2] or other producing firms and are sold or licenced to the innovating firm, which may acquire the invention either in order to develop and use it, or in order to suppress it.

The price for an invention is established as a result of negotiation between the inventor and the acquiring firm, usually in the form of a licence fee. The licence fee payment takes many forms, from lump sum payment to various formsof installment payments distributed over the period of agreement. We shall analyze the licence fee in terms of its expected present value and will also consider other revenues or costs that play a part in the analysis. We can analyse the market for inventions as an im-

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1 F.M. Scherer, ibid., p. 190.

2 Although the importance of the contribution of independent inventors is recognized, statistically it has been steadily declining. For the discussion of the problem see for instance: R. R. Nelson, M.R. Peck, E.D. Kalachek, Technology Economic Growth and Public Policy, The Brookings Institution, (Washington, D.C., 1967), pp. 56-58.

perfect market for a factor of production.

Determination of the licence fee.

For the firm, it will be profitable to acquire a licence for the use of the invention as long as the present value of expected marginal cost, which is the sum of the licence fee and additional R and D expenses necessary for introducing the invention into production, is less[1] or at most equal to the present value of expected marginal revenue attributable to the exploitation of the "marginal product" of the invention.[2]

Using the analysis introduced in sections 2.1 and 2.2.1 above, we can substitute in the profit increment functions (equations (2.2), (2.2a), (2.2b) the value of the licence fee L_{ij}, and the change of expected R and D expenses attributed to the development and/or introduction of an acquired invention, $\frac{dD_{ij}}{dP}$. There may be cases where the $\frac{dD_{ij}}{dP}$ may be either non-existing or included in the licence fee L_{ij}, when the firm buys not only the right to use an invention but also the know-how necessary to operate it. The total derivatives of profit with respect to the invention will be equal to:

$$(2.3) \qquad \frac{d\Pi_{ij}}{dP} = (p_{ij} - \bar{c}_{ij}) \frac{dx_{ij}}{dP} + x_{ij} \left(\frac{dp_{ij}}{dP} - \frac{d\bar{c}_{ij}}{dP}\right) - \frac{dD_{ij}}{dP} - L_{ij} > 0$$

for the general case, corresponding to equation (2.2) and the case of the invention leaving unchanged market share:

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1 Due to the monopsony or oligopsony situation likely to exist in the market for most inventions, the licence fee (the payment to the "employed factor") will be less than marginal revenue even if additional R and D expenses were absent.

2 In the case of a defensive patent suppression, the cost of acquiring a patent is less than the present value of the loss of profit anticipated if the patent were used by competitors.

(2.3a) $$\frac{d\Pi_{ij}}{dP} = x_{ij} \cdot \left(\frac{dp_{ij}}{dP} - \frac{d\bar{c}_{ij}}{dP}\right) - \frac{dD_{ij}}{dP} - L_{ij} > 0$$

and for the invention resulting in an increased market share:

(2.3b) $$\frac{d\Pi_{ij}}{dP} = S_i \cdot \frac{ds_{ij}*}{dP} \cdot k_{ij} - \frac{dD_{ij}}{dP} - L_{ij} > 0$$

The profit increment is likely to be distributed unequally between the inventor and the innovating firm. Introducing a factor q $(0 < q < 1)$ expressing the distribution of profit increment in favour of the innovating firm,[1] the licence fee will be equal to:

$$L_{ij} = q \left\{\left(\frac{dp_{ij}}{dP} - \frac{d\bar{c}_{ij}}{dP}\right) \cdot x_{ij} - \frac{dD_{ij}}{dP}\right\}$$ in case (2.3a)

and:

$$L_{ij} = q \cdot \left(S_i \cdot \frac{ds_{ij}*}{dP} \cdot k_{ij} - \frac{dD_{ij}}{dP}\right)$$ in case (2.3b)

Let us now have a brief look at the seller's situation in the market for inventions.

For the inventor, the licence fee L_{ij} represents his marginal revenue and as we expect him, for the sake of economic analysis at least, to behave as an profit maximizer, we assume that he should go on inventing as long as the expected marginal cost attributed to the creation of

[1] The value of the q-factor will depend ultimately on the competitive character of the industry i; the closer the situation is to a monopsony the smaller the value of q can be expected.

the given invention $\frac{dRD_{in}}{dP}$, is less than the licence fee L_{ij}.[1]

The total profit variation is distributed between the firm and the inventor:

$$\frac{d\Pi_{ij}}{dP} = \frac{d\Pi}{dP}\text{(firm)} + \frac{d\Pi}{dP}\text{(inventor)}$$

The total profit variation owing to the invention in the case of a constant market share is:

$$\text{(2.4a)} \quad \frac{d\Pi_{ij}}{dP} = x_{ij}\left(\frac{dp_{ij}}{dP} - \frac{d\bar{c}_{ij}}{dP}\right) - \frac{dD_{ij}}{dP} - \frac{dRD_{in}}{dP} > 0$$

and for inventions resulting in change of market share,

$$\text{(2.4b)} \quad \frac{d\Pi_{ij}}{dP} = S_i \cdot \frac{ds_{ij^*}}{dP} \cdot k_{ij} - \frac{dD_{ij}}{dP} - \frac{dRD_{in}}{dP} > 0$$

These results again express the profit variation in terms of cost or price variation and in terms market share and size variation respectively, but on the R and D side, the expenses are explicitly divided between the additional development cost $\frac{dD_{ij}}{dP}$, expected to be incurred by the firm and the proper R and D cost of the inventor $\frac{dRD_{in}}{dP}$.

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1 $\frac{dRD_{in}}{dP}$ includes the present value of all expenses attributed to the given invention, including patent and legal fees, etc. There, is however, a possibility that the actual cost of inventing the given invention exceeds the licence fee L_{ij}. Owing to the fact that the inventor sells an already existing invention, its cost in this case was already incurred, and if $\frac{dRD_{in}}{dP} > L_{ij}$, he suffered a loss. This is a case of a private cost exceeding social benefits discussed by Arrow in: K. Arrow, "Economic Welfare and the Allocation of Resources for Invention," in R.R. Nelson, ed., The Rate and Direction of Inventive Activity, (Princeton University Press, 1962), pp. 609-625.

Summary

This section analyzed invention in a microeconomic context. By applying rules of production theory we were able to establish the contribution of an invention to the profitability of the innovating firm. The price (the market value) of an invention was then expressed, in terms of variables relevant for an analysis of oligopolistic competition, as being proportional to the contribution of the invention to the profitability of the firm.

Owing to the fact that an inventor is not in all cases identical with the innovator (the innovating firm), we have explicitly stated that the final distribution of the profit increment resulting from the use of the invention is indeterminate and depends on several factors, such as the competitive character of the industry, the negotiating strength of the inventor, and so on.

If we are interested in the overall profit increment resulting from the use of an invention, we can neglect the problem of distribution of profit and concentrate only on the formulas (2.2a) and (2.2b), depending upon the type of change anticipated. Although these formulas could be used for establishing equilibrium conditions for profit maximization, we consider the non-equilibrium situation of a positive profit increment as being more interesting for our purpose.

From the formulas for the profit increment $\frac{d\Pi}{dP}$ it is evident that the economic incentive for inventive activity may come from demand conditions of the particular market as well as from the cost conditions resulting from the inventive activity. It therefore seems inappropriate to consider the economic factor as being exclusively a function of demand conditions, as it has been often interpreted in the past. As elsewhere in economics, the economic factor is an outcome of an interaction between demand and supply.

CHAPTER 3

THE EMPIRICAL MODEL

The first of two interrelated parts of this chapter is an attempt to make the theory developed in the previous chapter operational. The second part of the chapter deals directly with the statistical model and data actually employed. Thus in section 3.1, we introduce a model of R and D inventive activity and we discuss alternative proxies for expected profitability of inventive activity which would make it possible to test the model empirically. Section 3.2 is concerned with the specification and estimation of a simultaneous equations system for a regression analysis of cross-section data covering an international sample of manufacturing industries. The final section of this chapter is devoted to describing the data and variables used in the cross-sectional analysis.

3.1 A simple model of R and D activity.

Let us suppose that the R and D activity of a firm can be conceptually divided into three components, according to the objectives pursued.

a) The R and D effort is directed toward inventing new products and processes. The expenses for this component of R and D constitute the cost of inventing. As discussed in the first chapter, the cost of inventing is related to the level of scientific and technological knowledge and will therefore likely vary considerably among industries.

The period between the date of the decision to strive for an invention and the date of the grant of patent for the created invention is the inventing lag.

b) The R and D work necessary to introduce a new patented product or process into commercial production is a function of the number of inventions created and acquired by the firm in a previous period.[1] The lag between the creation or acquisition of an invention and its use in commercial production, i.e. the innovating lag, is a function of the technical difficulties involved and of other variables.[2]

c) To the extent that some R and D activity is geared directly toward product differentiation or cost reduction, this portion of the research effort will increase the profitability of a firm without reflecting on the contribution and the cost of patented inventions.

The relationship between the three components of R and D activity of a firm and their outputs may be schematically represented in a graph (Fig. 1).

Let RDI be the R and D necessary to create inventions, and RD-2 the component devoted to the commercialization of created and acquired inventions. Finally, RD-3 is the component which directly increases the profitability of a firm through product and process changes other than inventions.

1 By making this assumption, we implicitly assume that all patented inventions represent the same degree of technical difficulty for implementation; this is often certainly far from reality.

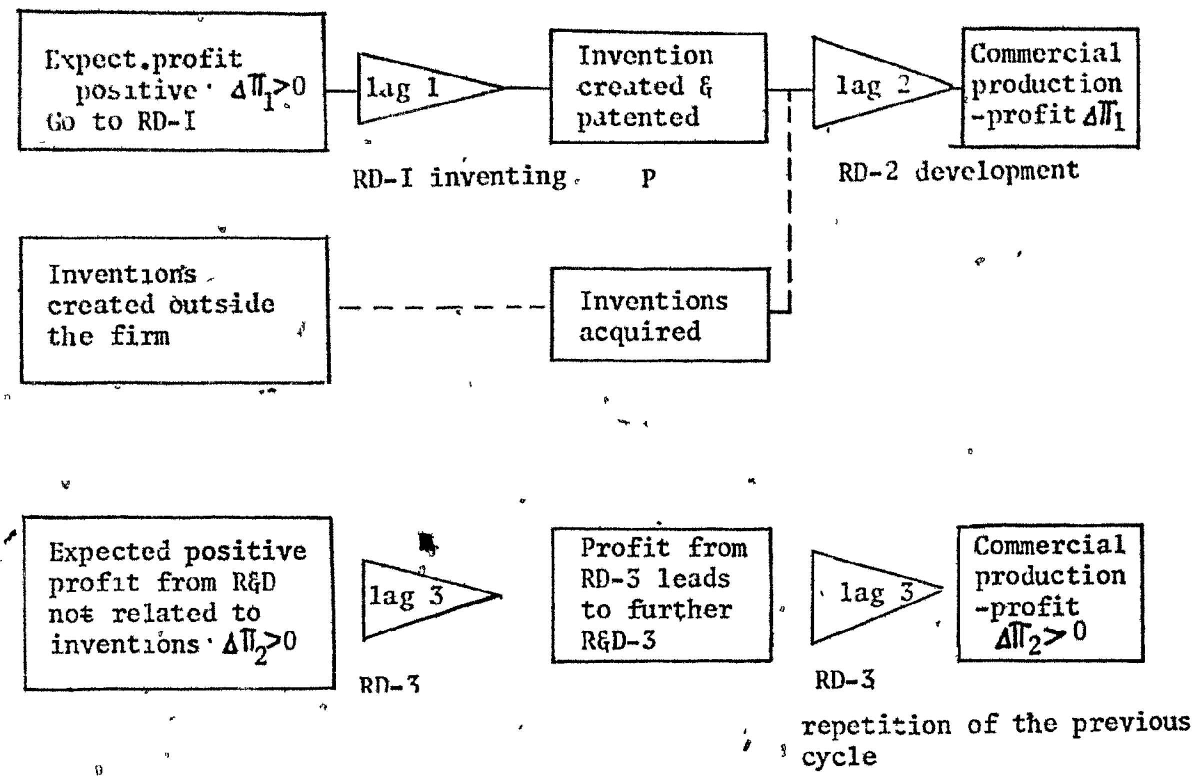
2 The length of the innovating lags vary from case to case, from industry to industry, and likely from country to country. However, there are some statistical studies available that indicate certain regularities for the "typical" or average case, see:
Jewkes, Sawers, Stillerman, op. cit.

As the model of RD activity has to reflect the lags between various variables, we shall simplify the complex reality by assuming that the lags are of unitary length, so that component RDI, for example, undertaken in period t, will result in a patented invention in the next period t + 1, the length of the respective lag being assumed to equal 1.

Now, we will analyze this R and D model in order to find out whether we can use outlays for R and D of firm j in industry i as a proxy for the expected change in the variables underlying the profit change, such as Δs_{ji}, $-\Delta c_{ji}$, Δp_{ji}. The cost of inventive activity in our model is represented by component RDI, which precedes with an inventive lead (1) the creation of inventions patented at period t. The cost of inventing done by inventors independent of industry i is not included in the aggregate of RDI_i and the cost of inventing for industry i will therefore be underestimated, if there have been inventions acquired from outside sources.

The following diagram (Fig. 1) represents the R and D activity in form of a cycle leading from profit expectations to creation of one invention, to its commercial development and to resulting increased profits. In a parallel direction, the R and D leading directly, through changes other than patented inventions, to profit increments is also included. The diagram simplifies reality; there are usually several R and D programs running at the same time, their objectives and timing being different. Thus, in reality, several sequences similar to the one represented in Fig. 1 exist superimposed and lagged with respect to each other.

Figure 1:



Legend:

P	:	Patented invention (s).
RDI	:	R and D inventing activity.
RD-2	:	Development work necessary before invention can be used in production.
RD-3	·	R and D work not related to creation or development of inventions.
Lag 1	:	Inventing lag = time elapsed between the start of the inventive activity and the grant of patent for successful invention.
Lag 2	:	Innovation lag = time period necessary to adapt the invention to commercial production.
Lag 3	:	Improving lag = time necessary to improve the product or the productive process through non-patentable technical change.
$\Delta\Pi_1$	:	Profit increment due to exploitation of patented inventions.
$\Delta\Pi_2$	:	Profit increment due to R and D not related to inventions.

The relationship between the inventions patented by the j-th firm of the i-th industry at period $t+1$, $P_{ji(t+1)}$, and inputs, i.e. m-groups of non-competing R and D labour [1] specializing in inventive activity, RDI_{jimt}, may be expressed as a Cobb-Douglas production function. [2]

$$(3.1) \qquad P_{ji(t+1)} = b_o \prod_{m=1}^{M} RDI_{jimt}^{b_m} \qquad b_o, b_m > 0, \; m = 1, M$$

This formulation of a generally non-linear[3] homogeneous production function for b_o, $b_m > 0$, can be justified mainly by an argument in favour of maximum mathematical convenience subject to given theoretical constraints. By choosing the RDI_{jim} as the only inventive inputs to explain the number of patented inventions in a given firm, we have to account somewhat for the fact that there is a certain, non-negligible number of inventions created by individuals completely independent of any form of organized R and D activity. We account for this by stipulating that the in-

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1 The R and D labour engaged primarily in inventive activity consists of qualified engineers and scientists, technicians and other supporting staff. The R and D statistics break down the manpower data also by the main activities, i.e. by basic research, applied research and development. It is, therefore, possible to break down the total R and D manpower working on inventions into several non-competing groups in order to identify their respective contributions to the inventive output.

2 This formulation gives rise to an aggregation problem, which will result in an aggregation bias. This is a familiar problem related to macro aggregates which were aggregated from micro units in an arithmetic instead of geometric fashion, as the multiplicative micro-production function would require. As in other production function studies, we can only ascertain the existence of the problem; the unavailability of disaggregated data prevent us from solving it. For detailed reference see:
A. Nataf, "Sur la possibilité de Construction de certains Macromodèles," Econometrica, vol. 16, (July 1948), pp. 232-244.

3 Except for the exceptional case of $\sum_m b_m = 1$ which cannot à priori be excluded.

tercept $b_o > 0$, i.e. even if there is a very low level of R and D activity, we expect a positive number of patented inventions to be created. Short of trying to include the independent inventors directly in our model, this specification is plausible in the light of facts known about invention activity.

As for the non-homogeneity, we are forced by our ignorance to specify the b_m in the least possible restrictive manner. A priori we can be sure only of the non-negativity of b_m. As for their actual values, they will be determined to a certain extent by other assumptions incorporated in our model through the first and second order conditions of the constraint maximum solution for maximum profit. There is no theoretical or empirical reason why the relationship between R and D inputs and the number of patented inventions should be linear, i.e. $\sum_m b_m = 1$, or subject to increasing $\sum_m b_m > 1$, or decreasing $\sum_m b_m < 1$, returns.

The present value of the expected revenue from the use of patented inventions R_{jit} is equal to the product of the expected number of patented inventions $P_{ji(t+1)}$ and of their present value of their average expected contribution to revenue, r_{jit}.

(3.2) $$E(R_{jit}) = E(r_{jit}) \cdot E(P_{ji(t+1)})$$

The expected contribution of an invention to the revenue of its user can be considered as a shadow price of the invention; as long as the invention is exploited by the firm which created it, it is an implicit price. It becomes a market price only when the invention is sold by its inventor (or owner) for money or exchanged for some other assets. Even when they enter the market, the incomparability of patented inventions forces us to consider them as objects giving rise to economic rents; the price, therefore, for any invention is determined by demand.

The relevant factor market, the market for R and D personnel can generally be considered as being imperfect and therefore, there is a dependence between the quantity of R and D manpower demanded and its price, i.e. the wage rate. A general formulation of the supply functions would relate the supply of various groups of R and D labour to the wage rates paid to all groups. Assuming a log linear relationship, the supply of each type of R and D labour:

$$\text{(3.3a)} \quad \begin{aligned} \log RDI_{jilt} &= \log c_{10} + c_{11} \log W_{jilt} \cdots c_{1M} \log W_{jiMt} \\ \log RDI_{jiMt} &= \log c_{M0} + c_{M1} \log W_{jilt} \cdots c_{MM} \log W_{jiMt} \end{aligned}$$

This system of M log-linear simultaneous equations yields a general solution for the respective wage rates, subject to a necessary condition that the matrix of partial elasticities of supply, $C = [c_{nm}]$, be non-negative and $/C/ \neq 0$. Denoting the elements of the inverse C^{-1} as $[c^*_{nm}]$, we can write:

$$\text{(3.3b)} \quad W_{jint} = \prod_{m=1}^{M} (RDI_{jimt} / c_{mo})^{c^*_{nm}} \qquad n = 1, M, \; c_{mo} > 0, \; m = 1, M$$

Owing to our assumption that inputs are non-competing groups of R and D personnel, supply of each m-th group is only of function of its own wage. Therefore, only elements c^*_{nm} (n=m) on the diagonal of the inverted matrix C* are different from zero, ($c^*_{mm} = \frac{1}{c_{mm}}$), other elements vanish.

The wage rate for the m-th group of R and D labour is:

$$W_{jim} = (RDI_{jim} / c_{mo})^{1/c_{mm}} \qquad m = 1, M \tag{3.3c}$$

Cost of R and D activity is then equal to:

$$\text{COST } RDI_{jit} = \sum_{m=1}^{M} RDI_{jimt} \cdot (RDI_{jimt} / c_{mo})^{1/c_{mm}} \tag{3.4}$$

$$= \sum_{m=1}^{M} \delta_m \, RDI_{jimt}^{\gamma_m} \qquad m = 1, M$$

where $\delta = (1/c_{mo})^{1/c_{mm}}$ and $\gamma_m = (1 + 1/c_{mm})$.

It is now possible to express the expected profit by subtracting (3.4) from (3.2) and maximize it subject to the constraint provided by the production function (3.1).

$$\max \Pi = P_{ji(t+1)} \cdot r_{jit} - \sum_{m=1}^{M} \delta_m \, RDI_{jimt}^{\gamma_m} \tag{3.5}$$

$$\text{Subject to:} \quad 0 = P_{ij(t+1)} - b_o \prod_{m=1}^{M} RDI_{jimt}^{b_m}$$

Solution by Lagrange multipliers gives the first order conditions for maximum profit.

$$r_{it} \cdot P_{ji(t+1)} \, (b_m / RDI_{jimt}) = W_{jimt} \cdot \gamma_m \qquad m = 1, M. \tag{3.6}$$

The second order condition [1] requires that $b_m < \gamma_m$. From (3.6) and (3.2) the equilibrium demand for R and D personnel as a function of the expected revenue and of the equilibrium wage rates is given by the elasticities of labour supply.

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[1] See appendix D for calculation of the constraint maximum conditions. The second order condition $b_m < \gamma_m$ implies that at the extreme case of perfectly elastic supply of RD labor, $\gamma_m = 1$ and $b_m < 1$; in the more likely situation of $\gamma_m > 1$, $0 < b_m < \gamma_m$.

(3.7) $$RDI_{jit} = F(R_{jit}) \cdot b_m \cdot \gamma_m^{-1} \cdot W_{jim}^{-1} \qquad m = 1, M$$

RDI_{jit} in equation (3.7) is the "equilibrium demand" for R and D at the "equilibrium wage rate".

In the previous chapter, we found (2.2b) [1] that for a firm using mark up pricing the expected revenue from invention was:

(3.8) $$E(R_{jit}) = \Delta s^*_{jit} \cdot S_{it} \cdot k_{jit}$$

where the change of the market share Δs^*_{jit} and mark-up coefficient k_{jit} are both functions of firm size relative to industry size.

3.1.1 Aggregation to industry level. [2]

The data [3] covering patented inventions, R and D and other economic variables are available on the industry level only. In order to use them in the empirical tests of our model, we have to aggregate the relationships which are to be estimated, from the level of a firm to the level of an industry.

Assuming that all firms in an industry i and a country h are the same size [4] and that R and D is also the same for all firms, [5] we then have:

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1 Substituting the finite difference Δs^* for the derivative used in (2.2b).

