Technical change in the metal products industry : an analysis from the production of hydraulic turbines

Juan J. Jardon U. *

UNAM, and RIC, E-mail: 100774.2610@compuserve.com and jjju@servidor.unam.mx

Communication to

European Meeting on Applied Evolutionary Economics

7 - 9 June 1999, Grenoble, France

Organised by the Institute for Energy Politics and Economics
Organisé par l'Institut d'Economie et de Politique de l'Energie /
IEPE, BP 47, 38040 Grenoble Cedex 9, France

And the INRA-Unit of Sociology and Economics of Research and Development
Et l'unité Sociologie et Economie de la Recherche Développement de l'INRA
INRA/SERD, BP 47, 38040 Grenoble Cedex 9, France

Abstract

This article analyses those factors underlying the technical change of hydraulic turbines and the metal products industry within an evolutionary framework, looking at two aspects: industrial tree turbines constituted by processes, equipment and materials (PEM), and the evolution of each of these measured through a functional techno-economic Index. Technical and economic factors are analysed and identify the ruling variables. These factors come from the evolution of the turbines since the beginning of the century, from the data of the main turbine producers, and from time series of sectors such as the metal products industry, and the machinery and steel industry. The conclusive facts are: first, size and potency together with intensity of the metal cutting operations and the welding compound, on the technical side, and, the price of steel on the economic side, are the major determinants of the technological change. Secondly, we conclude that there are potential variables such as the intensity of design processes and soldering operations (which impact the process of metal cutting and the process of forming) and new materials (based on firmer alloys, soldering feasibility and mechanisation capacity), all of them may come to replace the actual technological regime for a certain period.

1. Introduction

Within the evolutionary perspective, the concept of technological trajectories has been central to differentiate it from equilibrium and optimisations. In addition, it has also been a coherent way to analyse firms in the market within a certain time framework. There have been several studies devoted to the analysis of technological trajectories in industry. These analyses have in many cases resulted from industrial typologies in which one of the variables of the typology has been the determinant of the trajectory. Both sectorial and specific analyses have been made. Within the former, Pavit *et al*’s typology of industries (1984) and the variables determining the technological trajectory of these industries have laid the foundations for other studies.[1] It is used in particular to typify a country’s industry and to obtain an industrial and technological profile so that the foundation for specialisation can be understood and national and industrial policies can be designed. The latter studies have been concerned with analysing a specific industry in greater detail and with analysing the determinant variables in the technological trajectory. The objective of these analyses has been much more biased toward understanding the industry’s future and has become a type of forecasting by analysing industry’s most

[1] It is difficult to mention all theoretical and applied works which has helped to understand the technical change process. However must be mentioned to this respect Rosenberg (1979,1983), Nelson and Winter (1977,1982) Dossi (1982,1988), Freeman (1974,1982,1988), Abernathy and Clark (1985), Abernathy and Utteback (1978), Utteback and Burack (1975), Griliches (1990, 1995), Patel and Pavit (1995), Scherer (1982). A taxonomy of Mexican industry based on Pavit approach is given by Dutrenit and Capdeville (1993).

important components. Sahal (1985a, 1985b) has pioneered this kind of analysis by identifying technological avenues.[2]

In this second aspect, the approach, based on a techno-economic function, has managed to achieve a certain degree of consistency in evaluating industrial change. These models, however, must be based on a broader model in order to make an economy's industrial context as a whole more coherent. That is why it is considered that the technometric function should be complemented by the industrial tree concept (Rp) in such a way that industry's technoeconomic evolution may be based on a concept of a elemental industry (where the word elemental refers to production's basic components). An industrial tree constituted by processes, equipment and materials can thus be referred to as a basis to get production going.[3]

Industrial tree approach permits us to evaluate more accurate where the technical change take place since it permit organise production activity and technology activity. Technical changes can happen before production, that is, when a new conception or a upgrade of something, an equipment, a devise can be conceive. But also technical change can take place in the production process itself, that is, all the changes required in the production to carried out the new production. In this way, any technical change can be located by means of organising both design process and production and sale process. Industrial tree means that physical production have to do with the transformation of raw material and in order to transform it, it is required to look at the process, the equipment (to transform the row material), and material itself. In this way, any technical change can be more precisely localised by looking how , when, and how much a process change or do not change, how a equipment is transformed or do not, and how materials are substituted or improved or do not. Industrial tree approach is a powerful tool to look how production is carried out. It is like to look production inside and not around it. It is like to see how row material are changing physically and not just in terms of value. Certainly the way how have been seen changes in production and changes in productivity have been one of the real problem. Obviously, productivity changes have to do with values where assumption have done in order to interpreted them in physical terms. So industrial tree is used here to understand the problem the other way round.