2 Formulation of this section (3.1.1) was kindly suggested by my thesis director, professor P.B. Huber.

3 Description of data follows in section 3.3 of this chapter.

4 Note that the number of firms per industry per country J_{ih} varies by industry and by country.

5 The time subscript is suppressed from now until the end of this section for the sake of clarity.

$$(3.9) \quad \sum_{j=1}^{J_{ih}} P_{jih} = J_{ih}\, b_o \prod_{m=1}^{M} RDI_{jimh}^{b_m}$$

$$= J_{ih}\, b_o \prod_{m=1}^{M} \left(\sum_{j=1}^{J_{ih}} RDI_{jimh} / J_{ih} \right)^{b_m}$$

$$= J_{ih}\, b_o \prod_{m=1}^{M} \left(RDI_{imh} / J_{ih} \right)^{b_m} \qquad m = 1, M$$

and for R and D assuming that $W_{jimh} = W_{imh}$

$$(3.10) \quad \sum_{j=1}^{J_{ih}} RDI_{jimh} = RD_{imh}$$

$$= b_m \cdot \gamma^{-1} \cdot W_{imh}^{-1} \cdot \sum_{j=1}^{J_{ih}} E(R_{jih}) \qquad m = 1, M$$

Substituting from (3.4) and (3.8) and assuming that mark up constant is invariant over firms in one industry and country, we reach an equilibrium demand for R and D labour.

$$(3.11) \quad RDI_{imh} = b_m (1 + c^{-mm})^{-1} W_{imh}^{-1} S_{ih} k_{ih} \sum_{j-1}^{J_{ih}} \Delta s^*_{jih}$$

Given the assumption that all firms are the same size in a given industry and country

$$(3.12) \quad J_{ih} = S_{ih} / \bar{S}_{jih}$$

Hence we may substitute (3.12) in (3.9) and write

$$(3.13) \quad P_{ih} = \sum_{j=1}^{J_{ih}} P_{jih}$$

$$= \frac{S_{ih}}{\bar{S}_{jih}} \cdot b_o \prod_{m=1}^{M} \left[(RDI_{imh} \cdot \bar{S}_{jih}) / S_{ih} \right]^{b_m}$$

$$= S_{ih} \cdot \bar{S}_{jih}^{-\alpha} \cdot b_o \prod_{m=1}^{M} (RDI_{imh} / S_{ih})^{b_m}$$

Where exponent $\alpha = \sum_{m=1}^{M} b_m - 1.$

Equation (3.13) rewritten for purpose of estimation.

$$(3.14) \qquad P_{ih} / S_{ih} = \bar{S}_{jih}^{\alpha} \, b_o \prod_{m=1}^{M} (RDI_{imh} / S_{ih})^{b_m} \cdot u_{ih}$$

All variables, except average sales per firm $\bar{S}_{jih}$, are now aggregated to an industry level. The exponent of $\bar{S}_{jih}$ is probably close to zero, because the $\sum_{m=1}^{M} b_m$ is not likely to be à priori significantly different from unity. Most of its variation may be captured by introducing dummy variables, thus avoiding most bias in estimation of b_m which otherwise would be introduced. The equilibrium demands for m-groups of R and D personnel, theoretically expressed by (3.11), must be deflated by industry sales to make them consistent with the formulation (3.14). Their theoretically predicted values cannot, however, be expected to be identical with the actual R and D employment.

Imperfect information, lack of management skill and practical impossibility of instantaneous adjustment of the R and D manpower to the profit maximizing level are the main reasons for a discrepancy between the actual R and D employment and the equilibrium profit maximizing demand for R and D personnel. The simpliest approach to handle the deviation would be to account for the deviations by the random disturbance term only. There is however a great likelihood that the deviations from equilibrium will show some non-random pattern which may be associated with the importance of the variables considered in decision making. Accordingly, the wage rate paid to R and D personnel and the expected revenue from inventions may be associated with deviations from equilibrium although it is difficult to specify à priori if the relationship is direct or inverse.[1]

[1] G.H. Hildebrand and T.C. Liu, Manufacturing Production Functions in the United States, 1957, (The N.Y. State School of Industrial and Labour Relations, Cornell University, Ithaca, N.Y., 1965), discuss in detail the possible relationships between the deviation from equilibrium and wage rate and the size of producing units. They concluded that it is impossible to determine à priori the direction of these relationships.

The more research oriented an industry is the more likely it is that it has greater incentive and capacity to converge to an optimum use of R and D personnel. On the other hand, the more R and D oriented the industry the stronger the tendency toward inefficiency and rigidity in organization of R and D, especially toward staff reducing changes. Similarly, the influence of wages paid by an industry may represent a strong incentive to achieve the optimum. On the other hand, low wages may attract more of R and D activity with entrepreneurs trying to employ as much of R and D personnel as possible up to the optimum quantity.

The deviations of the actual R and D employment from the equilibrium demand can also be associated with industry size and with expected profitability. The age and technological character of an industry are likely to play a role here, but it is difficult to predict it a priori for a heterogeneous sample of industries. Their sign and magnitude will be determined by the empirical data.

The equilibrium demand for R and D personnel, accounting for the deviations discussed above is:

$$(3.15) \quad RDI_{imh} / S_{ih} = (b_m/\gamma_m) \cdot W_{imh}^{\omega-1} \cdot \left(\sum^{Jih} \Delta s^{*}_{jih} \right)^{1+\psi} k_{ih} S^{\theta}_{ih} \cdot v_{ih}$$

$$m = 1, M$$

Where the parameter ω expresses influence of wage rate on deviation from equilibrium and parameters ψ and θ are similarly interpreted for the expected profitability and industry size. The random disturbance v_{ih} has unitary mean and is independently distributed among industries and countries. Variations of mark-up constant k_{ih} by industry and country provide justification for industry and country dummy variables.

Before proceeding, it is necessary to discuss the proxies for the sum of the expected market share increments, i.e. the proxies for expected profitability.

3.1.2 R and D proxies for the profitability and cost of invention.

Referring to the Fig. 1, we can relate the increment of profit Π_g attributed to exploitation of patented invention(s) to the portion RD-2, that is to the development work necessary to introduce the invention(s) into commercial production. We can assume that the greater the expected benefits from the use of inventions, the greater the expenses for their development the firm will be ready to disburse. Therefore, we assume that there is a high correlation between the development expenses RD-2 of a firm and the variables indicating profit changes, such as the increase of the firm's market share or, alternatively, the changes of production costs or prices in the subsequent period.[1]

Given this relationship between RD-2 and the set of variables (Δs^*; Δc; Δp) we can use, for a given size of industry i, the sum of the development expenses of all its firms j, in country h

$$\sum_{j=1}^{J} RD\text{-}2_{jiht} \,/\, S_{iht}$$

at period t, as a proxy for the expected aggregated changes of the market shares or of the costs and prices in the later period t+1.

The proxy $RD\text{-}2_{it}$ better reflects the expected variables $\Delta s^*_{i(t+1)}$, $\Delta c_{i(t+1)}$, $\Delta p_{i(t+1)}$ the closer the actual cost of development work is to

1 See the empirical evidence in the article:
J.R. Minasian, "The Economics of Research and Development," in The Rate and Direction of Inventive Activity, National Bureau of Economic Research, (Princeton University Press, 1962).

the value of the benefits expected and the more competitive the industry is.[1] Owing to those two qualifications we may expect that the proxy will underestimate the correct value of the variables it represents.

However, this downward bias is likely to be compensated when for RD-2 we use the statistical data for development expenses, because they include the R and D expenses not related to inventions (RD-3 in our model) and thus inflate the development expenses. With reference to our model in Fig. 1, it should also be noted that the proxy $RD\text{-}2_{it}$ represents the expected changes of profit variables for all inventions created for industry i, including inventions which originated from independent inventors.

3.1.3 Alternative proxies for the profitability of invention.

Conceptual, as well as empirical problems related to the R and D proxies for the profitability of invention discussed in the previous section suggest that we try to specify some alternative proxies. In contrast with the R and D proxies which directly reflect the expected contribution of inventive activity to future profits, the proxies which we introduce in this section are not constrained to reflect the portion of profit expected from the inventive and subsequent innovative activity. They stand for overall profit. We assume that anticipation of future profits in an industry will motivate inventive activity to exploit this

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1 In the case of a monopolistic industry, the expected benefits of Δ RD-2 will be greater than their cost, the difference between the two contributing to the monopolistic profit.

profit potential in the future.[1] Unavailability of data on profits or stock-market valuations leaves as choice the rate of growth of value added. We can assume that the greater the past rate of growth of the value added in an industry, the greater the present value of expected future profits due to new inventions and consequently, the greater the flow of patented inventions in the future.

Another possible proxy for profitability is the investment in plant and equipment. The relationship between patented inventions and investment was extensively studied by Schmookler and we refer to the discussion of his findings in the first chapter of this study.

However, Minasian's[2] finding that R and D and investment appeared to be competing for the same funds suggests that investment is not necessarily a good proxy for the portion of profit expected to result from technical change through invention. Kuh's finding[3] that investment behaviour was better explained by sales than by profits, can be stated as another objection against the use of investment as a profitability proxy. The empirical test of the investment variable will show whether it adds any explanatory power to the other exogenous variables.

The last proxy for profitability is the ratio of exports to imports of the given industry. The competitiveness of manufacturing ex-

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1 This assumption is probably justified if we deal with a high level of aggregation. Theoretically however, this is not necessarily the only possible outcome; anticipation of important future profits will lead to inventive activity only if this activity is considered to be at least as good as or a better source of future profits than the other available alternatives such as improved management, capital investment, etc..

2 Minasian, op. cit.

3 E. Kuh, Capital Stock Growth: A Microeconomic Approach, (North-Holland Pub. Co., Amsterdam, 1963).

ports is believed to be determined to a great degree by the technological advance over competitors. Thus the high value of the ratio $\frac{EX}{IM}$ is likely to reflect high profits due to technical change.

5.2 Cross-section analysis of an international sample of manufacturing industries.

The basic hypothesis we want to test is that the number of inventions patented in an industry is a positive function of the present value of the profits expected to result from the use of those patented inventions in the future.

We assume that the decision to invent is taken in the year t, and the basis for evaluation of the present value of the expected profits due to the new inventions is the current performance of the industry. Therefore, the profits due to the technical change for the year t, are assumed to serve as a base for estimating the expected profitability of future inventions.[1]

The decision to invent taken in period t, will be reflected by a patent issued at period (t + 1). The dependent variable, the number of patented inventions at period (t + 1) will be estimated from the "production

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1 The view that the profit expectations are based on past and current situation is well accepted in investment theory. See for example: Jan Tinbergen and J.J. Polak, The Dynamics of Business Cycles, a Study in Economic Fluctuations, (Chicago 1950), pp. 166-167.

For a direct reference on R and D decision making in firms, see: E. Mansfield, "Industrial Research and Development Expenditures Determinants, Prospects, and Relation to Size of Firm and Inventive Output," The Journal of Polit. Economy, Vol. LXXII, No 4 (August 1964), pp. 319-340.

function" (equation (3.14) in the previous section), using various categories of R and D manpower as the only "inventive" factor.[1]

Due to the exploratory character of this study, we shall estimate and report the results of several alternative versions of the model. The main differences between the specifications of the first two versions are in the type of R and D variables used. This reflects the state of our ignorance as far as what component of the data on R and D, not withstanding the accounting definitions applied in their collection, best reflects the organized inventive activity. We want, therefore, to test various components of the R and D activity with respect to their role in the inventing process. The first two versions consist of a simultaneous system of equations estimated by the two stages least square method. The use of this estimation method is justified not only on the ground of the simultaneous character of the relationships analyzed but also because of the suspected measurement problem. As we cannot be sure that the demand for the inventive manpower is correctly measured by one of the R and D variables used, it is advantageous to work with their predicted demand rather than with the measured one.[2]

The last version is a single equation specification of the model. The two resulting equations (3.14) and (3.15) of the theoretical formulation are obviously a rather simplified picture of the complex reality they purport to represent. The unavailability of data for patents and R and D

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1 The time subscripts will be suppressed from now on for the sake of clarity.

2 The use of the 2SLS as a solution of the measurement problem is discussed by Aigner c.f. D.J. Aigner, Basic Econometrics, (Prentice Hall Inc., N.J., 1971), pp. 152-155.

for more than one period imposed serious limitations on the choice of variables and relationships available for empirical analysis. If we add to this the problem of the interpretation of R and D data, it becomes difficult to reject the temptation to simplify the specification of the model by expressing it in a single equation testable by the ordinary least squares method. Also, the cross-section analysis of production functions [1] has shown very small differences between the estimates resulting from ordinary least squares and two stages least squares and Griliches used this as an argument to justify the use of a simple least square estimation of the single equation model. [2]

The data which are described in detail in section 3.3, represent a cross-section of observations on ten manufacturing industries from six countries. It is obvious that the inventive activity and its economic determinants will, to a certain degree, be associated with country and industry specific differences. Industry differences in market structure are likely to influence the conduct of firms in technological competition. Firms in highly concentrated industries have financial and technical resources to be technological leaders. [3] On the other hand, the empirical

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1 Hildrebrand & Liu reported both OLS and 2SLS estimates of production function estimates that were very close:
G.H. Hildebrand and T.C. Liu, Manufacturing Production Functions in the United States, 1957, (The N.Y. State School of Industrial and Labor Relations, Cornell University, Ithaca, N.Y., 1965).

2 Z. Griliches, "Production Functions in Manufacturing: Some Preliminary Results," The Theory and Empirical Analysis of Production, A Conference, Studies in Income and Wealth, vol. 31, National Bureau of Economic Research (Columbia University Press, N.Y., 1967), pp. 275-279.

3 See statement by J.K. Galbraith on this subject: "...Benign Providence has made the modern industry of a few large firms an almost perfect instrument for inducing technical change."
J.K. Galbraith, American Capitalism, (Houghton Mifflin, rev. edition, 1965), p. 86.

evidence suggests that lack of competition in highly concentrated industries is conducive to technological stagnation.[1] It is not possible, a priori, to be sure which of the two tendencies is stronger. It will be determined by the empirical data. We specify a concentration variable $\bar{C}_{1h}$, which measures the percentage of the total employment of an industry employed in firms with more than five hundred employees.

Country specific differences are likely to exist for two reasons. First, national patent systems are not identical and we use the variable patenting ratio G_h to capture the inter-country differences existing among national patent systems. There remains however, another source of inter-country differences, this one asociated with national characteristics influencing inventiveness. According to theories of invention, these characteristics may be associated with the level and organization of technical education. We shall use the education variable E_h to reflect this.

The quality, and therefore the productivity, of the R and D personnel is also likely to vary substantially between countries. For lack of a more appropriate variable, the above mentioned education variable will be used. To capture the rest of the inter-country variance, unexplained by the two country specific variables G_h and E_h, we introduce country dummy variables, X_g.

The industry specific differences are likely to be more important on the side of inventive input, i.e. affecting the quality, organization and use of R and D and generally, the technological climate of an industry.

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1 One of better known case studies is:
W. Adams and J.B. Dirlam, "Big Steel, Invention and Innovation," Quarterly Journal of Economics, (May, 1966), pp. 167-189 and the series of articles which followed.

The economic variables and the aggregate R and D employment cannot be expected to explain all this industry specific variance. If we had available data on education disaggregated to an industry level, it could prove useful in providing additional explanation. In absence of an additional variable of this sort we shall use industry dummy variables Y_i, to extract the inter-industry variance. This proxy will be used in the first stage equation, predicting the R and D manpower. The inter-industry differences within national patent systems are less likely to show any determinate pattern but we shall experiment with the industry dummy variables in the second stage to see if inclusion there may be helpful.

3.2.1 Alternative specifications.

The first stage equations estimate the predicted demand for the respective category of R and D personnel. The dependent variables are regressed against all compatible predetermined variables of the model. The predetermined variables include the size of the i-th industry measured by its sales S_{ih}, the proxies for profitability: the development expenditure deflated by sales, D/S_{ih}, the growth rate of value added in the five preceding years $\dot{VA}_{ih}$, the gross investment deflated by sales I/S_{ih}, the ratio of exports to imports EX/IM_{ih} and the average size of firm $\bar{S}_{jih}$. To this list is added the concentration C_{ih}, the patenting ratio G_h, the education variable E_h, the industry dummy variables $\sum_{i=1}^{10} d_i Y_i$ and the country dummy variables $\sum_{h=1}^{6} g_h X_h$. Some of the alternative profitability proxies are not mutually exclusive; we estimate first the equation with all of them (EX/IM, VA, I/S) included at the same time and then eliminate those which are significant at less than 70% level. All variables are transformed into logarithms. The general form of the 1st stage equation can be written as follows,

$$(1)\quad \log RDI_{imh} / S_{ih} = \log a_0 + a_1 \log S_{ih} + a_2 \log EX/IM_{ih} + a_3 \log VA_{ih} + a_4 \log I/S_{ih} + a_5 \log D/S_{ih} + a_6 \log \bar{S}_{jih} + a_7 \log \bar{C}_{ih} + a_8 \log E_h + a_9 \log G_h + \sum_{i=1}^{10} d_i Y_i + \sum_{h=1}^{6} g_h X_h + \log v_{ih}$$

where the symbol RDI_{imh} stands for employment of various categories of R and D manpower considered as inventive input.

In the second stage of 2SLS, the number of patented inventions deflated by industry sales P_{ih} / S_{ih}, is function of the predicted values of R and D employment (inputs), the average firm size $\bar{S}_{jih}$, the concentration percentage $\bar{C}_{ih}$, the patenting ratio G_h and the education variable E_h. Alternatively, the vector of country dummy variables X_h (h=1...6), is used, instead of both G_h and E_h. The definition of inventive inputs, i.e. of the relevant categories of R and D employment, is constrained by the framework used for the compilation of international R and D statistics by the OECD. Basically, we have two alternatives open to us. According to the first, only applied research is considered as an invention creating activity and, according to the second, both applied research and development create patentable inventions.[1] For both alternatives, the R and D man-

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[1] The first alternative represents Kuznets' position, the second corresponds broadly to Schmookler's. The discussion of identification and measurement of input of inventive activity is given in S. Kuznets, op. cit., pp. 31-35, and J. Schmookler, "Comment" to Kuznets' article, ibid.

power employment may be broken down into two categories, the Qualified Engineers and Scientists (QSE) and their supporting staff (ST).

Version I.

In this specification we assume that applied research, as defined and measured by R and D statistics, represents the organized inventive activity. The inputs in the production function for patents will be the predicted number of qualified engineers and scientists employed in applied research $\widehat{QSEA_{ih} / S_{ih}}$, and their supporting staff $\widehat{STA_{ih} / S_{ih}}$ or, alternatively, the total employment in applied research $\widehat{MRA_{ih}/S_{ih}}$. The 2nd stage equation of this 1st version is

$$\text{(II-1)} \quad \log P_{ih}/S_{ih} = \log b_0 + b_1 \log \widehat{QSEA_{ih} / S_{ih}} + b_2 \log \widehat{STA_{ih} / S_{ih}} + b_3 \log \bar{S}_{jih} + b_4 \log \bar{C}_{ih} + b_5 \log G_h + b_6 \log E_h + \sum_{i=1}^{10} d_i Y_i + \sum_{h=1}^{6} g_h \cdot X_h + \log u_{ih}$$

As pointed out above, the country specific G and E variables cannot be estimated simultaneously with the country dummy variables. We shall therefore try both alternatives and compare their results. Should the estimation of the patents as a function of the two closely related inputs QSEA and STA fail because of a multicollinearity problem, appropriate changes in the specification will be introduced and discussed in the next section.

Version II.

The definition of inventive inputs is now extended to include both the employment in applied research MRA and in development MD. An attempt will also be made to use the breakdown of inputs to the QSE and Staff categories for estimation.

$$(II-2)\quad \log P_{ih} / S_{ih} = \log b_0 + b_1 \log \widehat{MRA_{ih}} / S_{ih} + b_2 \log \widehat{MD_{ih}} / S_{ih} + b_3 \log \bar{S}_{jih} + b_4 \log \bar{C}_{ih} + b_5 \log G_h + b_6 \log E_h + \sum_{i=1}^{10} d_i Y_i + \sum_{h=1}^{6} g_h X_h + \log u_{ih}$$

The same comments concerning country dummy variables and modifications apply here as in the case of Version I. There is only one important difference: the profit proxies used in the first stage do not include the development proxy D/S, development now being one of the jointly dependent variables.

Version III.

In this specification, we estimate by the ordinary least squares method only one equation resulting from direct substitution of equation (3.15) into equation (3.14) in the theoretical model of section 3.1. The estimation is performed for two variants corresponding respectively to the first and second versions above. In the first variant, the profitability proxy is development deflated by sales D/S. In the second, we use those of the three alternative profitability proxies which pass the test of being significative at a level higher than 70%. The two variants of the Version III are generally specified as follows:

$$(III\text{-}a)\quad \log P_{ih} / S_{ih} = \log c_0 + c_1 \log D/S_{ih} + c_2 \log S_{ih} + c_3 \log W_{ih} + c_4 \log \bar{S}_{jih} + c_5 \log \bar{C}_{ih} + c_6 \log G_h + c_7 \log E_h + \sum_{h=1}^{6} g_h X_h + \sum_{i=1}^{10} d_i Y_i + \log u_{ih}$$

$$(III\text{-}b)\quad \log P_{ih} / S_{ih} = \log c_0 + c_1 \log I/S_{ih} + c_2 \log EX/IM_{ih} + c_3 \log VA_{ih} + c_4 \log S_{ih} + c_5 \log W_{ih} + c_6 \log \bar{S}_{jih} + c_7 \log \bar{C}_{ih} +$$

$$c_8 \log G_h + c_9 \log F_h + \sum_{i=1}^{10} d_i Y_i + \sum_{h=1}^{6} g_h \cdot X_h + \log u_{ih}.$$

3.2.2 Estimation procedure.

There are several econometric problems related to the proposed specification and to the only available cross-section data. The simultaneous nature of the relationships between the jointly dependent variables, i.e. the number of patented inventions, the R and D employment and the wage rate of the R and D personnel, requires the use of one of the estimation methods appropriate to interdependent linear systems. The equation we are interested in is the production function for patented inventions which, as the rank criteria for the identification shows, is over-identified. We shall estimate its coefficients by applying the two stages least square method. Due to the unavailability of data on lagged employment of R and D personnel mentioned earlier in the theoretical part of section 3.1, we cannot estimate the equation of the demand for R and D personnel. The equation expressing R and D employment as a function of all predetermined variables in the system is therefore not to be interpreted as the demand function for R and D personnel - it is only the first stage of the 2SLS estimation procedure.

The cross-section sample consists of observations on units of widely differing sizes. There is therefore an a priori possibility that one of the basic assumptions for the use of single and two stages least squares method will be violated by the variation of the variance of the dependent variable over observations, i.e. by the presence of heteroscedasticity. However, this possibility should be eliminated in our specification by the logarithmic transformation of both dependent and independent variable and the use of the stochastic term in multiplicative form.[1] The use of cross-section data for a sample of industries originating in several countries leads to several methodological problems for the estimation and interpretation of results.[2] According to the theoretical model, inter-industry differences in the demand function for the R and D personnel are to be expected. The industry dummy variables are specified in the first stage equations to capture the interindustry differences and to translate

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1 Aigner shows that the logarithmic transformation forces homoscedascity on a multiplicative function such as ours. The estimates of the regression coefficients will maintain their BLUE properties, except for the intercept coefficient which will be biased downwards by $E(\log \varepsilon) < 0$. The sketch of the proof is as follows:
Let us have a function $y = \beta_0 x_1^{\beta_1} \cdot x_2^{\beta_2} \ldots x_k^{\beta_k} \cdot \varepsilon$

If heteroscedascity exists then the variation in y (conditional on $x_1, x_2 \ldots x_k$) is proportional to the squared conditional expectation of y.

$E[y - E(y / \{x_j\})]^2 = [E(y / \{x_j\})]^2 \sigma^2$

Transforming the dependent and independent variables into logarithms, we force homoscedascity.

$E(\log y) = \log \beta_0 + \beta_1 \log x_1 + \beta_2 \log x_2 \ldots \beta_k \log x_k$

(1) $\log y = \log \beta_0 + \beta_1 \log x_1 + \beta_2 \log x_2 \ldots + \beta_k \log x_k + \log \varepsilon$

Let us define $\varepsilon^* = \log \varepsilon - E(\log \varepsilon)$, $E(\varepsilon^*) = 0$
The it is possible to write:

(2) $\log y = \log \beta_0 + E(\log \varepsilon) + \beta_1 \log x_1 + \beta_2 \log x_2 + \ldots \beta_k \log x_k + \varepsilon^*$

(3) $\log y = E(\log y) - \varepsilon^*$

so that the conditional variance of log y is just the conditional variance of ε^*, $E(\varepsilon^{*2})$ a constant over (x_j).

For details see: Aigner, op. cit., pp. 164-166.

2 Methodological problems concerning cross-section analysis of industries located in different geographical areas (states in US) were discussed by authors working on production function measurement. In what follows, I will borrow the approach used by Griliches:
Griliches, op. cit., pp. 275-279.

them into industry specific intercepts of the regression function.[1] The interindustry differences remaining in the second stage equation, after they have been accounted for by dummy variables in the first stage, are difficult to predict.[2] We shall experiment with industry dummy variables and report the results.

By imposing the same regression coefficients on all industries in the sample we, in fact, estimate the weighted averages of corresponding individual industry coefficients.[3] The statistically, perhaps more satisfactory approach of estimating equations separately for individual industries is not feasible here because the number of observations is insufficient. On the other hand, we are interested in the general relationship existing between patented inventions and economic variables for the international sample as a whole.

The country specific differences are to be reflected in the regression coefficients of the G and F variables. Both variables are country

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[1] The more complete use of dummy variables for both intercept and slope coefficient cannot be applied here because of the relatively small sample. Specification of intercept - slope dummies would drastically reduce the available degrees of freedom.

[2] If the productivity of R and D personnel were homogeneous across the industries of the sample and if there were no other industry specific influences affecting the output of patents, there would be no inter-industry differences left in the 2nd stage equation. To what extent this strong assumption is justified can only be determined by empirical investigation.

[3] The ordinary least square estimates of b_k (k=1, 2) will be unbiased and consistent estimates of a general weighted average (with weights adding to unity) of the corresponding true industry coefficients b_{kij}; (k=1, 2; i=1 ... 10; j=1 ... 6) plus a general weighted average with weights that sum to zero for each set of non corresponding industry coefficients. This latter term drops out if there is no particular correlation between the various coefficients and the average deviations of the independent variables in the order industries.

specific, therefore, it is impossible to include country dummy variables at the same time with G and E variables. In order to find out whether there remains an important part of inter-country variance not reflected by the G and E variables, we replace them experimentally by country dummy variables and compare the two estimated equations.

The specifications using two or more closely related inputs in the 2nd stage estimation of the production function may lead to multicollinearity problems. We reserve the discussion and description of alternative specifications by leaving this problem for the next section.

The results of estimated equations are presented and interpreted in the next chapter.

3.3 The data and the variables.

We present here a brief description of the variables used in the cross-section analysis.

The first part is devoted to a methodological discussion of the data on patenting, followed by a description of some preliminary tests of hypotheses performed on the patent data that justify the choice of the dependent variables in the described form.

The second part of this section contains a description and discussion of the main explanatory variables of the model.

The details concerning the sources of data, methodology of sampling procedure from the national patent statistics and other details concerning data, as well as the table containing the values of variables used, are presented in Appendix C.

3.3.1 Data on patenting.

As was already stated at the beginning of chapter 3, we are analyzing the international distribution of patented inventions aggregated on the two digit manufacturing industry level. Thus, logically, the number of patents awarded is the variable to be explained.

Unfortunately, the situation is not as simple as it appears. There are several methodological problems to be solved before we can attempt to tackle the most tedious practical problem of collecting the relevant information from national patent statistics. The first one is to resolve the question of whether the number of patents is a correct measure of inventive activity. [1] We may partly avoid the problem by directly considering the number of patents awarded as the endogeneous variable to be explained, without insisting on its being the correct measure of inventive activity.

In order to test our model, it is necessary [2] to distinguish between patents awarded in country-h, to resident inventors (we shall

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1 For our study, the measure of inventive activity is the number of patents granted. The methodological problems related to the use of patented inventions as a measure of inventive activity have been extensively discussed in the literature, e.g.
S. Kuznets, "Inventive Activity: Problems of Definition and Measurement," The Rate and Direction of Inventive Activity, (Princeton University Press), 1962.
J. Schmookler, "Comment" to the Kuznets'article, ibid, pp. 44-45.
B. Sanders, "Comment", ibid.

2 The necessity to distinguish between the two categories of patentees is demonstrated in the following part of this section.

call them nationals) whose inventive activity is believed to be directly associated with the size of the market and with R and D effort of the given industry, and patents awarded to foreigners whose inventive activity is believed to respond primarly to economic stimuli and the R and D effort of their home country. The second criteria of classification is aggregation on the level of two digit manufacturing industries. Theoretically, there are two options to choose from: classification of inventions either according to the industry of their origin or according to the industry of their use. [1] As we want to relate the number of patented inventions not only to the size of the market but also to R and D activities that created them, the industry of origin seems to be a more appropriate choice [2] and in fact the only available one.

The details of the methodology used in reclassification of patents according to the above mentioned criteria and the sampling procedure used are described in Appendix C. It also contains an estimate of the patent

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1 Schmookler, (Op. cit., p. 166-178), illustrates the two possibilities by using an input-output type of table, where the invention is considered as the input or output according to whether it is used by an industry or invented by an industry. The distinction is important even when very often it is the same industry who creates and uses its own invention. Although theoretically, both criteria of classification could be used, it is practically impossible to classify the patents by the industry of their use unless we have direct information from all firms. This information is obviously not available for an international sample like ours.

2 By applying this criterium of classification, we are in fact assuming that if a given industry, let us say producing a capital good, does not directly serves the consumer market, an invention improving this capital good is stimulated by the derived demand for the capital good, e.g. by the size of the market of the industry producing this capital good. Of course, in the case of an invention directly improving a consumer good invented in the industry, the size of the market of this industry is the relevant measure.

distribution, classified by industry of origin and two classes of inventors (national / foreigner) for each of the six countries of the sample for 1967, extrapolated from the analysed samples.

The data on patenting lend themselves to tests of two hypotheses that should be rejected before a meaningful analysis of economic determinants of inventive activity can be undertaken. The first hypothesis to be rejected is that inventive activity is a random process. In order to test this possibility, we adopt two restrictive assumptions: 1) The number of patents awarded reflect the inventive activity uniformly among countries; 2) The national patent systems are comparable, especially as to the criteria of patentability. We adopt the first assumption with reservation that if there are some inter-country differences in the propensity to patent inventions, these differences should be negligible in the case of countries on a similar level of economic development, belonging to the same basic economic system as is the case of the countries in our sample. The importance of those differences should be found negligible in comparison with the inter-country differences associated with the differences in industrial structure. This will be object of our second test.

As for the assumption of comparability of the various national patent systems, we shall maintain it at first in spite of the many possible objections which may be raised against. If the international distribution of patents is found to be the result of a random process, then it would be difficult to claim that the differences existing among national patent systems were of a such a character as to contribute to the randomness of the patenting. On the other hand, if the hypothesis of the random patenting is rejected, then the forthcoming analysis will enable us to identify the national peculiarities in the number of patents awarded and it will be possible to analyze to what extent (approximately) they may be attributed to international differences in the criteria of patentability.

According to the criteria of novelty which is applied by all national patent systems as one of the prerequisites to a patent grant, new inventions patented by nationals in the country of their origin form disjoint subsets (partitions) of the set of all new inventions. Thus each invention patented by its inventor in the country of its origin is counted only once in the pool of countries forming the sample. [1] We may therefore postulate our hypothesis in terms of a single classification problem as follows:

If the inventive activity and therefore patenting were a random process, we would expect the number of patents awarded to nationals in a given country to be distributed among countries according to the distribution of total population. To test this hypothesis, we have constructed a simple one way classification table for an expanded sample of countries, containing the main industrialized countries of the world with exception of the socialist countries of Eastern Europe, and calculated the chi-square statis-

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1 There is no obligation in the national patent laws that an invention be first patented in the country of its origin. However, in the majority of cases, this is the common practice; the grant of patent in the country of origin gives the inventor a right of priority for twelve months in all other countries of the International Union for the Protection of Industrial Property.
For details concerning international implications of the Patent System see, e.g.,
E.T. Penrose, Economics of the International Patent System, (The John Hopkins Press, 1951).

Table 3.1 International Distribution of Patents and Population

	fi. Observed No of patents to nationals	Population in 1963 (in.10^3)	Fi: Expected No of patents to nationals (total)	(fi-Fi)	$\frac{(fi-Fi)^2}{Fi}$
Germany	11520	55430	- 12408	- 888	63
Belgium	1586	9290	- 2082	- 496	118
France	15246	47816	+ 10714	4532	1917
Canada	1263	18964	- 4249	- 2986	2098
Japan	13877	95900	- 21476	- 7599	2688
Sweden	1776	7604	+ 1706	70	3
** U.K.	13945	53637	+ 12009	1936	312
Austria	1188	7172	- 1610	- 422	111
Denmark	338	4684	- 1053	- 715	485
* Italy	9067	50641	- 11343	- 2297	465
U.S.	51274	189417	+ 42409	8855	1848
Σ	121059	540555	121059		10108 = χ^2

χ^2 = 10108 > 25.19 (at 99.5% probability)
We reject the hypothesis that the patents are distributed according to population e.g. randomly.

* Data for 1968.

** The numbers of specifications filed.

<u>Sources</u>: Patent data: Industrial Property - Dec. 1968, Annex, Chart Ia, BIRPI, Geneva, 1968.

Population data: Demographic Yearbook, 1970, (United Nations, N.Y., 1971), Table 2.

tics (see Table 3.1).[1] The calculation of chi-square shows that the hypothesis of a random distribution of patents among countries must be rejected beyond any doubt.

The random character of the international distribution of patents being rejected, the next question is whether there is any meaningful difference between the number of patents granted to nationals and to foreigners when the patents are classified according to the industry of origin.

Unfortunately, no country in the world publishes the patent statistics in a form suitable for answering this question and therefore the published patent statistics present very little real information on the relative strength or weakness of a country's inventive output.[2]

We have used the periodical publications of national patent offices and constructed a random sample of awarded patents during the year

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[1] The observation for this test being the number of patents awarded to nationals, we were able to use the published statistics from Industrial Property, op. cit., and test the hypothesis for a greater sample than the one we shall use in subsequent analysis. The socialist countries were not included in order to maintain a certain homogeneity of the sample with respect to economic system. However, inclusion of the socialist countries would not have changed the result of the test. It would have been more appropriate to associate the number of patents with the number of educated adults or with the number of working adults. The overwhelming rejection of the hypothesis calculated for total population shows however that it would not have changed anything in the substance of the argument.

[2] The sole quasi-exception to this critique is Japan, which publishes annually a break down of patent applications according to patent classes, industries and (national/foreigner) inventors. See: Statistical Report of Industrial Property, 1971, (Patent Office, Ministry of International Trade and Industry, Japan, Tokyo).

1967 for each of the six countries included in our study.[1] The patents awarded in an h-th country were then classified according to the industry[2] of origin and broken down, according to the origin of the inventor, into patents awarded to nationals of the h-th country and to foreigners.

The two-way classification tables constructed for each country revealed that the distribution of patents according to the two criteria, i.e. according to industry and origin of inventor, is not independent: the number of patents awarded in country-h, to her nationals and to foreigners in industry i, is not independent of the distribution of patents among industries in the given country. Results in Table 3.2 show that the distinction between the number of patents granted in a country-h to her nationals and to foreigners, broken down according to the industry of origin, is necessary for further analysis. Therefore, the main dependent variable of the study will be the number, i.e. the annual flow of patented inventions created by nationals of the h-th country and patented in the i-th industry of country h during the calendar year 1967,[3] deflated by sales.

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[1] The six countries eventually included were those for which we were able to find patent data in a form allowing reclassification according to ISIC and for which data for P and D and for industrial production were available in sufficient detail. The countries included are: Canada, Belgium, France, Germany (Federal), Japan and Sweden. The details concerning sampling and reclassification are in Appendix D.

[2] See Appendix C, Tables 1 to 6.

[3] Although it would have been very desirable for further analysis to have had the data on patenting for several periods, the time and effort required to collect the patenting data from the technical publications of national patent offices for only one year were such that the idea to repeat this exercice had to be abandoned. In order to leave the specifications of the estimated equations in a general notation, we use the time symbol in its general form (t + 1). Through out the empirical part of the study, the period (t + 1) is the year 1967. 1967 was chosen because, according to the majority of empirical studies of inventing and patenting activity, the average lag between the beginning of the inventive activity and patenting of an invention is approximately 4 years.

Table 3.2: Results of the Two-way Classification Test

Results of the two-way classification tests for the distribution of the number of patents awarded, classified according to the industry of origin and according to the origin of inventor.

Country	Chi-square calculated	d.f.	Chi-square ($P_{99.5}$) for rejection of H_0 (independence)
Belgium	432.12	10	25.19
Canada	70.72	7	20.28
France	1608.34	8	21.96
Germany	214.56	8	21.96
Japan	539.43	6	18.55
Sweden	525.12	11	26.76

3.3.2 Other variables.

The list of data starts with measures of the market demand. The first one, theoretically the most appropriate is the value of industry sales S_{ih}.[1] The available statistics in most cases give the value of deliveries, evaluated at current prices in national currencies. The differences of price levels for comparable products in different countries, as well as the deviations of exchange rates from the real purchasing power of different national currencies make direct comparison of the value of deliveries between different countries of the sample difficult. However, our unit of observation is one national industry, so the variables remain related between themselves and the above mentioned problems of comparability will arise only when we shall try to draw some conclusions for the sample as a whole, for instance when the value of regression coefficients is interpreted. The use of country dummy variables should partially offset this problem.

Before we can define the variables measured by the R and D statistics, it is necessary to stress that in spite of the uniform international methodology underlying accounting of R and D expenditures and manpower data, it is difficult to associate those statistics with the usual categories of technological change such as invention, innovation and imi-

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1 Here it is necessary to point out the differences that exist, on the theoretical level, between the uses of size variables. The profitability of an invention is likely to depend on the industry's size as a whole rather than on the size of the firm performing the inventive activity since the motivation for the invention is supposed to be the potential demand of the whole industry.
On the contrary, when we are interested in the existence of the economies of scale or in the relationships between the cost of inventing and the size variables, then the relevant variable is the size of the firm.

tation. The existing accounting of R and D expenditures for the business sector only partially reflects the components introduced in our model and it is a well known fact that in reality the distinction between the various types of R and D, that is between the basic and applied research and between the development, is always somewhat artificial and therefore unrealistic. As the controversy between Kuznets and Schmookler indicated,[1] there is not even unanimity among theorists as to which R and D component measures inventive activity.

We shall first use Kuznets' approach and identify inventive activity with applied research. Therefore, in specifications of Version I, we assume that the inventive input is measured by the personnel engaged in applied research MRA_{ih}. As the total manpower affected to applied research may not correctly reflect the inventive input, we use the number of qualified scientists and engineers engaged in applied research $QSEA_{ih}$ and separately their supporting staff STA_{ih}. Other variables intended to measure the inventive work are the personnel employed both in applied research and development $MRAD_{ih}$ and the personnel employed in development only MD_{ih}, the latter corresponding to Schmookler's interpretation and the former representing a compromise conciliating both positions.

The average wage rate W_{ih}, paid to R and D personnel, is derived as the ratio of labor cost of all R and D personnel to total manpower working on R and D in full time equivalent. The wage rate is therefore calculated in \$/man-year. The development proxy for the profitability of invention D/S_{ih}, will be used in value terms, i.e. the industry's

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1 Kuznets, op. cit., pp. 44-45.

total development outlays, deflated by the value of the industry's sales.

As for the other proxies for profitability, the data on industry profits being unavailable, we shall use the rate of growth of value added VA_{ih}. The growth rate is calculated by the terminal year method [1] using the index numbers of industrial production for the 1958 to 1963 period. The alternative proxy for profitability is the value of gross investment in plant and equipment deflated by the value of sales I/S_{ih}. The last proxy for profitability is the ratio of exports to imports EX/IM_{ih}. The value of exports and imports for each industry is calculated from the OECD commodity trade statistics for the base year 1963. The average size of firm $\bar{S}_{jih}$ is calculated as the ratio of industry's sales to the number of establishments. Closely related to the average size of firm of an industry is its concentration. The only internationaly comparable measure of industry concentration is the proportion of the total employment of an industry employed in firms with more than five hundred employees $\bar{C}_{ih}$. The list of explanatory variables is closed by two variables which ought to express national influences on patenting not related to particular industries. The first, the patenting ratio G, is the ratio of the number of patents granted to patent applications in the h-th country and period (t + 1), i.e. 1967 to nationals. This variable summarizes most of the national influences on patenting. When a country has a relatively lenient screening system for patent applications, the proportion of applications refused for lack of novelty or for lack of practical utility is relatively low and, therefore, its patenting ratio is higher than in countries with

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1 For details, see Appendix C, note e.

more rigorous patent regulations. The lower the value G of a country, the higher the number of patent applications in this country, assuming all other things equal. Thus, we expect a negative relationship to appear between patents granted and the patenting ratio.

The overall level of inventive activity in an h-th country will also be influenced by the technical level of its working force. The variable we shall use is the number of engineers and technicians to the total employment of the manufacturing sector of the h-th country E_h.

The market structure of an industry is likely to influence strongly technological competitiveness, the level of R and D activity and possibly the output of patented inventions. The concentration variable $\bar{C}_{ih}$ is defined as the percentage of the total employment of a given industry, concentrated in firms with more than five hundred employees. We are aware that this is not the most appropriate measure of concentration, but it was the only one for which the internationally comparable data were available.

CHAPTER IV

RESULTS OF THE EMPIRICAL ANALYSIS

The results will be presented with reference to the versions of specifications listed in section 3.2.1. As it will become clear during the discussion, the results of various versions are not in all cases strictly comparable, because the data matrix used for their calculation did not always include all observations.[1] Although a series of explanatory regression analysis in the initial stage of this study were made before the theoretical and empirical models were constructed in the present form, their results were not used to "improve" the estimation of the equations presented here. Thus, although the preliminary empirical results admittedly helped my understanding of the relationships between the analyzed variables, the results of the estimations presented here can be considered as being a "correct" test of the hypothesis advanced, with the levels of statistical significance of the results as indicated in the tables.[2]

4.1. Version I

Before we present and interpret results of the estimation of the second stage equations which are our main interest, we review the results of the 1st stage. We estimated equations predicting the equilibrium employment of inventive factors as a function of all predetermined variables of the model. All profitability proxies were included at

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1. The details concerning observations used for estimation of particular versions are given in the legend of each table with regression results.

2. Unless it is not specified otherwise, the statistical significance level measured by the t-ratio is given in parenthesis under the respective regression coefficients. Estimates significant at the 5% level are indicated by one asterisk and qualified in the text as "significant". Estimates significant at the 1% level are indicated by two asterisks. The same also applies to F-ratios.

the same time[1], See Equation (1), Table 4.1a. The investment and value added variables were not significant and were consequently deleted from further computations. The development proxy D/S was the most significant of all profitability proxies and it was used in combination with the export-import proxy in subsequent estimations of this first stage equations.

The size variable should, theoretically, have a regression coefficient close to zero, because the influence of size of industry is supposed to be eliminated by deflation of the dependent variables by size. This is what actually happened in equation (2), Table 4.1a, reestimated with only the two well behaved profitability proxies. Thus, the size of an industry did not influence the predicted employment in applied research. There appeared, however, a weak, insignificant negative relationship between the average size of firm $\overline{S}_{jih}$ and the employment in applied research per sales. When we realize that $\overline{S}_{jih}$ is the average size of firm, we cannot readily claim that smaller firms employ relatively more R and D personnel per sales than the larger ones. The negative relationship between the average size of the firm in an industry and the R and D employment per sales in this industry could also exist if the generally more research intensive industries such as electrical machinery, chemistry and metallurgy had, on the average smaller firms

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1 In order to use all alternative proxies for profitability the sample of observations had to be restricted to 27 observations, excluding observations for Germany, for which the R and D breakdown did not single out a development variable, and for Sweden, owing to unavailable investment data. In addition, several other observations were deleted because of unavailable data for investment and concentration.

Table 1 a.

Version-I

Ordinary least squares estimates of the first stage equations.

Specification 3.2.1.

$\log QSEA/S_{ih} = \log a_0 + a_1 \log S_{ih} + a_2 \log EX/IM_{ih} + a_3 \log VA_{ih} + a_4 \log I/S_h + a_5 \log D/S_{ih} + a_6 \log \bar{S}_{jih} + a_7 \log \bar{C}_{ih} + a_8 \log E_h + a_9 \log G_i + \sum_{i=1}^{20} d_i Y_i$, R^2, n

	log QSEA/S_ih	log a_0	a_1 log S_ih	a_2 log EX/IM_ih	a_3 log VA_ih	a_4 log I/S_h	a_5 log D/S_ih	a_6 log S̄_jih	a_7 log C̄_ih	a_8 log E_h	a_9 log G_i	Σ d_iY_i	R^2	n
(1)	"	5.985 (2.72)*	-1.697 (-3.70)**	0.[illegible] (3.42)*	-0.593 (-1.29)	[illegible] (-1.2[illegible])	0.726 (3.97)**	-0.784 (-3.18)**	-0.432 (-0.80)	4.928 (4.14)**	-3.8[illegible]3 (-4.4[illegible])**	yes significant	0.[illegible]76 ([illegible])**	[illegible]
(2)	"	-0.12 (-0.08)	-0.002 (-0.01)	0.153 (1.[illegible])	—	—	0.576 (3.73)**	-0.318 (-1.86)	-0.086 (-0.34)	0.456 (1.21)	-0.[illegible] (-2.[illegible])*	yes significant	[illegible]	[illegible]
(3)	"	2.514 (1.44)	-0.030 (-0.24)	0.197 (1.45)	—	—	0.741 (6.38)**	0.038 (0.20)	-0.233 (-1.05)	-0.050 (-0.42)	-0.572 (-1.52)	no	[illegible] ([illegible])**	[illegible]
(4)	"	0.098 (0.09)	-0.056 (-0.44)	0.163 (1.52)	—	—	0.567 (4.05)**	-0.321 (-2.01)	—	0.423 (1.33)	-0.889 (-5.51)**	yes significant	0.[illegible]3 (11.6[illegible])**	4[illegible]
(5)	log STA/S_ih	1.298 (-0.57)	0.649 (2.42)*	0.[illegible]98 (0.46)	—	—	0.726 (2.96)*	-0.825 (-2.80)*	-0.169 (-0.42)	-0.467 (-0.78)	1.045 ([illegible].95)	yes significant	0.[illegible] ([illegible])**	[illegible]

Table 1 b.

Version-I

Estimates of the second stage equations.

Specification 3.2.2.