---

[2] Several analysis have discussed how to measure technical evolution. For example Martino (1985), Ayres (1985), Dodson (1970,1985), Esposito (1993), Basberg (1987), Alexander and Mitchel (1985), Gordon and Minson (1981), Zaidam and Cevidalli (1989).

[3] This analysis is in some way similar to the product value chain. However there are important differences since in the industrial tree raw material transformation is analysed in terms of how physical inputs are transformed in outputs by means of the process, equipment's and materials used in the transformation. The difference to the value chain methods is that it analyses the input and

From a technological perspective, an industrial tree allows a more detailed analysis of technological change in the transformation of the product, i.e., through the processes involved as well as the equipment and raw materials used. Price mechanism is thus isolated from the outset in order to analyse the probable existence of autonomous factors.[4]

In the past 20 years different approaches have been used to analyses technological change. Many questions have been answered and much has been learnt however still many issues remain addressed. One in particular is that of the process of diffusion of technological change, as has been indicated in various studies (see for example Nelson 1994, Jardon 1996, Lissoni and Metcalfe 1996). Specifically, the study of the diffusion process permits the understanding of the condition of the rate and direction of technical change. How innovation diffuses over industries, why certain innovation goes faster than others, what sectors are more akin to certain innovations than others, what is the impact of innovations on employment, why industries do not disappear and why firm survive, what are the common subject in industries and firms, These are some of the questions which need to be answered more fully.

The metal mechanic industry is an industry with a long history where we can learn much from studying and understanding its transformation from last century until now.[5] It is furthermore, an industry, where today many changes take place in process, the equipment and materials of final and intermediate products and services of every day life. It is also an industry still in process of deep transformation. Obviously, other industries and services have developed over the last decades but all the new industry and/or services are concerned in some way with the metal mechanic industry.

The argument that follows is that by studying the metal mechanic industry not only can we learn about the process of technical change but we can also have a better understanding of the diffusion process and future developments in other sectors of the economy.

The objective of this research is the analysis of the transformation of the process, equipment and material of the metal industry in order to assets radical and incremental technological changes and at the same time evaluate the diffusion process.

Because the metal mechanic industry is so vast, one way to measure the rate and direction of technological change is : a) a simplification the main features of the <u>process</u> <u>equipment</u> and <u>materials</u> (P,E,M) of the production of hydraulic turbines b) measuring the process, equipment and materials by means of techno-economic index.

---

output in value terms. In some way the industrial tree is a complement to the value chain *approach*. See Jardon (1997).

4 Autonomous forces here are understood as other forces neither market to provoke technical change.

5 See for example Patel and Pavit (1994) for metal mechanic and Bourgeois (1998) for the processing industry.

The first is based on the industrial tree concept (Jardon, 1997, 1998) by means of ordering the main process, equipment and materials (P,E,M) needed for production of turbines. The resulting industrial tree represent de group of variables which can illustrate the main changes of the industrial transformation. In other words, the variables of the industrial tree indicate where the most significant changes from the design to the production an sale have occurred. At the same time, these variables provide the information required to evaluate technological changes more accurately.

The second aspect take into account the variable of the industrial tree in order to built a techno-economic index which suggest what kind of variable (technical and economic) exert a more important influence on the rate and direction of technical change. From the data of the main turbine producers, and from time series of metal products industry, and machinery and steel industry a time series were built since 1930s to 1990s in order to asses a functional techno-economic index.

This piece of research provides five sections. In the follow section the methodological basis with which a specific case of turbine production is analysed is constituted by a functional technometric index with which to measure technological change in the framework of the conception and development of an industrial tree. In the third section, the industry producing hydraulic turbines is assessed by quantifying the functional techno-economic index in the industrial tree of turbine production and the metal mechanic industry. This has been done on the basis of data collected of the main variables analysed in the industrial tree, process, equipment and material from a technical and economic analysis The results allow us to advance in an evolutionary framework for the analysis of existing potential technological trajectories. In the fourth section the concept of latent variables is developed giving way to speculate of the future of the metal products industry. Finally, in the conclusions several aspects can be said. On the one hand, all the relevant aspects for the understanding technological change within the context of an industrial tree, the parallelism existing between turbine production and the metal-mechanic industry as a basis for analysis, and the concept of technological change on its own terms (equipment) *v*s a co-evolution of equipment and P,E,M. On the other hand, discussion of the diffusion process based on the relation between P,E,M and rate and direction of technical change as a way to understand the overall industrial economy.