$\log P/S_{ih} = \log b_0 + b_1 \log \widehat{QSFA/S}_{ih} + b_3 \log \bar{S}_{jih} + b_4 \log \bar{C}_{ih} + b_5 \log G_h + b_6 \log E_h + \sum_{i=1}^{10} d_i Y_i + \sum_{h=1}^{4} g_h Y_h$, R^2, n

Equation (no.)	log P/S_ih	log b_0	b_1 log QSFA/S_ih	b_3 log S̄_jih	b_4 log C̄_ih	b_5 log G_h	b_6 log E_h	Σ d_iY_i	Σ g_h Y_h	R^2	n
(1)	"	-1.918 (-1.96)	0.674 (4.05)**	-0.461 (-2.17)*	—	-0.639 (1.42)	0.515 (0.98)	—	—	0.[illegible]18 (6.05)**	4[illegible]
(2)	"	-1.459 (-0.74)	0.765 (2.19)*	-0.220 (-0.61)	—	-0.400 (-0.68)	0.341 (0.55)	yes not significant	—	0.599 (3.[illegible])**	47
(3)	"	-3.974 (-2.51)	0.602 (3.51)**	-0.493 (-2.05)*	0.433 (1.82)	-0.670 (-1.36)	0.655 (1.21)	—	—	0.457 (4.[illegible])**	40
(4)	"	-4.118 (-1.60)	0.466 (1.23)	-0.431 (-1.15)	0.240 (0.59)	-0.676 (-1.1)	0.621 (0.93)	yes not significant	—	0.602 (2.34)*	40
(5)	"	-2.989 (-1.68)	0.474 (1.44)	0.036 (0.09)	0.154 (0.38)	—	—	yes not significant	yes not significant	0.650 (2.81)*	40
(6)	"	-2.021 (-1.07)	0.700 (2.13)*	—	0.191 (0.46)	-0.283 (-0.54)	0.066 (0.14)	yes not significant	—	0.558 (2.35)*	40

Notes:

a) t-ratios and F-ratio are given in parantheses under the regression coefficients and under R^2 respectively, significant at the 5% level ( )*, significant at the 1% level ( )**.

b) The number of observations in the sample is given in column -n-. Sample of 27 observations excluded German and Swedish observations and also several French and Belgian observations. Sample of 40 observations excluded German and several French and Belgian observations. Sample of 47 observations excluded only [illegible] observations compared with other industries. Our results show[1] that after this relationship had been accounted for, there still remained a very weak negative correlation between the average size of the firm in an industry and its employment in applied research. In addition, the concentration variable was also negatively correlated with employment in applied research. Owing to the low statistical significance of these negative correlations, we can conclude only very tentatively that the less concentrated industries, with smaller average size of firm employed more personnel in applied research per unit of sales than the more concentrated ones with larger average size of firm. Inclusion of industry dummy variables was statistically significant and indicated that there are significant interindustry differences as far as the predicted employment in applied research per sales is concerned. With reference to equation (3.15) in the third chapter, the interindustry differences may be attributed to interindustry variations of this mark-up constant and of elasticity of supply for R and D personnel. In addition, deviations from equilibrium adjustment to profit maximizing demand for R and D personnel in each industry may also lead to interindustry differences captured by dummy variables. The intercept of the regression plane for the chemical industry and to a lesser degree, also for metallurgy and electrical machinery shifted upwards. The opposite was true for non-electrical machinery and the textile industry. Thus, ceteris paribus,

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1 The relationship between $QSEA/S_{ih}$, $\overline{S}_{jih}$ and research intensity of an industry was analyzed by means of the regression:

$$QSEA/S_{ih} = -3.06 + 1.76\,Z - 0.21\,\overline{S}_{jih}$$
$$(-18.3)\quad(5.5)\quad(-1.3)$$

where Z is a dummy variable assuming unitary value for the following research intensive industries: metallurgy, electrical machinery and chemistry.

for a given level of profitability employment in applied research relative to sales was highest in chemical, metallurgical and electrical industries and lowest in mechanical and textile industries.

Table 4.1a also includes equation (4) from which the concentration variable was deleted. Elimination of the concentration variable enabled us to include in this sample those observations for which value of the concentration variable was unavailable. The results show that consenquently the statistical significance of the estimated coefficients improved, but the estimated coefficients did not change significantly.

The good fit of the estimated equations shows that the predicted level of employment in applied research is not substantially different from the observed level. It is therefore interesting, from the empirical point of view, to find out which observations deviated most from the predicted level and whether there is any regular pattern in the residuals. A perusal of residuals, not presented in Table 4.1, showed that the deviations of actual from predicted values of OSEA/S do not indicate presence of heteroscedascity. However the majority of Canadian[1], and to a somewhat lesser degree the majority of Swedish industries as well, appeared to have lower actual employment OSEA/S than the predicted one. On the other hand, the French and Belgian industries exhibited an opposite trend.

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[1] All Canadian industries except metallurgy, minerals and rubber employed fewer qualified engineers and scientists in applied research than predicted by the regression. The cause could be either a different distribution of R and D effort in Canada or a general technological lag of Canada behind other countries, e.g. owing to foreign control. We return to this problem in the next section.

The first stage equation for predicted employment of supporting staff per unit of sales STA/S, resulted in estimates similar to those discussed above. It does not need, therefore, any further comments. The estimated coefficients are presented in equation (5), Table 4.1a.

The predicted levels of R and D employment deflated by industry sales were used as inputs for estimation of the number of patented inventions per sales according to specification (3.2.2). When the two predicted input levels QSEA/S and STA/S were included together with the remaining independent variables, the estimated regression coefficients suffered from high standard errors and were very sensitive to inclusion of dummy variables. A check of correlation existing between the two input categories confirmed the suspicion that the problem is due to multicollinearity between QSEA/S and STA/S.[1]

Econometric theory offers two partial solutions for the extreme and near extreme multicollinearity[2]. According to the first one, it is possible to obtain an unbiased estimate of a linear combination of parameters. Thus, referring to equation (3.2.2), instead of attempting to estimate separately b_1 and b_2 for the two correlated inputs log QSEA/S and log STA/S, their sum $(b_1 + b_2)$ was estimated as reported in Table 4.1.b. Let us concentrate on equation (3), which includes all variables

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[1] $\log STA/S_{ih} = 0.56 + \underset{(9.1)}{0.951} \log QSEA/S_{ih}$ $R^2 = 0.681.$

[2] For general treatment see e.g. H. Theil, Principles of Econometrics, John Wiley & Sons, Inc., New York, N.Y., 1971, pp. 147-155. Application to multicollinearity between inputs of a Cobb-Douglas production function is discussed by J.P. Doll, "On Exact Multicollinearity and the Estimation of the Cobb-Douglas Production Function," American J. Agr. Econ. (August 1974), pp. 556-563.

and discuss the estimate of the regression coefficient of log QSEA/S. The estimate of the sum $(b_1 + b_2)$ i.e. the sum of elasticities of patented inventions to employment in applied research is 0.602 and before we discuss the estimated parameters let us see whether the second recommended method of conditional estimation[1] gives results comparable to those presented above. We chose three arbitrary values of b_1 ($b'_{10} = 0.50$; $b''_{10} = 0.30$; $b'''_{10} = 1.0$). The estimates of the parameter b_2 conditional on those values were: $b'_2 = 0.17$; $b''_2 = 0.27$; $b'''_2 = -0.06$ respectively. Although their sums varied slightly with values of b_1 and they were not exactly equal to the estimate of $(b_1 + b_2) = 0.602$ obtained above, the two sets of results match pretty well[2].

If we had additional information on the two categories of inputs, e.g. their respective wage rates, it would be possible to derive the values of parameters b_1 and b_2[3]. This not being the case, we cannot ask

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1 According to Theil, we can write for our case" The two inputs are linearly dependent" (1) log STA/S = c log QSEA/S.
Suppose we set $b_1 = b_{10}$, when b_{10} is an arbitrary given value. Then if b_{10} . log QSEA/S is subtracted from the dependent variable log P/S and from the right side of the equation (1), we can estimate a new equation with a new dependent variable:

$$\log P/S_{ih} - b_{10} \log QSEA/_{ih} = b_2 \log STA/S_{ih} + b_3 \log G_h + b_4 \log E_h + b_5 \log \overline{S}_{jih} + b_6 \log \overline{C}_{ih} + \sum_{i=1}^{10} d_i Y_i + \log e_{iht}.$$

The estimates of the regression coefficients $b_2 .. b_4$, $d_1 .... d_{10}$ are conditional for the given values of b_{10}.

2 The slight variation of $(b_2 + b_{10})$ may be attributed to the lack of exact correlation between the two inputs; the method is based on the assumption of exact correlation between the independent variables.

3 See J.P. Doll, op. cit., p. 558.

more than our data are able to answer; only the sum $(b_1 + b_2)$ is estimable from the data. Given this situation[1], it does not seem helpful to distinguish between qualified engineers and scientists and their supporting staff as far as their contribution to the creation of patented inventions is concerned.

Five different estimates of equation 3.2.2 are presented in Table 4.1.b. Let us first focus on equations (1) and (2) estimated from a larger sample of observations which did not include the concentration variable and therefore was not strictly comparable with the remaining equations.

The explanatory variables in equation (1) explained only about 42% of total variance, but the F ratio was significant beyond the 1% level. Comparison of equations (1) and (2) shows that interindustry differences were mainly associated with the average size of the firm because inclusion of industry dummy variables sharply decreased the value and the statistical significance of the regression coefficient b_3. Addition of dummy variables was not, however, statistically significant.

In the following equations the concentration variable was added to the vector of explanatory variables. Its addition did not significantly improve the explanatory power of the estimated equation (cf. (1), (3)). On the contrary, when concentration was included together with industry dummy variables in equation (4), the F ratio decreased noticeably and so did the value and statistical significance of the regression

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1 The high degree of multicollinearity between the QSEA and STA appears to be at least partly due to the data compilation by OECD. Their statistics give the ratio (ST/QSE) already aggregated for all three types of R and D activity (basic, applied and development). This homogenizes the ratio (ST/QSE) and probably erases some important differences that might have existed between QSEA and STA.

coefficient of the QSLA/S. The value and the statistical significance of the regression coefficient of concentration also decreased when industry dummy variables were added. It appears, therefore, that interindustry differences are closely related to concentration. The low statistical significance of the regression coefficient however makes any conclusion about this influence of concentration on patents very risky and we refrain from it until the results of other versions are presented. The average size of the firm, which is weakly positively correlated with the concentration of industry, also exhibited a negative correlation with the dependent variable. Estimate of the regression coefficient of the average of size of the firm was very close to the theoretically predicted value, $\sum_m b_m - 1$.

Regression coefficients of both country specific variables G and E had the expected signs, however they did not account for all variance within each country as can be seen from comparing equations (11-4) and (11-5). The latter equation was estimated with country dummy variables which explained an additional eight percent of the variance and practically eliminated the average firm size variable. The statistical significance of this regression coefficient for QSLA/S increased marginally but remained insignificant.

Analysis of residuals revealed that all Canadian industries except electrical machinery exhibited lower actual number of patented inventions than predicted by the regression. On the other hand, the number of inventions patented by French industries was generally higher than the predicted one. The seemingly good performance of French industries probably results from the benevolent patent regulations applied in

France.[1] The low inventive productivity displayed by Canadian manufacturing industries very likely results from Canadian depending on foreign ownership and technology. We return to this problem in the conclusion of this chapter.

4.2. Version II

In this specification, we assume that both applied research and development are invention creating activities. The inventive inputs are therefore the two manpower categories, the MRA and MD. The line between applied research and development activity is not clear-cut. Some cases of better known inventions show that patentable inventions are likely to be created at different stages of organized research activity[2]. The model using both applied research and development manpower as inventive inputs is, therefore, à priori not less realistic than the preceeding one. Using both MRA and MD as inputs has, however, one rather annoying consequence for the specification of the 1st stage equations. The development being now one of the jointly dependent variables, it is impossible to use the development proxy for the expected profitability D/S as one of the explanatory variables of the 1st stage[3]. Instead of D/S, the 1st

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[1] According to the French rules there is no à priori screening of patent applications and patents are awarded to all applicants except in the case where a third party intervenes.

[2] See. Jewkes, J., Sawers, D. and Stillerman, R., op. cit.

[3] This is a measurement problem rather than an invalidation of the theory which considers the intensity of current development activity as an indicator of the expected profitability of inventive activity. Referring to the three components of R and D activity specified in section 3.2. above, the invention creating input (RD-I) is now approximated by the personnel working in applied research MRA and in development MD. To the

stage specification included first all three alternative profitability proxies, EX/IM, VA, I/S at the same time. Only the I/S variable[1] proved to be consistently significant with a probability higher than 70%, therefore, the other two proxies were dropped from further estimation. The 1st stage equations reestimated with the I/S proxy and the remaining predetermined variables is presented in Table 4.2a, equations (1,2,4). The predetermined variables explain 92% of total variance. There were significant interindustry differences, mainly related to the degree of concentration, as can be seen from comparison of equations (2), (5) and (6). Industries with high concentration of employment in large firms exhibited high employment in development and high employment of supporting staff in both applied research and development. Electrical machinery, followed by chemical and transport equipment industries, displayed a positive shift of the intercept. Residuals for the whole sample did not reveal any definite patterns, except for Canada, where the difference between the actual employment and predicted employment in both categories of R and D is positively related to the degree of foreign control over the respective industry, i.e. industries with a high degree of foreign control employed less R and D personnel per sales than predicted

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3 (continued) extent that an important part of applied research and of development does not, in reality, qualify as "inventive activity", the use of the total employments, MRA and MD respectively, represents an "overestimation" of the "true" inventive input. We shall return to this problem at the discussion of results.

1 The I/S variable, investment per sales, is likely to much better measure the general profitability than the profitability of the technical change. The two profitabilities can, but need not, be correlated. The investment into inventive and innovative activity may be a substitute as well as a complement to other types of investment. In our sample, the D/S and I/S are practically uncorrelated (r = 0.09).

Table 4.2 a.

Version-II

Ordinary least square estimates of the first stage equations.

Specification 3.2.1.

Regression coefficients of independent variables

Dependent variable = $\log a_0 + a_1 \log S_{ih} + a_2 \log EX/IM_{ih} + a_3 \log VA_{ih} + a_4 \log 1/S_{ih} + a_5 \log \bar{S}_{jih} + a_6 \log \bar{C}_{ih} + a_7 \log I_h + a_8 \log G_h + \sum_{i=1}^{10} d_i Y_i$

Dependent variable	$\log a_0$	$a_1 \log S_{ih}$	$a_2 \log EX/IM_{ih}$	$a_3 \log VA_{ih}$	$a_4 \log 1/S_{ih}$	$a_5 \log \bar{S}_{jih}$	$a_6 \log \bar{C}_{ih}$	$a_7 \log I_h$	$a_8 \log G_h$	$\sum_{i=1}^{10} d_i Y_i$	R^2	n
(1) $\log MRA/_{ih}$	-1.137 (0.36)	-4 91 (-1 02)	——	——	1.501 (3.32)	-0.3[illegible] (-0.86)	0.656 (0.78)	1.562 (1 11)	-2.008 (-1 35)	yes	0.8[illegible] (5 2[illegible])	2[illegible]
(2) $\log MD/S_{ih}$	2.891 (1.03)	-0.214 (-0.58)	——	——	1 262 (3.15)	0 239 (0.71)	0 449 (0.61)	-0.4253 (-0 34)	-0.5[illegible] (-0 [illegible]3)	yes	[illegible]	2[illegible]
(3) $\log MRAD/S_{ih}$	2.916 (1.12)	-0.413 (-1 04)	——	——	1.299 (3.49)	0.012 (0.04)	0.547 (0.79)	0.548 (0.47)	-1.318 (-1 0[illegible])	yes	0.[illegible]4 ([illegible])	2[illegible]
(4)	3.865 (1.60)	0.019 (0.07)	-0.078 (-0.46)	-0.315 (-0.81)	1 362 (4.34)	0.037 (0.17)	0.007 (0.01)	-0.645 (-1.09)	-0.234 (-0.53)	yes significant	[illegible] (12.1[illegible])	[illegible]
(5)	2.983 (1.76)	-0.042 (-0.2)	——	——	1.259 (5.33)	-0.015 (-0.07)	-0.014 (-0.04)	-0.288 (-0.75)	-0.262 (-0.[illegible])	yes significant	[illegible]	[illegible]6
(6)	-3.559 (-1.95)	0.158 (0.75)	——	——	0.675 (1.95)	-0.255 (-0.84)	1.465 (3.92)	-0.861 (-1.48)	0.083 (0.1[illegible])	no	0.534 (1.5[illegible])	3[illegible]

Table 4.2.b.

Version-II

Estimates of the second stage equations.

Specification 3.2 3.

$\log P/S_{ih} = \log b_0 + b_1 \log MRAD/S_{ih} + b_3 \log \bar{S}_{jih} + b_4 \log \bar{C}_{ih} + b_5 \log G_h + b_6 \log E_h + \sum_{i=1}^{10} d_i Y_i + \sum_{h=1}^{4} g_h X_h$

Equation (no.)	$\log b_0$	$b_1 \log MRAD/S_{ih}$	$b_3 \log \bar{S}_{jih}$	$b_4 \log \bar{C}_{ih}$	$b_5 \log G_h$	$b_6 \log E_h$	$\sum_{i=1}^{10} d_i Y_i$	$\sum_{h=1}^{4} g_h X_h$	R^2	n
(1)	-2.592 (-17.25)	0.832 (7.50)**	——	——	——	——	——	——	0.[illegible] (26 [illegible])**	36
(2)	-2.558 (-16.7)	0.852 (7.68)**	-0.174 (-1.09)	——	——	——	——	——	0.617 (26.6)**	36
(3)	-1 073 (-0 95)	1 113 (6.80)**	——	-0.793 (-2.46)*	-0.[illegible] (-2.[illegible]6)*	0 726 (1.80)	——	——	0.[illegible] (12.03)**	36
(4)	-2 599 (-1.41)	1.063 (6.44)**	-0.274 (-1.04)	-0.481 (-1.11)	-0 02 (-2.[illegible]1)*	0 993 (2,15)	——	——	0.[illegible] (11.3)**	36
(5)	-1.33 (-1.01)	0.966 (3.64)**	——	-0 897 (-.91)	-0.[illegible]03 (-2,71)*	0.572 (1.36)	yes not significant	——	0 [illegible]3 (4.76)**	36
(6)	-1.197 (-0.71)	0.646 (1.55)*	——	-0.799 (-1.65)	——	——	yes not significant	yes not significant	0.820 (4.06)**	36

Notes:

a) t-ratios and F-ratio are given in parantheses under the regression coefficients and under the R^2 respectively, significant at the 5 % level ( )*, significant at the 1 % level ( )**.

b) The number of observations in the sample is given in column -n-. Sample of 27 observations excluded German and Swedish observations and several French and Belgian observations. Sample of 36 observations excludes Swedish and several French and Belgian observations.

by the regression[1].

The original specification of this version, (3.2.3), using both MRA/S and MD/S input catagories, was intended to determine the contribution of the two inputs to the inventive output. Unfortunately, the attempts to estimate the equation as specified failed because of multicollinearity between the two inputs[2]. Without additional data, it is impossible to estimate with any degree of confidence the regression coefficients b_1 and b_2 individually. It is, however, possible to estimate their linear combination $b_1 + b_2$. The methodological considerations discussed above for the estimation of the first version apply here also. We can estimate $(b_1 + b_2)$ by dropping one of the input variables

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[1] $$RES_i = \underset{(-1.15)}{-0.13} + \underset{(2.10)^*}{0.50} \log DFC_i + \underset{(1.18)}{0.31} Z \qquad R^2 = 0.45$$

where RES = log MRADS - log $\widehat{MRADS}$, log DFC is the deviation of the logarithm of foreign control from the mean value of foreign control for Canadian industries log DFC = $\overline{\log FC}$ - log FC, and Z is the dummy variable.

[2] At the first sight, the estimated equation with both MRA/S and MD/S inputs looks quite plausible, except for less statistical significance of the estimated coefficients:

$$\log P/S_{ih} = \underset{(-0.81)}{-3.39} + \underset{(0.65)}{0.43} \log MD/S_{ih} + \underset{(0.94)}{0.51} \log MRA/S_{ih} - \underset{(-0.20)}{0.19} \log \overline{C}_{ih}$$
$$+ \underset{(0.32)}{0.20} \log \overline{S}_{jih} + \underset{(0.65)}{0.89} \log E_h - \underset{(-0.87)}{0.81} \log G + \sum_{i=1} d_i Y_k$$
$$R^2 = 0.78 \quad n = 27$$

However, the estimates were extremely sensitive to industry dummy variables. When the later were deleted, the sign and significance of estimated coefficients changed rather drastically. Small sample size and high correlation between the two inputs

$$\log MD/S_{ih} = \underset{(1.7)}{0.35} + \underset{(8.2)^{**}}{0.897} \log MRA/S \qquad R^2 = 0.73 .$$

resulted in a severe case of multicollinearity.

from the estimated equation and interpret the estimated coefficient of the remaining input as the sum $(b_1 + b_2)$. Alternatively, it is possible to use the aggregate of the two inputs MRAD = (MRA + MD); the estimated regression coefficient will also be an unbiased estimate of $(b_1 + b_2)$; although the constant term will be biased.[1] Thus, if MRA/S and MD/S were exactly correlated, all three estimates of the coefficients would be identical. The correlation between MD/S and MRA/S is high but not perfect, therefore, the three estimates of $(b_1 + b_2)$ cannot be expected to be identical, but should be close to each other. In fact, their values range from 1.204 (log MD/S) to 0.849 (log MRA/S) and 1.083 (log MRAD/S). Which of the three possible specifications should we use and analyze? The closeness of the estimate of $(b_1 + b_2)$ for log MD/S and log MRAD/S indicates that the estimate of $(b_1 + b_2)$ is biased downwards for log MRA/S and upwards for log MD/S[2].

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[1] Demonstration of the unbiasedness of the regression coefficient of the aggregate of two perfectly correlated inputs in a Cobb-Douglas function is given by Doll, op. cit.

[2] Assuming that both inputs MRA and MD belong to the "true" production function, it is possible to determine the specification bias due to omission of one of the inputs from the estimated production function by using the method of "auxiliary" regression, elaborated by Theil and Griliches. When we want to estimate $(b_1 + b_2)$, we do in fact estimate the returns to scale. The bias in our estimate of returns to scale will be equal to: $E(\hat{e}-e) = b_k\ (p_1-1)$ where $e = b_1 + b_2$, is the sum of the true coefficients of the production function and $\hat{e} = b_1$ is the estimated coefficient of the included input. The weight, P_{MD} is the coefficient from the auxiliary equation log MD/S = P_{MD} log MRA/S. In our case $P_{MD} = 0.897 < 1$, therefore, the bias is < 0. This finding conciliates the discrepancy between the two estimates of $(b_1 + b_2)$. The unbiased value of the sum $(b_1 + b_2)$ i.e. of the returns to scale should effectively be lower than 1.204 and higher than 0.849. The value 1.083 estimated when the aggregated input MRAD was used is, therefore, consistent with the other two estimates.
Methodology for this analysis is based on Griliches:
Z. Griliches, "Specification Bias in Estimates of Production Functions", Journal of Farm Economics, 39, (1957), p. 8-20.

The estimation of all relationships related to the IInd version was so far performed for a limited sample of observations, excluding both Germany and Sweden[1]. The use of this limited sample was however necessary for comparability of various specifications. In what follows, the production function with inventive input specified as the total employment in applied research and in development is examined. This specification, apart from being likely less or not more biased than the other specifications, offers the practical advantages of relying less on the ill defined distinctions between the different categories of R and D manpower and, at the same time, it also permits us to include the German data in the sample. The equation was estimated "stepwise" from a sample of 36 observations and results are reported in Table 4.2.b, equations (1) to (6).

The predicted level of MRAD/S and all other explanatory variables and industry dummy variables explain 80 percent of the total variance. In comparison with the estimation based on the restricted sample, the inclusion of German data leads to a slight decrease of the regression coefficient $(b_1 + b_2)$, its statistical significance however rises and is well beyond the 99% level.

Let us first concentrate on the regression coefficient of the invention input. When the number of patents per unit of sales was regressed against the input variable MRAD/S only, the later explained sixty percent of the total variance and the estimate was significant well beyond one percent level. Comparison of equation (1), in Table 4.2.b

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[1] German data were excluded because they did not distinguish between applied research and development. Swedish data, on the other hand, do not include investment expenses. Aside from the exclusion of all observations for Germany and Sweden, some Belgian and French observations had to be excluded for lack of investment and concentration data as well. The size of the restricted sample was 27 observations.

with the following equations, which include other explanatory variables, shows that the value of the estimated coefficient does not change significantly. None of the estimated coefficients is significantly different from unity.

In agreement with the theoretically predicted value of $\sum_m b_m - 1$, the regression coefficient of the average firm size $\bar{S}_{jih}$ is not significantly different from zero and therefore can be deleted.[1] Owing to intercorrelation of variable $\bar{S}_{jih}$ with concentration variable $\bar{C}_{ih}$, deletion of the former improves the statistical significance of the latter, which remains weakly significant at the ten percent level even after industry dummy variables are included. Somewhat surprising is the negative sign of the concentration variable. It indicates that the less concentrated industries exhibited a greater number of a patented inventions per sales. This finding is contrary to the result of the first version which, however, was not statistically significant.

The next variable is the country specific patenting ratio G_h, i.e. the number of patents granted relative to the number of patent applications. The production function for inventions (3.14) is a relationship between the number of patented inventions and the inventive inputs plus other explanatory variables under the assumption that the patenting criteria are the same among countries and industries. The patenting criteria vary, however, from one national patent system to another as it is demonstrated by the variability of ratio G_1 which ranges from 27% (Japan) to 99% (Belgium). In order to assure inter-

[1] See equation (3.14) and comments in Chapter 3.

national comparability of estimated production functions, the output should be measured in numbers of created inventions or in numbers of patent applications.[1] It is, therefore, necessary to transform the present measure of inventive output P, i.e. the number of patents granted, into the number of patent applications Pap. This was achieved in the estimated equation by variable G which has a significant negative regression coefficient.

The education variable E, although not always significant, indicates that the output of patented inventions is higher in countries with better technical education. This is certainly not surprising but it shows that contrary to the opinion of some authors, inventive activity is related to technical knowledge and education.[2]

The differences existing among industries are not significant ($F_{2y} = 1.04 < 2.77$) but addition of industry dummy variables shows that the interindustry differences bias the regression coefficient of MAD/S upwards, (cf. equation (3) and (5), Table 4.2.6). The dummy variables "clean" the regression coefficient of the inventive labour ($b_1 + b_2$) of its industry specific bias and may be, therefore, worth the interpretation in spite of their low statistical significance. The highest value of the intercept was exhibited by the non-electrical machinery industry followed by electrical machinery and textile industries. At the other extreme was the industry of non-metallic minerals.

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[1] Given G = P/Pap. and estimating log P/S = b log MAD/S, we get log Pap./S = b log MAD/S - log G.

[2] See Chapter 1 - Introduction, p.9.

The last equation was estimated with country dummy variables in order to capture country differences remaining in equation (6). The effect of country dummy variables is however, entirely insignificant and it is possible to conclude that both country specific variables G_h and E_h captured practically all country specific variance.

There does not appear to be any regular pattern in the residuals.[1] They are more or less regularly distributed among industries and countries. The often repeated claim that Canada's inventive capacity is lagging behind that of other industrialized nations[2] was not substantiated by the present data. Given the employment in applied research and development, four out of nine Canadian industries, i.e. metallurgy, machinery, electrical machinery and rubber, exhibited a higher number of patented Canadian inventions per sales than predicted by the regression. This indicates that as for the inventive productivity of Canadian industries in the sample, i.e. the number of patents relative

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[1] Regressions of residuals from eg. (5) on all relevant explanatory variables, including industry dummy variables, resulted in $R^2 = 0$. The following residuals were recorded for Canada:

	1st stage equation:	2nd stage equation:
Positive residuals: Industry no.:	5,6,7,12	2,4,7
Negative residuals: Industry no.:	1,2,4,10,13	1,5,6,11,12,13

[2] For example O.J. Firestone, stressed the fact that among industrialized countries, Canada has the lowest ratio of patents granted to her own nationals and ranks very low in terms of inventions per thousand population. Neither of the two measures is however very meaningfull for evaluation of inventive capacity. The low ratio of patents granted to nationals indicates the degree of integration of Canadian and foreign, mainly U.S. industries. The number of inventions per thousand population is not very meaningful either, because the number of persons engaged in invention creating, i.e. mainly manufacturing industries would be a more relevant measure.
O.J. Firestone, op. cit., p. 45.

to the number of Rand D personnel engaged in inventive activity, it was not worse than the average of this sample. However, the level of Rand D employment was lower in six out of nine industries, as is indicated by residuals of the first stage operation. Taking this lower than predicted employment in applied research and in development into consideration, it is possible to say that the lower number of patents then predicted in food, chemical and non-metallic mineral products industries was caused by the low level of inventive productivity in those industries.

On the other hand the metallurgy, machinery and rubber industries, which all had more patents than predicted, exhibited a better than average inventive productivity, because these industries employed less Rand D personnel than predicted. According to the same reasoning, the textile and paper and wood products industries displayed lower inventive productivity.

4.3. Version III

The dependant variable, the number of patented inventions per sales, is now regressed directly on the variables determining the magnitude of organized inventive activity. The independent variables include the same variables as those used in the first stage equation of the previous 2SLS estimation. Because this specification ignores the simultaneous character of the relationships involved, included are not only the independent profit variables such as the size of sales S, profitability proxy D/S, or alternatively IS, EXIM and VA, but also the wage rate of R and D personnel, W. The Wage rate is therefore considered as being given. This is perhaps not a completely unrealistic assumption in the world of rigid wage scales for engineers and scientists prevailing in industrialized countries today. The wage rate thus becomes, in our equation, a proxy for the cost of inventive activity.

This naive specification must be expected to yield estimates suffering from a simultaneous equation bias. On the other hand, the simple least square method of estimation is potentially more efficient than the theoretically more appropriate 2SLS method. A practical advantage of the OLS estimation in our case is that it permits to reestimate coefficients of profitability variables which were estimated in the 1st stage of the 2SLS estimation. Although both estimates are admittedly biased, the bias is due in each case to different causes and it is difficult, if not impossible, to predict. A comparison of the estimates from 2SLS and OLS may, therefore, be informative.

We present and discuss first the results of the OLS estimation of specification 3.2.4a, using development and export-import ratio proxies for profitability. Two equations are presented in Table 4.3. The first does not include industry dummy variables. Comparison of this equation result with the estimation of the 2nd stage equations of the 1st version, eqs. (1), (2), Table 4.1.b. shows that the present equation explains about the same proportion of the total variance and the regression coefficients of most variables have the same sign. The coefficient of the profitability proxy D/S is significant and very close to the value of the D/S variable in the 1st stage equation of 1st version. Similarly the value of the regression coefficient of the size variable S is not significantly different from zero. The regression coefficient of the average size of firm is also comparable to the one estimated in

Table 4.3

Ordinary least square estimates.

Version-III

Specification 3.2.4a

log P/S_{ih} =	log C_0 +	C_1 log D/S_{ih} +	C_2 log S_{ih} +	C_3 log EX/IM_{ih} +	C_4 log W_{ih} +	C_5 log $\overline{S}_{jih}$ +	C_6 log $\overline{C}_{ih}$ +	C_7 log G_h +	C_8 log E_h +	$\sum_{i=1}^{10} d_i i_i$	$\bar{R}^2$	n
(1) "	-9.359 (-2.17)*	0.666 (4.40)**	0.088 (0.51)	0.043 (0.26)	-1.202 (-1.65)	-0.379 (-1.50)	0.131 (0.45)	-0.678 (-1.46)	1.486 (1.34)	no	0.5[illegible]3 (4.[illegible]3)**	40
(2) "	-12.920 (-2.45)	0.273 (1.02)	-0.286 (0.81)	0.291 (1.26)	-1.728 (-1.82)	-0.343 (-0.93)	-0.121 (-0.28)	-1.093 (-1.86)	2.288 (2.27)*	yes not significant	0.654 (2.[illegible]4)*	40

Specification 3.2.4b

log P/S_{ih} =	log C_0 +	C_1 log I/S +	C_2 log S_{ih} +	C_3 log W_{ih} +	C_4 log $\overline{S}_{jih}$ +	$\overline{C}_5$ log C_{ih} +	C_6 log G_h +	C_7 log E_h +	C_8 log $\bar{D}/S_{ih}$ +	$\sum d_i Y_i$	$\bar{R}^2$	n
(3) "	-0.885 (-0.29)	1.243 (3.47)**	0.273 (1.00)	0.077 (0.23)	-0.368 (-1.41)	-0.707 (-1.63)	-0.523 (-1.18)	0.282 (0.49)	———	yes significant	0.55[illegible] ([illegible])**	36
(4) "	-9.289 (-2.78)	0.554 (1.37)	0.385 (1.54)	-0.079 (-0.19)	-0.669 (-1.82)	1.271 (2.86)*	-0.224 (-0.39)	0.033 (-0.05)	———	———	0.[illegible] (1.5[illegible]	36
(5) "	10.091 (-1.41)	0.178 (0.44)	0.205 (0.73)	-1.305 (-1.11)	-0.428 (-1.16)	0.130 (0.26)	-0.61 (-0.47)	1.605 (1.52)	0.747 (3.95)*	———	0.[illegible] (4.53)**	[illegible]
(6) "	-2.496 (-0.23)	1.697 (2.05)*	0.090 (0.153)	-0.207 (-0.12)	0.046 (0.1)	-0.095 (-0.1)	-0.43 (-0.19)	0.054 (0.03)	-0.215 (-0.52)	yes not significant	0.6[illegible] (3.5[illegible])*	[illegible]

Notes

a) t-ratios and F-ratio are given in parantheses under the regression coefficients and under the $\bar{R}^2$ respectively, significant at the 5% level ( )*, significant at the 1% level ( )**.

b) The number of observation in the sample is given in column -n-. Sample of 27 observations excluded German and Swedish observations and several French and Belgian observations. Sample of 36 observations excludes Swedish and several French and Belgian observations. Sample of 40 observations, excluded German and several French and Belgian observations.

Table 4.4.

Correlation matrix

	log P/S	logMRA/S	log MD/S	log MRAD/S	log $\bar{S}$	log $\bar{C}$	log E	log G	log S	log I/S	log D/S	log EX/IM	log W
col.	1	2	3	4	5	6	7	8	9	10	11	12	13
row													
1	1.00	0.72	0.79	0.80	-0.04	0.31	-0.29	-0.40	- 0.29	0.21	0.68	0.12	-0.39
2		1.00	0.85	0.94	-0.01	0.42	-0.35	-0.29	0.01	0.44	0.77	o.29	-0.37
3			1.00	0.98	0.04	0.54	-0.38	-0.38	0.10	0.19	0.94	0.23	-0.35
4				1.00	0.06	0.51	-0.36	-0.36	0.06	0.28	0.91	0.24	-0.36
5					1.00	0.55	0.45	0.06	0.27	-0.12	0.20	0.21	0.46
6						1.00	0.05	-0.01	-0.12	-0.01	0.63	0.57	0.12
7							1.00	0.74	-0.01	-0.17	-0.19	0.12	0.86
8								1.00	-0.56	0.05	-0.15	0.16	0.78
9									1.00	-0.11	-0.01	0.14	-0.19
10										1.00	0.14	0.27	-0.26
11											1.00	0.22	-0.06
12												1:00	-0.17
13													1.00

Version I. The concentration variable plays a negligible role. The patenting ratio G appears again with a negative coefficient and the education variable E with a positive coefficient. All variables which were included in the 2SLS estimation of the first version performed very similarly in this simpler, OLS specification. The wage variable, which was not included in the first version, comes out with a negative coefficient.

When we reestimated the equation with industry dummy variables (equation (2) in Table 4.3) their contribution was insignificant ($F = 0.89 < F_{9,23} = 2.21$). Comparison of equations (1) and (2) shows, however, that both the value and statistical significance of the regression coefficient for D/S_{ih} decreases noticeably. This effect of the industry dummy variables shows that the differences among industries consist mainly of differences in intensity of development. Inclusion of industry dummy variables increased, however, the statistical significance of most of the remaining variables.

Let us now concentrate on the role played by the wage variable. Under some very special conditions the negative sign of the wage variable could lead to a tentative interpretation that the wage rate differentials between the industries indeed reflect the differences in the cost of inventing activity. This could be so if, for instance, the offer of the R and D personnel was very, or completely, elastic in the relevent range of the supply function and there were marked differences in the wage rates among industries. On the other hand, the derived demand functions for the services of inventive R and D personnel would have to be either rather similar among industries or at least behave so as to result in a negative relationship between the wage rate and the demanded number of R and D personnel. The last condition seems to be at least partly, fulfilled. As it can be seen from the correlation matrix, Table 4.4, log W is correlated negatively to log MRA/S (r = - 0.39).

Another, probably more acceptable explanation can be based on the fact that the bulk of patenting is done by the traditional R and D intensive industries such as machinery, both non-electrical and electrical, and in the chemical industry. The greater scale of R and D in those industries favours a division of labour between the qualified personnel QSE, and their supporting staff. The employment of the supporting staff is, therefore, in the R and D intensive industries, relatively higher than in the other industries. The greater proportion of supporting staff in the total R and D employment in the former industries leads to a lower average wage rate of their R and D personnel.

This interpretation is supported by the negative correlation existing between the wage rate and the ratio of the supporting staff to QSE, R/Q (r = -0.333). Both interpretations of the negative relationship between the wage rate of the R and D personnel and the number of patented inventions support the theoretical hypothesis that the maximization of the expected profit from inventive activity leads to a tendency to minimize the cost of R and D inputs.

When the OLS method of estimation is applied to the modified specification on 3.2.4b using the alternative proxies of profitability, the following results are worth noting. First, the profitability proxy I/S passes the significance test and is used. The remaining two proxies, EXIM and VA were deleted from further calculations. Secondly, the industry dummy variables were highly significant and increased the explained variance by 46%, to $R^2 = 0.859$. The addition of dummy variables improved the standard error of the investment variable and lead to a change in the sign of the wage rate variable from negative to positive, but which remained insignificant.

Comparison of the present equation with the previous one which used D/S as profitability proxy, is interesting in two ways. First, the good fit of the present equation is, to a large extent, due to the industry dummy variables. In comparison to the D/S variable, it appears that the I/S variable better explains the variance existing within each industry, after the industry specific influence was accounted for by industry dummy variables. The role of the two profitability proxies in explaining the variance of log P/S is therefore different. The intensity of development D/S explains well why different types of industries exhibit different outputs of patented inventions and the investment proxy sheds more light on the causes of differences in profitability of invention within the same industry. In order to confirm this hypothesis, the two profitability proxies were used at the same time with the other independent variables. The equation was estimated for a restricted sample[1] of 27 observations and is reported in Table 4.3, eq. (6).

When the remaining unexplained interindustry differences were

[1] The sample excludes both German and Swedish observations as well as nine other observations because of data unavailability. Note that because of the differences in the samples used for the present and the two preceding estimations, the results are not strictly comparable.

absorbed by industry dummy variables eq. (7), the percentage of the explained variance rose by 16 percent and the significance of the I/S variable increased notably at the expense of the significance of both the D/S and W variables. This confirms that, in the OLS specifications, the D/S and W variables capture the interindustry differences[1] whereas the I/S and S variables reflect the profitability of the inventive activity within the industry.

1 With respect to explaining interindustry differences the effect of the D/S variable in this specification is consistent with the findings of the previous version, i.e. that the employment in development reflects mostly interindustry differences.

4.4. Summary

Our attempt to separately evaluate the contribution of each group of R and D labour to invention was impeded by multicollinearity. Indeed, groups of R and D labour were highly intercorrelated.

In the first version, the number of patented inventions per sales was a function of R and D employment in applied research, the latter being composed of qualified engineers and scientists and their supporting staff. The estimated regression coefficient, i.e. the elasticity of the number of patented inventions with respect to employment in applied research, was significantly greater than zero and smaller than unity. There were some statistically insignificant differences among industries, mostly related to the average size of firm. The average size of firm was negatively correlated with the number of patents and with the inventive input. The concentration of employment in large firms was negatively correlated with employment of qualified engineers and scientists in applied research, but the correlation was not significant and became even less so after the industry dummy variables were included. There was practically no association at all between patents per sales and concentration. The explanatory variables, including industry dummy variables, explained only about sixty percent of total variance. The estimated value of the elasticity of patented inventions to employment in applied research appeared somewhat unstable and quite sensitive to differences existing among industries.

The fact that about 20 percent of the total variance of employment in applied research was significantly accounted for by interindustry differences, which played also a non negligible role in the second stage equation, suggests that there are important differences in the underlying science base, technological opportunity and pricing.[2]

To sum up, employment in applied research, in conjunction with other explanatory variables, gave only a partial and somewhat inconsistent explanation of the number of inventions created and patented in each industry.

In the next step, the concept of inventive input was extended to include development. Two inventive inputs were specified. The first was the number of persons employed in applied research, i.e. the input of the first version, and the second, the number of persons employed in development.

The first stage equation is interesting in two respects. First, it indicates that employment in applied research and development is closely related to investment per sales when the industry differences are captured by dummy variables. Second, there is a significant positive relationship between R and D employment and concentration of industries which is however eliminated by introduction of industry dummy variables. This suggests that as far as the employment in development is concerned, interindustry differences are likely to be function of concentration, rather than of underlying science base, technological op-

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[1] This corroborates Scherer's and Philips' findings for the U.S. and Belgian industries respectively.
F.M. Scherer, op. cit., and L. Philips, op. cit.

[2] See equation (3.15). There may be different values for the mark-up constant l_{ih} in each industry and country. On the other hand, the industry specific variations in the underlying science base are likely to affect the elasticities b_m and c_m, as well as wages of R and D labour.

portunity or pricing[1]. The same reasoning probably applies also to employment of supporting staff[2] in applied research.

Although the separate estimates of elasticity of patented inventions to employment in applied research and in development are highly unreliable owing to multicollinearity, they suggest that each of the two categories of labour accounts for about fifty percent of the estimated sum of coefficients $(b_1 + b_2)$, which is not significantly different from unity. This conclusion is corroborated by results of an alternative specification in which the input is the combined employment in applied research and in development.

The differences existing among industries are again not significant, but introduction of industry dummy variables hardly affects the estimates of elasticity of patented inventions to R and D employment. Non-electrical machinery followed by electrical machinery industries, and surprisingly by the textile industry, exhibit at any level of inventive inputs higher output of patented inventions than other industries of the sample.

The number of patented inventions per sales is higher in less concentrated industries;however, this negative relationship is somewhat unstable and, except for one specification (3), insignificant. The effect of the average size of firm on the dependent variable is negligible. This is in agreement with the theoretical model, which predicts that the regression coefficient of $\bar{S}_{jih}$ should vanish when $\sum_m b_m = 1$, as

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1 See note no. 2, p.103.

2 Remember that supporting staff is now included, but it was not included in the 1st stage equation of Version I, which predicted employment of qualified engineers and scientists. The latter variable was negatively correlated with concentration.

it is in our case.[1]

Countries which employ a high proportion of engineers in their manpower exhibit a high output of patented inventions per sales.[2] There are significant intercountry differences in the criteria of patentability. Therefore, it could be advantageous in future research, to specify the dependent variable as the number of patent applications rather than as the number of awarded patents.

Finally, an analysis of residuals did not reveal any regular pattern. The residuals are not correlated with any specific country, industry or explanatory variable.

In general, it is possible to conclude that the present specification of inventive inputs which include employment in applied research and in development, proved to be empirically superior to the alternative specification, which confined the inventive input to employment in applied research only.

The ordinary least square estimates of the two varieties of the third version tend to confirm the conclusions presented above. The only new variable in this specification, the average wage rate of R and D personnel, is not quite significant, but its negative regression coefficient can tentatively be interpreted as an indication of a cost minimizing behaviour of the firms employing R and D personnel.

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[1] See equation (3.14) p.47.

[2] High percentage of engineers in the total manufacturing employment means high value of variable E.

In addition, comparison of the effects of the two profitability proxies on the dependent variable suggests that the development expenditure per sales explains well why different types of industries exhibit different outputs of patented inventions. The investment expenditure per sales sheds some light on the causes of differences in profitability of invention within the same industry.

Comparison of all three estimated versions leads to the conclusion that the second version, specifying the inventive input as employment in applied research and in development, explains a higher proportion of the variance and estimates more stable and more significant regression coefficients than both other versions. It is therefore statistically superior. As far as its theoretical and practical plausibility is concerned, the definition of inventive input in terms of employment in both applied research and development is less restrictive and therefore more acceptable than the alternative definition comprising inventive input to applied research only.[1]

The third version, in which the dependant variable is regressed directly on all exogenous variables, appears to be statistically inferior to the second one. It has, however, the practical advantage to enable us to estimate, and possibly to predict the number of inventions patented in an industry even when the R and D data are not available.

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[1] This conclusion is in agreement with Schmookler's definition of inventive input as opposed to definition suggested by Kuznets. See note no. p.

CHAPTER 5

CONCLUSION

The objective of this study was to analyze technical inventions as an economic phenomenon and to find the economic determinants which explain the international distribution of patented inventions.

The growing economic literature focussing on inventive activity shows that invention is, from the economic point of view, motivated by the expected profit. A microeconomic analysis of inventive activity on the markets with oligopolistic pricing established that the main economic determinants are the size of the industry, the expected change of the market share and the expected cost of the inventive activity. The first two determinants reflect the demand for, the last one the cost of, a new invention. A set of criteria which have to be satisfied by an invention before it can be commercially exploited was developed in an activity analysis framework as a by-product of the microeconomic analysis.

The microeconomic framework elaborated in the second chapter had to be substantially modified in order to be usable for the empirical analysis of a cross-section of manufacturing industries. The operational model presented in the third chapter develops the relationship between the number of patented inventions created by an industry and the employment of the various categories of the R and D personnel under the assumption of profit maximization. The necessity to work with variables which are not directly measurable e.g. the expected profitability of the invention, lead to construction of several proxies for profitability among which the employment in development deflated by sales and the investment deflated by sales, performed best empirically.

The empirical analysis indicated that the relationship between the inventive inputs and the inventive output measured by the number of patented inventions created by nationals in the given national manufacturing industry is rather stable and can be aggregated in terms of a production function. The elasticity of the number of patented inventions to the inventive labour input, i.e. to the number of persons employed in applied research and in development, is not significantly different from unity.

There is no significant difference between the contributions of the two R and D labour groups to the output of patented inventions. There are, however, some interesting differences as far as the determinants of the predicted employment in applied research and in development are concerned. Although both categories of R and D labour are positively correlated with the proxies for profitability, there is an important difference in their relation to the concentration of employment in large firms. Employment in applied research is weakly negatively correlated with our concentration variable, in contrast with the significant positive correlation between employment in development and concentration. This difference can be interpreted as an indication that the two R and D labour inputs are responsible for two different categories of inventions. Applied research is more likely to turn out basic inventions, which are subsequently improved and adjusted to commercial production in the course of development. Development may be performed by other, often larger, firms which sometimes belong to other industries than the one where the original basic invention originated. Our data suggest that inventions originating in development are frequent in highly concentrated industries. This conclusion supports Hamberg's hypothesis that the large industrial laboratories, which are more frequent in highly concentrated industries, are likely to be responsible mainly for improvement types of inventions.[1] The highly concentrated industries show, however, low inventive productivity, i.e. a low number of patented inventions per sales for the given level of R and D inputs. The resulting net effect of concentration on patents is statistically insignificant.

As for differences existing among industries, our results show that these differences play a significant role in the determination of R and D employment, but an insignificant one in the production function for inventions. However, as expected, the "high technology" industries such as electrical and non-electrical machinery, surprisingly followed by the textile industry, exhibit a greater number of patented inventions for a given level of R and D employment, than the rest of the sample.

The respective roles of explanatory economic variables were not very visible in the two stage least square specification used for the estimated of the production functions. They showed up much better in the last, third version estimated by the ordinary least square method. The size of the market and the profitability proxies alone explained most of the total variance in the number of patented inventions by national industries. There appeared to be significant interindustry differences in the intensity of development per sales and intraindustry differences in the investment per sales. Although the average wage rate

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[1] See D. Hamberg, op. cit., p. 103.

appeared with a negative regression coefficient, this can be only very tentatively interpreted as an indication of a cost minimizing behaviour with respect to the R and D personnel. The present specification constrained by the available data did not lend itself to a solid evidence for this affirmation.

Given their R and D employment, the Canadian industries do not turn out significantly less or more inventions than their foreign competitors. However, six out of nine Canadian industries have a lower employment in applied research and development than the employment predicted by the economic characteristics of the respective industries. The gap between the actual and predicted employment of R and D is positively related to the degree of foreign control of Canadian industries, and is generally found in high technology industries rather than in others[2]. Thus it is possible to draw the conclusion that the foreign control of Canadian industries leads to a lower level of employment in applied research and development and indirectly to a lower output of patented inventions.

The degree of foreign control of domestic industries influences the distribution of patents between the nations and foreigners. Foreign control of a domestic industry is usually accompanied by a transfer of technology and know-how from the parent company. Foreign subsidiaries

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[1] Owing to the fact that the above mentioned groups of industries are composed of many, narrowly specialized industries, which vary in age, scientific base and industrial structure, it would not be appropriate to try to find a unique and common explanation for their above-average output of patented inventions.

[2] Similar correlation does not exist for other countries.

protect their monopolistic technological advantages through patenting, in the host country, all inventions which are likely to be commercially exploited there. Industries with an important proportion of firms under foreign control are likely to exhibit a high proportion of patents issued to foreign inventors.

On the other hand, if the foreign control is either absent or equally distributed among domestic industries, a high proportion of patents issued to nationals in a given industry indicates that the industry has a comparative technological advantage, which is likely to be reflected in a positive trade balance.[1] Data in our sample convincingly corroborate the two hypotheses. The percentage of patents issued to nationals relative to patents issued to foreigners, is indeed well explained by foreign control and export-import ratio[2] for the whole sample.

The very low ratio of P/P_F for practically all Canadian indus-

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[1] There is a lot of evidence that technological advantage leads to comparative advantage in foreign trade. For an international comparison see: P. Hanel, The Relationship Existing Between the R and D activity of Canadian Manufacturing Industries and their Performance in the International Market, an unpublished study, Dept. of Industry, Trade and Commerce, Ottawa, (December 1975).

[2] $$\log (P/P_F)_{ih} = \underset{(-2.58)^{**}}{-0.63} + \underset{(2.3)^{*}}{0.33} \log EX/IM_{ih} - \underset{(-4.2)^{**}}{0.44} \log FC \qquad \underset{(9.76)^{**}}{R^2 = 0.35} \qquad \underset{56}{n}$$

When country dummy variables are introduced, they capture the remaining important influences such as the proximity of technologically dominant foreign industries, the size of the domestic market, the openness toward investment etc. The differences among countries are related mainly to foreign control which explains the ratio P/P_F well for Canada, but much worse for other countries. As result, the coefficient of FC is not significantly different from zero.

$$\log (P/P_F)_{ih} = \underset{(-7.1)^{**}}{-2.83} + \underset{(2.4)^{*}}{0.21} \log EX/IM_{ih} - \underset{(0.1)}{0.01} \log FC + \Sigma g_h . X_h \qquad \underset{(3.15)}{R^2 = 0.31}$$

Note that the regression reverses the direction of causality, which goes from P/P_F to EX/IM.

tries[1] reflects, therefore both the high degree of foreign control and, at the same time, the lack of technological comparative advantage of Canadian manufacturing industries.

We may now summarize the main empirical conclusion of this study:

1. Output of patented inventions in a given industry results from the R and D activity of profit maximizing firms. The average elasticity of patented inventions to employment in R and D is not significantly different from unity, and employment in applied research and in development appears to contribute equally to inventive output. There are no significant interindustry differences in the relationship between the inventive inputs and their output.

2. The level of employment in applied research and development is a function of the expected profitability of invention. There are significant interindustry differences as far as the determination of the "equilibrium" employment in R and D is concerned and these are, to a certain extent, related to the structure of the industry, i.e. to the degree of its concentration. The level of actual R and D employment in Canadian manufacturing industries is lower than the expected level owing at least partly, to foreign control.

3. Finally, the proportion of patents issued to nationals and foreigners is closely associated with the trade performance and foreign control of the domestic industries.

1 For details and discussion see, O. Firestone, op. cit., Chapter 4 and Table 49, p. 377.

The main shortcomings of this study are related to the level of aggregation used and to data in general. If the decision to invent or to acquire an invention is taken by a firm, the data on firms would, therefore, be the most appropriate ones. The aggregation to an industry level is not only undesirable from this point of view but also because of the problems it involves in the reclassification of patents.

The inherent incomparability of inventions and, to a certain extent, of the R and D personnel as well, appears to be incompatible with the very essence of the concept of the production function which presupposes the use of homogenous inputs creating a homogenous output. In the present context, every criticism of this sort is accepted; the only argument in favour of the use of the production function is the fact that in spite of their inherent factual heterogeneity, the number inventions patented annually in each country and even in each broadly defined national industry, is very regular and homogenous once the level of aggregation is high enough. The use of an aggregated production function appears, therefore, to be as justified here as it is for the aggregated output of the whole economy;it is a useful simplification of the complex reality.

The data for R and D leave a lot to be desired;they should give a closer definition of the invention R and D and they should include more detail concerning the employment and wages of the personnel. In general, the use of average data for inputs and outputs over a period of several years would have been more appropriate than the data for one period only.

The patent statistics are becoming an integral part of national accounting. They are regularly published in national statistical yearbooks and are intended to reflect a nation's inventive output. They should, therefore, be presented in a manner suitable for this purpose. The present practice of not distinguishing the patents awarded to nationals and to foreigners in each patent class makes the patent statistics quite useless for any meaningful evaluation of the national inventive activity.

Better statistical data on both R and D inputs and on patented inventions will hopefully make it possible to answer many interesting questions which remain so far unanswered. Better information should enable better decision making in this important field of economic activity.

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APPENDIX A

TRANSITION FROM INVENTION TO INNOVATION: THE NECESSARY CONDITIONS

The criteria to be fulfilled before a commercial exploitation of an invention (i.e. innovation) is considered economically feasible are analysed in the activity analysis framework. The approach represents a formalization and generalization of Lancaster's pioneering work.[1]

Initially, each good is associated with a vector of characteristics. The transformation of goods into characteristics is given by a matrix of "consumption technology". Consumers are consuming a combination of characteristics rather than goods as such and they are supposed to choose combinations that minimize the cost of their consumption at the given prices. On the production side, the motivation for production of goods is maximization of profits at given prices, technology and available resources. This initial situation is compared with the anticipated effects of a new invention.

Three main categories of technical change embodied in a new invention are examined:

1) New technology results in a new commodity which is associated with preexisting characteristics but available in new proportions.
2) New technology produces a given product with lower costs.
3) New technology adds new characteristics to the preexisting ones.

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1 K. Lancaster, "Change and Innovation in the Technology of Consumption", A.E.R. Papers & Proceedings, (1966), pp. 14-23.

The basic principle underlying the activity analysis approach is that in order to be economically feasible and therefore commercially exploited, an invention must represent an efficient solution of two linear programs. On the production side, the new technology must satisfy the criteria for an efficient production for the given vector of available resources and to be at least as profitable, considering the estimated costs of introducing the new technology into production, as the old technology. On the consumption side, the product produced by the new technology has to satisfy the criteria of an efficient consumption, i.e. not to be a more expensive menu of consumed characteristics than the one available from the old technology.

Application of the two above criteria in a form of solutions of two linear programs determines a price range with the lower boundary given by the solution of the production program and the upper boundary by the solution of the consumption program. In order to be commercially feasible and attractive, the new technology embodied in the invention must result in a positive price range, i.e. the highest price still acceptable to the consumer has to be higher than the lowest price acceptable to the producer. In the contrary case, the exploitation of the new technology can not be considered as being economically feasible at the existing prices and resource endowment.

Situation before invention.

There is a vector of existing goods $\bar{x}$, and a vector of characteristics $\bar{z}$, associated with the vector of goods. With each j-th good is associated a vector of its characteristics $\bar{b}_j$, so that $\bar{b}_{ij}$ is the amount of the i-th characteristic possessed by a unitary quantity of the j-th good. The set of all vectors $\bar{b}_j$ forms the consumption technology matrix B. We assume that there is a one to one correspondence between goods and activities.[1]

$\bar{z} = B.\bar{x}$ where the number of characteristics is -r- and the number of goods is -m-. Both vectors $\bar{z}$ and $\bar{x}$ are non-negative.

Creation of an invention or of a sequence of inventions makes it possible to produce a vector of goods $\bar{x}^1$ which contains at least one new good, x_{m+1}. The new consumption technology may be expressed:

$\bar{z}^1 = B^1 . \bar{x}^1$ the number of goods is now $(m+1)$ and $\bar{z} \neq \bar{z}^1$

To express the difference between the technically possible new good x_{m+1} and all the preexisting goods, we may write for the vector of characteristics of the (m+1)th good, $\bar{z}^1_{m+1}$

$\bar{z}^1_{m+1} = B^1 . \bar{x}^1$, where the vector of goods $\bar{x}^1$ has the elements

$x_k = 1,\ x_i = 0, (k=m+1)$ and $(i \neq k)$

Vector $\bar{z}^1_{m+1}$ will be equal to the $(m+1)^{st}$ column of the new consumption technology matrix B^1.

We express similarly $\bar{z}_m$ as a corresponding column of the previously existing technology matrix B.

$\bar{z}_m = B\bar{x}$ $\bar{x}$ vector of preexisting goods with elements

$x_k = 1,$

$x_j = 0$ for $k \neq j$ $(k,j = 1 \ldots\ldots m)$

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1 This corresponds to Lancaster's "simplified model", see: Lancaster, op. cit., p. 136.

Generally $\bar{\bar{z}}^{1}_{m+1} \neq \bar{z}_m$

Before we attempt to specify the conditions under which an invention is likely to be commercially exploited, that is conditions of innovation, let us classify the different types of technical change an invention can bring up.

We can first distinguish three main categories:

1) New technology results in a new commodity which is associated with preexisting characteristics in different proportions.
2) New technology does not at all change the characteristics of the final good but reduces the cost of production.
3) New technology adds new characteristics to the preexisting ones.

By distinguishing the three main types of technical change an invention may represent, we have prepared the ground for an analysis of screening criteria which must be satisfied before an invention can be considered for commercial production. We shall discuss each class separately.

Introduction of a new product on the market must be seen as a special case of monopolistic competition. The would-be innovator has to choose a price for the new commodity and we assume that he will do so in order to maximize profit. However, he can charge only as much "as the traffic will bear", that is as much as the consumer will be ready to pay.

Thus the price range for the new product is limited both from above and from below. We shall show that the boundaries of this price range can be determined objectively by means of activity analysis, but only for some types of technical change.

At this stage, we introduce the "producer" in the game, that is the potential innovator. We shall assume that the producer can acquire all the technology necessary for commercialization of the invention at a known cost and he is therefore capable to determine the total development cost involved.

As for the consumer, we shall assume that he makes his choice efficiently, that is, he will choose only those commodities whose characteristics form an efficient vector in the commodity characteristics space C. We shall further assume that preferences of consumers are well distributed in space C so that the commodity which represents an efficient choice, will effectively be chosen. Finally, by applying Lancaster's activity analysis consumer theory we have to adopt a rather strong version of the axiom of nonsatiation. Here, the consumer is supposed to have an utility function u(z) with the property $\frac{\partial u}{\partial z_i} > 0$. Lack of realism of this assumption pertaining to characteristics seems to be still more flagrant than it is in the conventional analysis, where it refers to nonsaturation in the consumption of goods. As a partial solution for this problem, we propose that those characteristics, which may be labeled by the consumer as undesirable, be thought of as transformed in their own inverse, so that maximizing them would mean minimizing the undesirable.

Determination of the price range.

First, let us discuss the price range for the 1st case of technical change, e.g. a new commodity associated with preexisting characteristics in different proportions. We must distinguish three different situations:

a) Goods are infinitely divisible and can be consumed in combinations. The convex cone in space C remains unchanged.

b) Goods are not divisible and therefore can be consumed only as an entity. The convex cone in space C remains unchanged.

c) The new good X_{m+1}, expands the cone of attainable characteristics in space C.

Ad a) Goods divisible and consumed in combinations.

This is the category, where we can successfully use Lancaster's approach to derive economically meaningful conclusions for our analysis. Lancaster's consumer is supposed to "consume a linear combination" of goods, which enables him to achieve the desired combination of characteristics. Unfortunately for his theory and our application of it, this assumption is as remote from reality as its neoclassical counterpart, the infinite divisibility and substitutability of goods. We cannot "consume" half a sports car combined with half a super safety car (yet to be produced), in order to achieve the desired mix of speed and safety.

The discrete choice seems to be the rule, rather than the exception in real situations and this limits the relevance of an approach which cannot cope with it.

Lancaster acknowledged this limitation,[1] but underplayed its importance.

We can determine the price range for the cases where the assumptions are satisfied, by deriving first the lowest price acceptable to producer and later, the highest price acceptable to consumer.

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1 Lancaster, op. cit., p. 22.

Let $\bar{p}$ be the vector of old prices for (m) goods and services.

$\bar{p}^1$ the vector of new prices for (m + 1) goods and services.

$\bar{c} = \bar{c}^1$ the vector of primary resources available for production - equal before and after the innovation has taken place.

Let us assume that $x(m+1)$ good is produced by a new activity $y(m+1)$. The original number of activities being (m).

As we suppose that there will be a new element in the goods vector, we can write for the producer two linear programs determining optimal conditions of production for the "old" production technology $T_{(m+n)}$, and for the "new" technology $T^1_{[(m+1)\times(n+1)]}$ including production activity producing the innovation.

We can write for the existing (old) production the following program:

$$\max \ \bar{p}\cdot\bar{x} = \max \bar{p}\cdot T\cdot\bar{y}$$

$$\text{subject to.} \ -T\cdot\bar{y} \leqq -\bar{c}$$

The optimal solution gives a vector of activities $\bar{y}^*$, which determines the optimal outputs and inputs $\bar{x}^*$, and the maximum value of $\bar{p}\cdot\bar{x}^* =$ profit.

The new production.

We want to determine what is likely to be the lowest price the innovator could charge for the new good x_{m+1}.

Let the new vector of prices $\bar{p}^1$ have all m-elements equal to the elements of the original price vector $\bar{p}$ and suppose that the innovator chooses an arbitrary price p^1_{m+1} for the x_{m+1}st good. Then the optimal production should satisfy the following program.

$$\max \ \bar{p}^1\cdot\bar{x}^1 = \max \bar{p}^1 \cdot T^1\cdot\bar{y}^1$$

Subject to $-T^1 \cdot y^1 \leqq -\bar{c}$ Optimal solution $\bar{y}^{1*}$ and resulting $\bar{x}^{1*}$.

The new product $\bar{x}_{m+1}$ would be considered for production only if it is an element of the new efficient production vector $\bar{x}^{1*}$ and if a price vector $\bar{p}^1$ satisfied the following condition:

$$\bar{p}^1 . \bar{x}^{1*} \geqq \bar{p} . \bar{x}^* + D$$

and element $\bar{x}_{m+1} \in \bar{x}^{1*}$, $x_{m+1}^* > 0$ Where D is the unit development cost necessary for introducing the production of $\bar{x}_{m+1}$.

The minimum price $_{min}\bar{p}_{m+1}$ then will be the price for which the profit from the new production would just be equal to the profit resulting from continuation of the old production.

$$\bar{p}^{1}_{m+1} \in \bar{p}^1 \qquad \bar{p}^1 . \bar{x}^{1*} = \left(\bar{p}.\bar{x}^* + D \right.$$

for $x_{m+1} > 0$

The upper boundary for this price range, will be determined from the demand side. In order for there to be a demand for the new product, the new characteristics of this new product x_{m+1} must give an efficient point $\bar{z}^*$ in the space of commodity characteristics C.

The efficiency frontier in C-space is a function of consumption technology given the price vector $\bar{p}^2$.

Suppose again that we compare the new vector of prices $\bar{p}^2$ which has all elements (m) equal to the preexisting prices of m-commodities and its $(m+1)^{st}$ element is the price of the new good x_{m+1}.

To find the price p^2_{m+1} we may proceed by introducing a vector $\bar{x}^1$ of commodities such that its element $x_k = 1$, $x_j = 0$ for $(k = m+1)$ $(j \neq k)$

As it has been shown above, this vector $\bar{x}^1$ will be associated with characteristics $\bar{z}_{m+1}$.

$\bar{z}_{m+1} = B^1 . \bar{x}^1$. is the $(m+1)^{st}$ column of matrice B^1.

The cost of consumption of a vector of characteristics $\bar{z}_{m+1}$ is then:

$$\bar{p}^2 . \bar{x}^1 = p^2_{m+1} \cdot 1$$

In order to find the highest possible price p^2_{m+1} of commodity x_{m+1}, that will still make it an efficient choice, we have to compare the value $p^2_{m+1} \cdot 1$ with the value of the efficient choice for the same vector of characteristics $\bar{z}_{m+1}$ under the conditions of the old technology.

A vector of characteristics $\bar{z}_{m+1}$ represents an efficient choice $\bar{z}^*$ if the vector $\bar{x}^*$ is the solution of the program:

$$\min \bar{p} . \bar{x}$$

Subject to: $B . \bar{x} = \bar{z}_{m+1}$

The new product will represent an equal or better choice only if:

$$p_{m+1} \cdot 1 \leq \bar{p} \cdot \bar{x}^*$$

That is only if the cost of a set of characteristics z_{m+1} associated with a unitary quantity of x_{m+1} is cheaper or at most equal to the cost of the "old" consumption, $p\bar{x}^*$.

Thus the upper limit of the price of the good x_{m+1} is $p_{m+1} = \bar{p} \cdot \bar{x}^*$ where $\bar{p}.\bar{x}^*$ is the solution of the program

$$\min \bar{p} \bar{x}$$

Subject to: $B\bar{x} = \bar{z}_{m+1}$

Ad b) Goods are not divisible and can be consumed only as an entity. The convex cone in space C remains unchanged.

Compared to the previous case, where the set of obtainable characteristics was convex (a convex cone with a weak convex boundary), the obtainable set now is constituted by discrete points within a convex cone and it is therefore possible to use methods of integer programming for finding the points of an efficient choice for consumption.

Thus, though we can find the lower boundary of this price range according to this same criteria as in case

Ad a), the upper limit of the price of the good x_{m+1} is $p_{m+1} = \bar{p}.x^*$, when $\bar{p}.x^*$ is the solution of the program:

$$\min \bar{p}.\bar{x}$$

Subject to: $B.\bar{x} = \bar{z}_{m+1}$ and $x_j = 0$, or 1, or 2 or an integer

$(j=1...m+1)$

Ad c) The new good x_{m+1}, expands the convex cone of obtainable characteristics in space C.

In the two previous cases Ad c) and Ad b), we have assumed that z_{m+1} is a vector in the characteristics space C, which can be expressed as a linear combination of r-characteristics $\bar{z}_{m+1}$ belonging to the convex cone, $c = \sum_{i=1}^{r} a_i z_i$ for $a_i \geqq 0$, $z_i \geqq 0$.

Now we consider the special case, where the commodity x_{m+1} is associated with a vector of characteristics z_{m+1} outside this convex polyhedral cone.

$$\bar{z}_{m+1} \notin \sum_{i=1}^{r} a_i \bar{z}_i \qquad \text{for any } \bar{z}_i \geqq 0,\ a_i \geqq 0,$$

where $\bar{z}_i = B.x_i \qquad (i = 1 \ldots m)$

for $x_i = 1, x_j = 0\ (j \neq i)$

The lower boundary of the price range will again be established as in case Ad a) assuming producer's profit maximizing behavior. However, in this special case the upper boundary will be an arbitrary price p^2_{m+1}, because the vector of characteristics $\bar{z}_{m+1}$ now becomes one of the half lines forming the cone and therefore a vector of characteristics $\bar{z}_{m+1}$ associated with an x_{m-1}, represents the optimal solution of the program.

$$\min\ \bar{p}.\bar{x}$$

Subject to $\qquad B\bar{x} = z_{m+1} \quad$ for $\bar{x}^* = x_{m+1}$.

2) New technology does not change the characteristics of the final good but reduces the cost of production.

This is the only case of new technology which can be dealt with by applying the ordinary production theory. It has been analysed for a special case of production of one final output by Simon.[1]

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1 H.A. Simon, "Effects of technological change in a linear model," in Koopmans ed., Activity Analysis of production and allocation, Cowles commission for research in economics, Monograph no. 13., John Wiley, N.Y., 1951.

Determination of the price range.

To determine the lower boundary of the price range, we can simply apply our Ad a) analysis for goods which are divisible and consumed in combinations, and look for the solution of a special case when

$\bar{z}_{m+1} = \bar{z}_m$ where $\bar{z}_m$ is the vector of characteristics associated with a unitary quantity of the good x_m before the new technology decreased the cost of its production.

By definition of this category of technical change, the two vectors of characteristics are identical, but the two technologies of production are not:

$$T^1 \neq T.$$

The new price p_{m+1} for the innovated good can be lower than the original price p_m. The lowest limit of the new price range can be determined by the now familiar criteria, used above in case Ad a).

$$p^1 \cdot \bar{x}^1* = \bar{p} \cdot \bar{x}* + D \qquad p^1_{m+1} \in \bar{p}^1, \quad \text{for } x_{m+1} > 0.$$

where $\bar{x}^1*$, $\bar{x}*$ are the vectors of optimal outputs for the two respective technologies T^1 and T.

The upper boundary of the price range is again determined on the basis of an efficient consumption criteria and using the same criteria as in Ad a).

The new product x_{m+1} (in fact the old product produced by new technology) will be considered an efficient choice only if its price is equal to or lower than the old price.[1]

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[1] We are looking for the value of consumption of characteristics $z_{m+1} = z_m$, associated with a unitary output of $x_{m+1} = x_m$. In terms of value: $p_{m+1} \cdot 1 \leq \bar{p} \cdot \bar{x}*$. Characteristics z_m are associated with good x_m, therefore the optimum output vector $x*$ is identical with element $x_m = 1$, $x_i = 0$, $(i = 1 \dots m-1)$ and $p_{m+1} \leq p_m$.

$$p_{m+1} \leqq p_m$$

The upper boundary is obviously $p_{m+1} = p_m$, i.e. no change in price.

3) New technology adds new characteristics to the preexisting ones.

In this case, we are helpless with the new approach. Addition of a new row to the consumption technology matrix B makes it impossible to compare the efficient choices before and after the introduction of a new technology.[1]

Therefore, the price range cannot be determined by the above methods.

Conclusion.

The combination of activity analysis of production and consumption enabled us to derive rigorous criteria for the classification of various types of technological change. It also enabled us to determine the price range into which the price of the new invention has to fall in order to be commercially exploitable. All but one type of technological change can be meaningfully evaluated.

We believe that the present approach represents a step forward from the accepted treatment of the technological change in the activity analysis of production, which so far has been limited only to the cost reducing inventions. On the other hand, it also represents a step forward

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1 Conceptually, it is possible to think of a matrix B having as many rows (characteristics) as conceivable, although those which are not yet displayed on any goods, would have values of zero. However, the practical usefulness of this arrangement would unfortunately probably be also close to zero.

from Lancaster's model by adding the production efficiency criterion to his criterium of consumption efficiency and by using the two criteria as a necessary condition for an economically viable invention.

The most interesting implication of the present approach is that it clearly shows the relationship existing between available resources, prices and the economic feasibility of an invention. An invention represents an economically attractive innovation only with respect to a given vector of prices and resources. A change in any of the two vectors leads to a change in the economic feasibility of an invention. A previously economically non-viable invention may become viable and even attractive for a new vector of prices and/or resources.

To make the present approach operational it would be necessary to introduce the time and probability dimension in the analysis and work with the expected rather than with the actual values.

APPENDIX B

1.- The market size S_i[1] and the market share of the j-th firm s_{ij} are both functions of x_{ij} and p_{ij}, under the assumption that the firm keeps its markup pricing coefficient k_{ij} constant. The profit function can be expressed as:

$$\Pi_{ij} = k_{ij} \cdot p_{ij} \cdot x_{ij} - RD_{ij}$$

The total differential of profit then equals :

(1) $$d\Pi_{ij} = k_{ij} \, (dp_{ij} \cdot x_{ij} + p_{ij} \cdot dx_{ij}) - dRD_{ij}$$

To express the total differential of profit in terms of market share and market size variables, we write:

(2) $d\Pi_{ij} = ds_{ij} \cdot S_i \cdot k_{ij} + s_{ij} \cdot dS_i \cdot k_{ij} - dRD_{ij}$ where the profit increment is a function of both market size and market share variations, and of change in R and D cost.

However, if we express the market share differential ds_{ij} in terms of a ratio of the firm's sales to the total market size.

$$s_{ij} = \frac{p_{ij} \cdot x_{ij}}{S_i}$$, the differential is then:

$$ds_{ij} = \frac{1}{S_i} (x_{ij} \cdot dp_{ij} + p_{ij} \cdot dx_{ij}) - \frac{p_{ij} \cdot x_{ij}}{S_i^2} \cdot dS_i$$

Where:

$\frac{1}{S_i} (x_{ij} \cdot dp_{ij} + p_{ij} \cdot dx_{ij}) = ds_{ij}^*$, equals the variation of the market share with respect to the original size of the market.

$$(\sum_j p_{ij} \cdot x_{ij} = \text{const.}).$$

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1 For the sake of simplicity, we omit the use of subscript t, in this appendix.

The variation of the market share then equals:

(2a) $$ds_{ij} = ds_{ij}^{*} - s_{ij} \cdot \frac{dS_i}{S_i}$$

Substituting the result for ds_{ij} into the profit increment formula (2), we simplify:

$$d\Pi_{ij} = (ds_{ij}^{*} - s_{ij} \cdot \frac{dS_i}{S_i}) S_i \cdot k_{ij} + s_{ij} dS_i k_{ij} - dRD_{ij}$$

(3) $$\boxed{d\Pi_{ij} = ds_{ij}^{*} \cdot S_i \cdot k_{ij} - dRD_{ij}}$$

Thus owing to the definition of our variables, the profit variation is dependent only on variation of the market share, R and D expenses and on the absolute size of market size, but not on the change of the size of the market size; however, the variation of the market share with respect to the original, constant market size is a function of both ds_{ij} and dS_i.

To verify the correctness of this result, we substitute the underlying exogenous variables x_{ij}, p_{ij} into formula (3).

$$d\Pi_{ij} = \frac{1}{\sum_{j=1} p_{ij} \cdot x_{ij}} (x_{ij} \cdot p_{ij} + p_{ij} \cdot dx_{ij}) \cdot \sum_{j=1} p_{ij} \cdot x_{ij} \cdot k_{ij} - dRD_{ij}$$

indeed the result:

$d\Pi_{ij} = (x_{ij} dp_{ij} + p_{ij} \cdot dx_{ij}) k_{ij} - dRD_{ij}$ is identical to the previous one (1).

APPENDIX C

Data and their sources.

C.1. Data on patenting.

National Patent Statistics are unfortunately aggregated in a form highly unsuitable for use in economic analysis and to make things worse, there are important differences in the national patent systems and still more so in their statistical presentation. Thus, although there has been in recent years a regular publication of the International Patent Statistics by the United International Bureau for the Protection of Intellectual Property (BIRPI) in Geneva,[1] the published tables do not permit to establish the proportion of the number of patents awarded to nationals of the reporting country and to foreigners except for the total number of patents issued in the given year. On the other hand, the distribution of patents by type of invention is done according to international patent classification which is quite remote from either Standard Industrial Classification or Standard International Trade Classification systems used for economic statistics.

In order to have the data on patented inventions in the desired form and aggregation, we were forced to extract the information form the bulletins of national patent offices and arrange them according to the above described requirements. These bulletins are usually published weekly

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1 Published annually in Industrial Property. For the data on the patents granted during 1967; see: Industrial Property, Annex, December 1968, pp. 2-11.

or in longer regular periods and contain a brief description of each of the patents. From this description, it is generally possible to learn the date of application for and issue of the patent, the name of inventor or proprietor of invention (if the two are not identical, very often both are given), the address of that person and in the case of foreign priority claimed, the date and country with reference to the original application. A brief technical description of the invention follows.

All patents are classified according to national patent classes, which basically vary from country to country. In some national bulletins, the published patents are also identified by the international patent classification class. The total number of patents issued varies from country to country, however, the number of patents published in the bulletins of each country is very uniform throughout the calendar year. According to experts of the Canadian Patent Office, this uniform distribution is also preserved within the broad classes, therefore, the published patent statistics may be sampled by random sampling if we are interested, as it is in our case, in numbers of patented inventions only. Due to the high number of inventions patented yearly, ranging in countries of our interest between eight and forty four thousand (Belgium and France respectively), the sampling was a practical necessity.

Before we proceed to a description of the details pertinent to the patent data of each country, it may be useful to mention the general methodological problem involved in reclassifying patents so that they may be related to the Standard Industrial Classification and Standard International Trade Classification used for economic data.

Contrary to the classifications used in economics which are based either on industry of origin, ISIC or on final products, SITC, the basis for classification of patents is either the function and/or the effect of an invention (the Canadian and US classification) or the combination of the product and industry of use principle applied in Germany, other European countries and in the Japanese system. The international system is more of European rather than North American inspiration and its chief advantage is that it offers a general unifying reference classification for the cases where the national system, such as the Canadian, does not give a clue as to which industry creates or uses an invention. In the case of Japanese data, available in Japanese only, the symbols of international classification were the only guiding element available.

The above mentioned differences in national patent systems make a perfect reclassification of patents according to ISIC impossible. However, due to the very broad classes of ISIC[1] used in the study, the concordance between the two systems is likely to be satisfactory in general, with a possibility of a few unavoidable mistakes in the case of Canadian patents.[2]

Now, we present the patent data for each country and discuss briefly the important details.

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1 Throughout the study, the version of ISIC revised in 1958 will be used.

2 See the subsequent details concerning Canada.

Germany.

The size of the sample was 2121 observations (patents) which corresponded to the total number of patents published in six randomly chosen weekly issues fo Patentblatt;[1] this sample largely exceeded the minimum sample size requirements for the chi-square distribution.[2] The distribution between nationals and foreigners in individual classes of the sample then was extrapolated by a factor 52/6x to obtain the estimate for the whole year 1967.

The following table contains the condordance between the classes of the ISIC used in our study and the corresponding classes of the German patent classification with the estimated frequency distribution of patents.

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1 Patentblatt, 87 Jahr, Heft 11, 18, 27, 30, 45, 50 (Bundes Patentamt, München, 1967)

2 The sample size must be sufficient to ensure that none of the theoretical frequences is less than I and not more than 20% of theoretical frequences are less than 5. In our case the smallest theoretical frequency was 10, for the foodstuff.
See c.f.
W.J. Dixon and F.J. Massey, Introduction to Statistical Analysis, (Mc Graw Hill 1969), p. 238.

Table 1.

Conversion of the ISIC groups in classes of the German patent classification and the estimated distribution of patents for 1967.

No	Industry group (SIC)	Corresponding German classes	No of patents to foreigners	No of patents to nationals	Total no of patents
1.	Food, bev, tobacco (20.21, 22)	2, 53, 66 79	86	87	173
2.	Textile, clothing...* (23, 24, 29)	3, 8, 25, 29, 33, 41, 52, 71, 73, 76, 86	372	442	814
4.	Paper & allied prod.** (27, 28, 25.26)	34, 38, 54, 55	424	581	1005
5.	Metallurgy (34)	18, 40, 48	320	338	658
6.	Machinery-non electrical (35, part of 36)	1, 4, 11, 13, 14, 15, 17, 24, 27, 31, 36, 38, 39, 43, 46, 47, 49, 50, 59, 67, 69, 70, 72, 75, 80, 82, 87, 88, 60, 81,	1723	2399	4122
7.	Electrical mach. (37)	21	1368	2338	3706
8.	Transport equipment (38)	20, 35, 56, 62, 63, 65, 67, 81	831	1421	2252
9.	Instruments (part of 36)	42, 51, 57, 79, 83	945	1213	2158
11.	Chemical ind. (31,32)	6, 10, 12, 16, 22, 23, 26, 28, 78, 85, 89	2281	2055	4366
12.	Rubber ind.*** (30)	39	109	98	198
13.	Nonmetallic mineral prod. (33)	32, 80	182	217	399

* Contains Textile, Clothing, footwear and leather industries.

** In order to correspond with the German R and D data, contains paper, wood & furniture and printing industry.

***Part of German class 39 (Plastics) included in Chemical industry. Due to the relatively low no of patents in this class represented in the original six week sample, eventually in eleven week sample was analyzed in order to arrive to the distribution between the national and foreign patentees. The extrapolation factor was accordingly $\frac{52}{11}$ for this class.

France.

French patent data are arranged according to the International Patent Classification, IPC. Therefore, it was possible to use at least for source of the industries the total number of patents given by the BIRPI tables [1] and apply the percentage distribution between patents to foreigners and nationals found from the sample for each of the industries.

The sample was constituted by six weekly issues of the official bulletin of the French Patent Office. [2] The official French patent bulletin classifies a patent in more than one class whenever the technical character of the invention makes it difficult to assign the patent to a single class. This peculiar practice - useful for patent searches by technicians and patent attorneys - involves multiple counting of patents. To avoid this, we have assumed that the distribution of patents classified in more than one class is the same for the patents created by nationals and foreigners and for all industries of our concern. [3] For the industries where our sample

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1 Industrial Property-Annexe, op. cit., Chart III, p. 11.

2 Institut National de la Propriété Industrielle, Brevets d'Invention: Vol. 2, Table des Brevets par Ordre des Matières, (Paris, Imprimerie Nationale, 1967), Following issues, identified by the data of publication were included in the sample: 3/17/1967, 6/23/1967, 6/30/1967, 10/13/1967, 11/29/1967, 5/5/1967.

3 The possibility that a patent is classified in more than one class depends entirely on the technical character of the invention and is therefore independent of the origin of the inventor. As for the equal distribution of the same phenomena between industries, we have checked this assumption for patents published during two weeks and found it confirmed.

findings served only to establish the distribution of patents between nationals and foreigners, the inflated count did not affect the results. For the remaining industries, defined narrower that the broad classes for which the totals were available from the BIRPI tables, the sample's patent counts were deflated by a factor of 0.787[1] and extrapolated by a factor of 8.666 to estimate the year's totals. The following table contains the conversion from the classes of ISIC to the corresponding classes of IPC used by the French patent office and the estimated frequence distribution of patents.

1 The deflator = True total of patents / Total of patents including patents counted more than once.

Table 2.

Conversion of ISIC groups in classes of the International Patent Classification (IPC) and the estimated distribution of French patents for 1967.

No	Industry group (ISC)	Corresponding classes of IPC	No of patents to foreigners	No of patents to nationals	Total no of patents
1.	Food, beverage and tobacco (20, 21, 22)	A21-A24	426	161	587
2.	Textile (23)	D01-D07	1094	166	1260
4.	Paper (27)	D21 (+part of B65)	192	81	273*
5.	Metallurgy (34)	C21-C23	906	144	1050
6.	Machinery non electrical (35, part of 36)	F01-F41 B01-B44 (except B29) B65-B68	9155	4692	13847
7.	Electrical machinery (part of 37)	H01-H05	3799	1545	5344
8.	Transport equipment (38)	B60-B68 part of F01	1707	1222	2929
9.	Instruments (part of 36)	G01-G12	3433	1722	5155
11.	Chemical industry (31,32)	C01-C14 except C03; 04	6551	1057	7608
12.	Rubber (30)	B29	165	67	232
13.	Minerals non-metalic (33)	C03,C04	532	184	716

* Also contains patents related to the manufacture of paper articles.

Belgium.

Belgium patent data, similarly to French patent data, are arranged according to International Patent Classification (IPC). Therefore, procedures similar to the one described for France were used, aplying the totals from the BIRPI[1] table wherever possible or estimating the adjustments, totals and the distribution between foreigners and nationals from a sample of 2543 patents covered by two monthly issues of the official patent bulletin.[2]

The following table gives the conversion between the ISIC groups and classes of IPC and the estimated distribution of patents.

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1 Industrial Property-Annexe, op. cit., Chart III, p. 11.

2 Service de la propriété industrielle et commerciale, Recueil des Brevets d'invention, Service de la propriété industrielle et commerciale, Bruxelles, Feb. Sept. 1967.

Table 3.

Conversion of ISIC groups in classes of the International patent classification (IPC) and the estimated distribution of Belgium patents for 1967.

No (SIC)	Industry group	Corresponding classes of IPC	No of patents to foreigners	No of patents to nationals	Total no of patents
1.	Food, bev. & tobacco (20, 21, 22)	A21-A24	142	17	159
2.	Textile (23)	D01-D07	635	106	741
4.	Paper**	D21, Part of B31 and B65	44	1	45
5.	Metallurgy (34)	C21-C23	407	48	455
6.	Machinery non-electrical (35, part of 36)	F01-F41 B01-B44 (exc. B29) B65-B68	4471	392	4813
7.	Electrical machinery (part of 37)	H01-H05	1408	40	1448
8.	Transport equipment (38)	B60-B64	630	51	681
9.	Instruments (part of 36)	G01-G12	1227	256	1983
11.	Chemical industry (31,32)	C01-C14 exc. C03, 04	3902	390	4292
12.	Rubber** (30)	129	25	1	26
13.	Minerals* non metallic (33)	C03, C04	180	18	198

* The totals and distribution between nationals and foreigners estimated from the sample as described above in the text concerning French patent data

** Due to a small number of observations in the sample, the whole population in the given classes counted.

Canada.

The sample used for analysis of Canadian patent data covered twelve randomly chosen weekly issues of the Patent Office Record amounting to the total of 5857 patents for the year 1967.[1] Due to the fact that patents to Canadian inventors represent only some five percent of the total of yearly awarded patents, the size of the subsample including the canadian inventors only is more important. It was 280 patents, i.e., 4.78% of the total. The corresponding percentage of the total number of patents awarded in 1967 was 4.88% which indicates a difference of 2%, which we found to be an acceptable error. As for the distribution in the groups of industries, the sample largely satisfied the minimum level requirements mentioned in footnote no. 6 p.

Unclear cases were classified, when possible, by the industry to which the firm which was proprietor of the patent belonged; when this criterion could not be applied, the class of the technically most closely related industry was employed. Cases where neither of these criteria applied were eliminated (715 patents by foreigners and 66 patents by Canadians were dismissed). Due to the logical differences between the principle of Canadian patent classification and the ISIC, the distribution we arrived at is to be regarded with a great caution and should not be taken as more than an educated guess of the actual numbers which simply do not exist and can-

1 Canada, Commissioner of Patents, The Patent Office Record, vol. 95, nos 1, 6, 13, 15, 20, 25, 29, 33, 37, 44, 46, 51. Patent Office, Ottawa, 1967.

not be reconstructed from the Canadian patent statistics.[1]

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1 The closest alternative data source, the result of a survey published by O. Firestone has potentially greater coverage of Canadian inventors and better assignment of industry groups. However, for our purposes, these advantages are offset by the relatively low response rate and by the period covered (1957-1963). The correlation of our distribution with that given by Firestone was acceptable, $R^2 = 0.92$. Firestone's data are in Table 43 of his book. O.J. Firestone, Economic Implications of Patents, University of Ottawa Press, 1971.

Table 4.

Conversion of the ISIC groups in classes of Canadian Patent Classification and the estimated distribution of patents for 1967.

No	Industry group (ISIC)	Canadian classes*	No of patents to foreigners	No of patents to nationals	Total no of patents
1.	Food, beverage tobacco (20,21,22)	17,99,107,131,146, 203,130(28-51,60), 200(21-30),201(82), 215(12-49),217(10, 14,17,19)	394	17	412
2.	Textile (23)	8,19,28,66,87,139, 118	490	13	503
4.	Paper (27)	9,92,129,156,93, 154,(99,133)	381	30	411
5.	Metallurgy (34)	22,38,53,75,148, 149,39,80,117(52-58,75-84,118,157-159),204(10-77,83-88)	676	35	711
6.	Machinery non-electrical (35, part of 36)	1,7,10,15,16,21, 29,30,34,37,48,51, 55,56,59,60,64,67, 70,74,77,78,76,81, 82,85,86,90,91,98, 100,103,109,110,112, 113,121,122,126,133, 137,138,140,141,147, 151,153,158,159,163, 164,170,183,185,187, 190,192,193,197,198, 205,211,212,214,230, 242,243,248,249,251, 254,257,259,262,268, 269,271,275,285,284, 292,294,299,302,308, 237,241,225,235,354	4173	277	4537
7.	Electrical machinery (Part of 37)	13,62,65,191,236,240, 290,306,309,310,313, 315-323,326-333,336-340,343,347,350-353-355-357,348	4546	221	4767
8.	Transport equipment (38)	104,105,114,115,123, 180,184,188,152(1-38),213,258,267,278, 238,246,280,293,295, 296,298,301,303,305, 244	654	56	719
9.	Instruments (Part of 36)	33,50,58,73,88,95, 116,117(2-25),150, 234,324,265,352	1187	48	1235

* Numbers in paranthesis indicate the subclasses of respective classes.

No	Industry group (ISIC)	Canadian classes*	No of patents to foreigners	No of patents to nationals	Total no of patents
11.	Chemistry (31,32)	6,18,23,31,32, 42,44,52,71,96, 127,134,195,202, 252,253,260,400, 401,154(exc. 99, 133),204(exc 10-77,83-88),361(22-24,27,29,34),196, 167	7718	156	7874
12.	Rubber (30)	157,154(13-24,55-76,98,104-106,132, 139,140),152(39-193)	178	9	186
13.	Mineral products (33)	4,25,49,125,261, 117(128,162),189, 51(293-309,282, 283,14-25)	399	17	416

* Numbers in paranthesis indicate the subclasses of respective classes.

Japan.

The source of patent data for Japan was the Statistical Report of Industrial Property (1971)[1], giving the number of patent applications broken down by major industries and by national and foreign inventors for 1968. However, a detailed break down of patent applications versus patent issued by industries is not available. Therefore, to obtain the distribution of patents issued by industries, to national and foreign inventors respectively, the average percentage reflecting the total numbers of applications to granted patents was taken separately for the two groups of inventors and the number of applications by industry was reduced by the two respective factors. The following table contains the estimated distribution of patents aggregated to given broad industry groups i.e. to the lowest available level.

1 Ministry of International Trade & Industry, Patent Office, Statistical Report of Industrial Property (1971), (MITI, Tokyo), Table 4, 17, I have received this report directly from the Patent Office of the Ministry of International Trade & Industry, Tokyo. Although it is written in Japanese, there are captions, numbers and titles given in English. This is likely to be the most comprehensive statistical document available, at least partly, in English.

Table 5.

Conversion of ISIC groups in classes of Japanese patent classification and the estimated distribution* of patents for 1968.

No	Industry group (ISIC)	Japanese classes*	No of patents to foreigners	No of patents to nationals	Total no of patents
1.	Food, Beverage tobacco (20,21,22)	34-38	95	454	549
2.	Textile, Apparel,** Furniture, Paper, Leather products (23,24,29,27, 28,25,26)	39-48,93-95,117-135	1059	2435	3494
5.	Metallurgy (34)	10,12,21	521	1033	1554
6.	Machinery non electrical (35, part of 36)	55-62,96-101, 105-113	2114	3360	5474
7.	Machinery elec ** and instruments (37, part of 36)	49-54,63-76, 102-104,114-116, 136	1726	5052	6778
8.	Transport equipment (38)	77-86,89-90	495	863	1358
11	Chemistry and** allied products (31,32,30,33)	9-31 (except 10,12, 21)	2966	3860	6826

* The estimation was limited to elimination of patents for agriculture from the broader Japanese industry no 1, elimination of patents for construction from the broader Japanese total for transport & construction and extraction of patents for metallurgy from the broader total for chemistry. However, the totals were actual numbers given by Japanese patent office in the document Statistical report, op. cit.

** These industries are an aggregation of several industries as can be seen from the accompanying ISIC classes This aggregation was necessary to reconcile the patent, R and D and Industrial Production data.

Sweden.

The data available for compilation of patents issued by the Swedish patent office were for 1966 only. However, the comparison of the total figures available from BIRPI tables for 1966 and 1967, enabled us to apply the distribution of patents issued to nationals and foreigners found for 1966 within individual classes to the totals of the respective classes given for 1967. This may, admittedly, lead to some error because the ratio of patents issued to nationals/total no of patents, changed slightly from 0.209 in 1966 to 0.188 in 1967. The alternative solution, to use the 1966 numbers, would have lead to a greater error because all totals would have been biased downward.

As for the sampling procedure, the sample size was 1125 observations from six randomly chosen issues of the official patent bulletin.[1] As there was greater variability in the coverage of individual classes and in the total number of patents issued from period to period, we have taken the ratio of patents issued to nationals/total patents issued, for every industry and applied this ratio to the industry totals where they were available from BIRPI.[2] In the case of industries for which the totals were not available because their definition did not coincide with one of the main international patent classes represented in BIRPI tables, we extrapolated the sample's figure by a factor of

$$8.274 = \frac{\text{Total of patents issued.}}{\text{No of patents in the sample}}$$

1 Svensk Tidskrift för Industriellt Rättsskydd, 1967, Following issues, identified by the date of publication, were included in the sample: 8/23/1967, 9/20/1967, 11/15/1967, 2/8/1967, 5/10/1967, 4/5/1967, and 4/19/1967. The total no. of patents included in this sample was 1125.

2 Industrial Property-Annexe, op. cit., Chart III, p. 11.

The following table contains the conversion from the classes of the ISIC to the corresponding Swedish patent classes and the estimated frequency distribution of patents.

Table 6.

Conversion of the ISIC groups in classes of Swedish patent classification and the estimated distribution of patents for 1967.

No	Industry group (ISIC)	Swedish classes	No of patents foreigners	No of patents to nationals	Total no of patents
1.	Food and tobacco (20,21,22)	2,53,66,79	70	24	94*
2.	Textile (23)	8,25,29,52,73, 76,86	9	395	404*
3.	Cloth, footwear, leather (24,29)	3,33,41,71	35	292	277*
4.	Paper & all. (27)	54,55	81	106	187*
5.	Metallurgy (34)	18,40,48	14	368	382*
6.	Machinery non-electrical (35, part of 36)	1,4,7,11,13,14, 15,17,24,27,31, 36,35,38,39,43, 46,47,49,50,59, 67,69,70,72,75, 80,82,81,87,88, 60,67	728	1911	2639
7.	El. Machinery (Part of 37)	21	199	1431	1630
8.	Transport equipment (38)	20,56,62,63,65	91	430	521
9.	Instruments (Part of 36)	42,51,57,74,83	119	468	587
11.	Chemistry (31,32)	6,10,12,16,22,23, 26,28,78,85,89	91	1042	1133
12.	Rubber (30)	39	41	323	369
13.	Mineral Products (33)	32,80	66	149	215

* The totals were taken directly from Industrial Property, op. cit., Chart III, p. 11.

C.2. Other variables.

The major empirical problem one encounters in collecting data for international cross-section analysis on a two and three digit manufacturing industry level is the heterogeneity of national economic statistics. This problem becomes more difficult as we increase the number of variables of the sample because unfortunately only few of the variables from published statistics are directly comparable, be it for reasons of different systems of classification, incompleteness of data on international differences in the collection and presentation of statistical material.

In order to overcome these problems, we have chosen the only existing "ready made" comparable international statistics of interest to our study, the international R and D statistics published by the OECD [1] as a framework to which we have adjusted other data. The first, and so far, the only year covered by these statistics was 1963 [2] which thus became the base period of our study and other data on explanatory variables were collected for the same year. The system of classification used is the International Standard Industrial Classification, but due to some incomparabilities and lack of data on some variables the break down used is less detailed than the ISIC and the correspondance

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1 OECD, International Statistical Year for Research and Development. Volume 2. Statistical Tables and Notes, (OECD - Paris, 1968).

2 The statistics for 1963 include for Germany and Sweden data for year 1964.

is rather broad.

The data originally given in national currencies were expressed in US $ at the official exchange rate effective at the time. The description of manipulation of data where it was necessary and all other details concerning the data are given in notes below the tables.

The R and D statistics on the business enterprise sector include the following data of interest to our study:

1) Intra-mural expenditures for R and D broken down into industries and countries, source of funds and type of cost.
2) Expenditure on R and D, broken down into type of activity (basic applied research and development), industry and country.
3) Extra-mural expenditures for R and D, broken down into industry, country and categories of recipients.
4) Total expenditure on R and D, broken down into industry and country.
5) Manpower working on R and D, broken down into industry, country and type of manpower.

The second major source of data is the UN publication. The Growth of World Industry 1968,[1] which contains data on the following indicators of industrial production:

1) Number of establishments.
2) Number of persons employed and salaries.
3) Gross output at current prices.

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[1] United Nations, The Growth of World Industry 1968 Edition, (United Nations, N.Y., 1970).

4) Value added at current prices.

5) Gross fixed capital formation - (Machinery and equipment at current prices).

6) Index numbers of industrial production (related to the value added at current prices in most cases).

The period covered by the industrial statistics varies from country to country; for each country however, data for 1963-4 and the index numbers for the period 1958-1967 are available. The data are aggregated on two (occasionally three) digit level industry groups according to ISIC.

The source of information available for exports and imports is the OECD statistics on international trade, [1] from which we have all the necessary statistics for the periods after 1963, broken down by product groups and countries of origin and destination. Although those statistics are classified according to the international trade classification system SITC (revised), the published statistics lend themselves to aggregation according to ISIC used in our study.

The source of data for the patenting ratio G was Industrial Property. [2] The education variable was taken from OECD statistics. [3]

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1 OECD, Foreign Trade Statistics, Series B. Commodity Trade, (OECD Paris, 1963).

2 Industrial Property, Annexe, (1968), op. cit., Chart 1.a.

3 OCDE, Statistiques relatives à la structure de la main-d'oeuvre par profession et par niveau d'éducation dans 53 pays, (OCDE, Paris, 1969).

The source of data for the concentration variable is the study by J.S. Bain,[1] which contains internationally comparable data for size distribution of plants in manufacturing industries. The data for Germany and Belgium, which were not included in Bain's study, were calculated from the respective national statistical year books.

Thus, in summary, the data for explanatory variables are available for a cross-section of national observations on R and D and main economic indicators of industrial activity and international trade for the level of aggregation corresponding to the groups of industries presented in the tables (1-2).

However, due to national pecularities, exceptions and special cases, it was not always possible to find data for all variables and all industries in the case of every country. Therefore, the sample of observations used for empirical analysis had to be reduced in cases where one of the independent variables used in a given regression was not available for one or several national industries.

In some cases it was necessary to proceed to a further aggregation of industries when an observation was not available in disaggregated form. Adjustments made are described in notes accompanying the following matrix of data on predetermined and dependent [2] variables.

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1 / J.S. Bain, International Differences in Industrial Structure, (New Haven and London, Yale University Press, 1966).

2 For the print-out of patent data see note (h), following the tables.

Table 1 Variables.

Country, industry (notes)	h i	P (g),(h)	P (g),(h)	NRA (f)	USIA (f)	MRAD (f)	W 10[6] $US/manyears	ID (f)	D/S (f)
	1011	86	87	0 0	0 0	585 40	0 0061	585 40	0 0065
	1021	372	442	0 0	0 0	2112 25	0 0028	2442 23	0 0015
	1041	424	581	0 0	0 0	714 51	0 0030	714 51	0 [illegible]
	1051	320	338	0 0	0 0	8158 79	0 0031	8158 79	0 [illegible]
Germany	1061	2554	3820	0 0	0 0	27930 83	0 0025	27930 83	0 [illegible]
	1071	2313	3551	0 0	0 0	38632 16	0 0034	38632 16	0 0344
	1111	1927	1620	0 0	0 0	39607 12	0 0028	[illegible]	0 [illegible]
	1121	109	89	0 0	0 0	2005 58	0 [illegible]	2005 58	0 0128
	1131	182	217	0 0	0 0	1117 11	0 0031	1117 11	0.0023
	2011	112	17	168 53	2 23	26[illegible] 09	0 [illegible]029	15[illegible] 56	0 [illegible]
	2021	636	106	37 08	5 61	118 04	0 0019	116 95	0 [illegible]
	2041	44	1	40 05	3 68	78 28	0 0020	[illegible]39 23	0 [illegible]28
	2051	407	48	69[illegible] 25	[illegible]3 12	1733 23	0 0020	[illegible]	0 [illegible]
Belgium	2061	4171	342	381 83	[illegible] 74	1632 27	0 0013	125[illegible] 43	0 [illegible]
	2071	1408	40	592 73	1 9 19	2209 68	0 [illegible]27	1615 95	0 [illegible]
	2081	630	51	26 03	1 25	265 15	0 [illegible]025	2[illegible] 11	0 [illegible]
	2111	3902	390	2677 62	4[illegible]3 55	[illegible]	0 [illegible]23	171[illegible]	[illegible]
	2121	25	1	35 50	3 82	[illegible] 72	0 0029	[illegible]	0 [illegible]
	2131	180	18	276 61	[illegible] 17	593 32	0 [illegible]016	316 91	0 [illegible]
	3011	426	161	458 63	1 1 01	772 23	0 0[illegible]78	313 59	0 [illegible]
	3021	1094	166	1591 26	1[illegible]5 36	2309 2	0 0021	705 85	0 [illegible]
	3041	192	81	125 99	9 99	188 99	0 0037	62 53	0.[illegible]
	3051	906	111	1232 19	2 6 67	37[illegible]7 19	0 0030	2525 [illegible]	0.[illegible]53
France	3071	3709	1515	5969 30	1401 81	21752 88	0 [illegible]58	15733 57	0 [illegible]459
	3081	1707	1222	[illegible]1 97	9 0 20	21759 72	0 0031	16821 75	0 [illegible]299
	3111	[illegible]	1077	5855 02	14 1 51	11115 49	0 0016	520[illegible]	[illegible]
	31[illegible]1	165	67	113 [illegible]	[illegible] 39	775.79	0 0 19	362 63	0 [illegible]27
	3131	532	184	630 34	1 3 04	1213.82	0 0032	613 48	0 0025
	4011	394	17	128 77	[illegible]1 52	429 10	0 [illegible]15	[illegible] 52	0 [illegible]
	4021	490	13	37 69	6 83	238 82	0 [illegible]038	291 12	0 [illegible]12
	4041	381	30	297 56	1 2 39	[illegible] 79	0 0077	352 23	0 [illegible]23
	4051	676	35	622 72	1 [illegible] 59	1113 52	0 0015	4[illegible] 80	0 [illegible]22
Canada	4061	11[illegible]3	277	1[illegible]5 25	[illegible]	11[illegible]2 [illegible]	0 [illegible]58	[illegible] 75	[illegible]
	4071	4546	221	397 84	1[illegible]2 39	3143 60	0 0043	2745 76	0 0220
	4081	654	56	20[illegible] 68	[illegible] 01	1520.28	0.[illegible]168	15[illegible]3 59	0 [illegible]
	411[illegible]	7718	156	1093 [illegible]9	9 8 79	2515 27	0 [illegible]15	142[illegible] 57	0 [illegible]1
	4121	26	9	53 [illegible]	[illegible] 55	162 [illegible]	0 [illegible] 17	11[illegible] 77	0 [illegible] 25
	4131	399	17	121 42	2 27	1[illegible]5 84	0 0058	[illegible]9 42	0 [illegible]
	7011	[illegible]5	454	1977 16	8 7 55	6035 67	0 0[illegible]58	40[illegible] 50	0 [illegible]
	7021	1059	2435	30[illegible]7 18	8 0 61	11656 8[illegible]	0 [illegible]	8[illegible] 55	0 [illegible] 11
	7051	521	1033	4043 17	1114 98	11500 28	0.0010	7457 11	0 [illegible]74
Japan	7061	2114	3360	2[illegible]15 03	7 8 83	16[illegible] 72	0 [illegible]	142[illegible]	0 [illegible]
	7071	17[illegible]6	5052	16169 [illegible]	53[illegible]6 92	455[illegible]	0 [illegible]	2733. [illegible]	0 [illegible]
	7081	495	865	2566 14	8[illegible] 24	13512.13	0 0010	10045 38	0 [illegible]
	7111	2966	3860	17755 13	62[illegible]6 89	45[illegible]4 13	0 [illegible]	27[illegible]3 93	0 [illegible]82
	8011	70	24	83 29	[illegible]1 78	293 32	0 [illegible]038	20[illegible] 03	0 [illegible]
	8021	395	9	38 54	[illegible]5 62	173 53	0.0039	134 99	0 0049
	8041	106	81	274 58	182 57	604 90	0 0030	420 31	0 [illegible]32
	8051	368	14	391 12	211 45	1182.38	0.[illegible]44	788 25	0 [illegible] 52
	8061	1911	728	249 27	164 23	3112 88	0 0045	2865 60	0 [illegible]127
Sweden	8071	1431	199	333.71	221 37	4303 66	0 0033	3069 54	0 [illegible]317
	8081	430	91	260 72	171 09	4410 16	0 0052	4140 43	0 [illegible]
	8091	468	119	26 94	17 59	97 99	0.0060	71 [illegible]	0.[illegible]03
	8111	1042	91	480 68	315 46	1497 65	0.0048	1016 96	0 0133
	8121	323	41	11 98	7 84	109 99	0.0065	98 00	0 0061
	8131	149	66	73 25	48 28	219 99	0.0065	146 73	0.0030

Table 2

Country, industry (notes)	h i	Variables EXP064 10^6 $US	IMP064 10^6 $US	[illegible] ( )	E (r)	S 10^6 $US	I 10^6 $US	[illegible] (e)	C [illegible]
Germany	1011	279	2699	[illegible] 29	5 13	12075	491	[illegible]	25.5
	1021	925	1341	[illegible] 29	5 13	8975	252	5 [illegible]	20.3
	1041	375	[illegible]	[illegible]	5 13	[illegible]	[illegible]	5 [illegible]	[illegible].5
	1051	1531	1570	0 29	5 13	[illegible]	655	5 [illegible]	[illegible].1
	1061	6863	1332	[illegible]	5 13	2112[illegible]	1237	[illegible]	[illegible]
	1071	1782	5[illegible]	0 29	5 13	[illegible]	251	8 66	[illegible]
	1111	2153	1058	0 29	5 13	[illegible]	922	12 [illegible]	[illegible]
	1121	1[illegible]	[illegible]	0 29	5 13	1125	72	[illegible]	[illegible].4
	1131	354	250	0 29	5 13	3123	257	[illegible]	[illegible].8
Belgium	2011	258	631	[illegible]	5 02	1320	100	5 [illegible]	11.0
	2021	568	262	[illegible]	3 02	641	67	[illegible]	2[illegible]
	2041	66	1[illegible]	[illegible]	3 02	159	26	[illegible]	[illegible]
	2051	1457	539	[illegible]	3 [illegible]	710	187	5 [illegible]	[illegible]
	2061	530	751	[illegible]	3 02	10[illegible]	—	[illegible]	—
	2071	234	2[illegible]	[illegible]	3 02	480	—	5 [illegible]	[illegible].0
	2081	432	522	[illegible]	3 02	810	—	[illegible]	[illegible]
	2111	554	490	[illegible]	3 02	700	87	[illegible]	[illegible]
	2121	31	45	[illegible]	3 02	57	2	[illegible]	[illegible]
	2131	447	292	[illegible]	3 02	340	45	3 [illegible]	25.[illegible]
France	3011	1139	1612	[illegible] 95	7 25	8211	565	2 [illegible]	11 2
	3021	693	2[illegible]	[illegible] 95	7 25	4017	[illegible]4	3 [illegible]	[illegible]
	3031	103	128	[illegible] 95	7 25	1[illegible]	146	6 [illegible]	[illegible]
	3051	1655	[illegible]	0 95	7.25	5[illegible]	491	[illegible]	[illegible]
	3071	419	387	0 95	7 25	2527	2573	11.[illegible]	[illegible].5
	3081	943	441	0 95	7 25	4950	355	[illegible]	[illegible]
	3111	1171	704	0 95	7 25	7794	—	10 [illegible]	[illegible].5
	3121	1[illegible]	13	0 95	7.25	1021	—	5 [illegible]	56.5
	3131	179	142	0 95	7.25	1763	—	6 [illegible]	[illegible]
Canada	4011	1615	675	0 97	5 19	6134	155	4 [illegible]	22.3
	4021	45	5[illegible]	[illegible] 87	5 19	1253	43	[illegible]	[illegible].5
	4031	837	[illegible]5	[illegible] 97	5 19	2323	183	3 [illegible]	[illegible]
	4051	1[illegible]	[illegible]	[illegible] 97	5 19	2265	167	[illegible]	[illegible].8
	4061	481	15[illegible]	[illegible]	5 19	2[illegible]	85	[illegible]	27.95
	4071	118	[illegible]2	[illegible] 37	5 19	1728	39	[illegible]	59.4
	4081	393	824	[illegible] 97	5.19	2868	73	5 [illegible]	—
	4111	266	570	[illegible] 87	5.19	3250	154	6 [illegible]	[illegible].0
	4121	44	12	[illegible] 87	5 19	407	15	4 [illegible]	8[illegible].4
	4131	17	151	[illegible] 97	5 19	820	49	4.52	[illegible]
Japan	7011	31[illegible]	1599	[illegible] 24	1.78	9[illegible]31	555	10 [illegible]	6.[illegible]
	7021	1502	89	24	1 78	16037	[illegible]	[illegible]	—
	7031	967	4[illegible]	[illegible] 24	1 78	7576	841	[illegible]	48.9
	7061	717	570	[illegible] 24	1 78	8251	525	23 [illegible]	—
	7071	920	181	[illegible] 24	1.78	6209	328	23 [illegible]	43.5
	7081	839	102	0 24	1 78	5881	347	23 [illegible]	57.[illegible]
	7111	805	279	[illegible].24	1 78	10238	1111	14 [illegible]	38.2
Sweden	8011	97	427	0 51	5.21	2300	—	4 56	—
	8021	49	249	0 51	5 21	369	—	5 04	11.2
	8031	370	[illegible]	0 51	5.21	1220	—	7 [illegible]	41.2
	8051	359	351	0 51	5.21	112[illegible]	—	[illegible]	53.3
	8061	690	533	0 51	5 21	2205	—	5 [illegible]	—
	8071	218	251	0 51	5 21	673	—	5 [illegible]	—
	8081	458	388	0 51	5 21	1350	—	8 01	84.[illegible]
	8091	20	73	0 51	5.21	54	—	8 01	—
	8111	141	674	0.51	5.21	748	—	7 [illegible]	24.0
	8121	27	39	0 51	5 21	141	—	4 [illegible]	73.8
	8131	27	63	0 51	5.21	452	—	8 06	7.7

NOTES

a) Germany: Industry 09 included in 07, Industry 08 in 06 because of aggregation problems.

b) Belgium: Industry 09 left out because of unavailable data for industrial production.

c) France: Industry 06 and 09 left out because of aggregation problems which made it impossible to arrive at a comparable industry definition for R and D and industrial production data.

d) Canada: Industry 09 left out because of aggregation problems.

e) The growth rate of value added (VA) calculated by the terminal year method:

$$\dot{VA} = \left[\left(\frac{\text{Index 1963}}{\text{Index 1958}}\right)^{1/5} - 1\right] \times 100,$$ using Index numbers of value added in respective industries.

f) Manpower in Full-Time equivalent numbers.

g) Data given in original units (see List of variables).

h) Due to aggregation of several industries, described in notes (a) to (d), the patent data aggregated accordingly are presented in numbers actually used coumputer runs.

APPENDIX D

Second order conditions for maximum profit.

Lagrangian function for the case of two R and D Labour categories:

$$L = P\cdot r - \delta_1(RD-I)_1^{\gamma_1} - \delta_2(RD-I)_2^{\gamma_2} + \lambda P - \lambda b(RD-I)_1^{b_1}(RD-I)_2^{b_2} \qquad (1)$$

Conditions of the 1st order:

$$L_1 = \frac{\partial L}{\partial P} = r + \lambda = 0 \qquad (2)$$

$$L_2 = \frac{\partial L}{\partial (RD-I)_1} = -\delta_1(RD-I)_1^{(\gamma_1-1)}\cdot\gamma_1 - \lambda b\cdot b_1(RD-I)_1^{(b_1-1)}(RD-I)_2^{b_2} = 0 \qquad (3)$$

$$L_3 = \frac{\partial L}{\partial (RD-I)_2} = -\delta_2\gamma_2(RD-I)_2^{(\gamma_2-1)} - \lambda b(RD-I)_1^{b_1}\cdot b_2(RD-I)_2^{(b_2-1)} = 0 \qquad (4)$$

$$\frac{\partial L}{\partial \lambda} = P - b(RD-I)_1^{b_1}\cdot(RD-I)_2^{b_2} \qquad (5)$$

lead to the following result:

$$(RD-I)_m = r\cdot P\cdot \frac{b_m}{(1+\frac{1}{C_{mm}})W_m} \qquad (6)$$

The conditions of the 2nd order for maximum require that the bordered Hessian determinant $\bar{H}$ has the sign $(-1)^n$ (n = 3, i.e. three variables P, $RD-I_1$, $RD-I_2$, the principal minor of order (m + n - 1) = 3 should have a sign positive, and successively smaller principal minors should alternate in sign.

The bordered Hessian determinant:

$$|\hat{L}| = \begin{vmatrix} 0 & g_1 & g_2 & g_3 \\ g_1 & L_{11} & L_{12} & L_{13} \\ g_2 & L_{21} & L_{22} & L_{23} \\ g_3 & L_{31} & L_{32} & L_{33} \end{vmatrix}$$

The partial derivatives are:

$L_{11} = 0 \quad L_{12} = 0 \quad L_{13} = 0$

$L_{21} = 0 \quad L_{22} = \delta_1\gamma_1(RD-1)_1^{(\gamma_1-2)} \cdot (b_1 - \gamma_1) \quad L_{23} = 0$

$L_{31} = 0 \quad L_{32} = 0 \quad L_{33} = \delta_2\gamma_2(RD-1)_2^{(\gamma_2-2)} \cdot (b_2-\gamma_2)$

$g_1 = 1$

$g_2 = -b \cdot b_1(RD-1)_1^{(b_1-1)} \cdot (RD-1)_2^{b_2}$

$g_3 = -b \cdot b_2(RD-1)_1^{b_1} \cdot (RD-1)_2^{(b_2-1)}$

Substitution of the partial derivatives into the Hessian determinant gives the following determinant:

$$\left|\hat{L}\right| = \begin{vmatrix} 0 & 1 & g_2 & g_3 \\ 1 & 0 & 0 & 0 \\ g_2 & 0 & L_{22} & 0 \\ g_3 & 0 & 0 & L_{33} \end{vmatrix} = 0\,[\ ] - L_{22}L_{33} + g_2[0] + g_3[0] = -L_{22}L_{33}$$

The largest principal minor $M_{33} = -L_{22}$

The last principal minor $M_{22} = -1$.

The sufficient condition for the solution to be maximum require that

$$-L_{22} \cdot L_{33} < 0, \quad -L_{22} > 0 \quad \text{and} \quad -1 < 0$$

Proceeding from the last condition which is evidently satisfied $(-1 < 0)$ we pose $-L_{22} > 0$: (or $L_{22} < 0$)

$$\delta_1\gamma_1(RD-1)_1^{(\gamma_1-2)} \cdot (b_1-\gamma_1)\Big| < 0$$

The specification of parameters in the text leads to

$$b, b_1, b_2 > 0, \quad \delta_1, \delta_2, \gamma_1, \gamma_2 > 0, \Big(\quad (RD-1)_1^{(\gamma_1-2)} \ldots > 0.$$

The maximum condition $L_{22} < 0$ can be satisfied only if $b_1 - \gamma_1 < 0 \Rightarrow b_1 < \gamma_1$.

The last condition requires that the $-L_{22}L_{33} < 0$.

From above we know that $L_{22} < 0$. Therefore $-L_{22} > 0$ and consequently $L_{33} < 0$, which implies again $b_2 < \gamma_2$. It follows that for a maximum to occur the respective coefficients of the production function b_m in general must be smaller than the values of the coefficients γ_m. This condition implies for the limiting case of the perfectly elastic supply of labour ($\gamma_m = 1$) $b_m < 1$. In the more likely situation of the less than perfectly elastic labour supply, $\gamma_m > 1$ and $0 < b_m < \gamma_1$.