2. Measuring Technological Evolution

Measuring technological evolution and explanation of the determinants of technological changes was based in the combination of an industrial tree scheme with a functional techno-economic index. The established industrial tree is the basis which reflect turbine evolution via the evolution of processes, equipment and materials (P,E,M). This form of evolution in each of these components is measured in turn by means of functional indicators which involve not only technical variables, but also economic, institutional and natural-cultural variables in each one of the processes, equipment and materials.[6]

Because of its complexities, the understanding of the evolution of technological change needs two comments regarding the analysis of the industrial tree. It is necessary, on the one hand, to simplify the industrial tree for turbine production by introducing the issue of terminal equipment duality and, on the other hand, to introduce turbine industrial tree scaling in order to interpret the scope of the P,E, M in an economy's metal mechanic industry and industrial structure. The latter is examined further in the conclusions.

Dualism in Terminal Equipment

Turbine can be considered terminal equipment, that is, not allowing a further transformation in itself and behaving as a final good. Turbines as equipment are the aim of an industrial tree and, at the same time, form the "equipment" component of the P, E, M (processes, equipment and materials) to produce turbines. That is the P, E, M are themselves part of the equipment element. This dualism enormously simplifies the analysis without reducing its strictness since the P, E, M to produce turbines do not differ from the P, E, M to produce the equipment to manufacture turbines such as machinery and the equipment required to transform material, to join metal, cutting, finishing, and transport. There will undoubtedly be differences in some cases, but in general terms whatever happens with the advances made in machinery-tools, materials, processes and economic variables will be reflected in the turbines.

In addition, it is assumed that, in contrast to other sectors, equipment faithfully reflects the processes and in evaluating the latter one indirectly evaluates the former. This is so because each process generally identifies with a piece of equipment and since it is not the case, as in other sectors, that different equipment is needed for one process only[7].

The Francis turbine industrial tree (R_f) may be determined by the following processes, equipment and materials (P, E, M):

---

[6] You are refereed to Jardon (1996) for further analysis in this subject.
[7] In other words to separate out processes according to equipment.

Processes	**Equipment**[8]	**Materials**
(P_i)	**(E_j)**	**(M_g)**
Design	Turbine	Steel
Conformation		Soldering
Mechanisation[9]		Lubricants
Finishing		Other
Transport		
Installation and testing		

In order to simplify and in view of information limitations, only one kind of equipment, one group of processes and one group of materials are considered. In the group of processes, the design process comprises almost all the turbines[10]. It is evident that there is a close relation between the design of the turbine, the generator, and the design of the project and the construction of the civil infrastructure. Conformation comprises all the processes that do not imply metal cutting process, whereas mechanisation does precisely the opposite. The former includes foundry (casting and smelting), forging, panning as well as soldering. The latter includes boring, brushing, milling, drilling, modelling and in general whatever is related to all forms of metal cutting. Both processes include placement and fixation processes as well as processes such as control and measurement. Since they are difficult to separate, it was not possible to isolate the latter two for a deeper analysis. Finishing includes thermal treatment to certain parts of the turbine as well as a treatment to avoid rusting. Transport, installation, and testing are grouped as part of the same process.

[8] The equipment required to produce a turbine is related practically to each process. Hence there is computing equipment (including here hardware and software), foundry (ovens, melting pot, forms, centrifuge), laminating and forging (laminated, rolled trens, hammers, hydraulic presses, bending machines), riveting, clinching , welding (arc, tubular), metal cutting and shaving mechanised (lathes, milling machine, planer machine, broaching machine), transporting (cranes, material hoist, truck, push, crane, industrial tractors), finishing (oventanks transporting devises). Each one of these analyses are complex because various them represent in turn subprocesses which imply different equipment. For the sake of simplicity it the hydraulic turbine was taken as equipment and at the same time as a product produced of the hydraulic industrial tree taking into account it represents well one important part of the process required to carried out production (and hence equipment).

[9] The operation represent all references of cutting, shaving, levying and every operation which imply steel wool by means of machines.

[10] By simplicity some parts of the turbine related to the regulation were not included.

Functional Technometric Index

Measuring innovative activity is based on the capture of technical and economic characteristics and events stated in the state-of-the-art as a convex surface in an *n* dimension space in which *n* is the technological, economic, cultural and natural characteristics. The proposed model is derived from Sahal's (1985a,b) and Esposito's (1993) approachs to study innovative activity characterised by a trade off among various characteristics.[11] It is well know Sahal's work calculating tech-nometric index. However because he only put emphasis in technical and scientific variables to explain rate and direction of technical change, other author like Esposito proposes to include other variables in terms of product development. The origin of these characteristics, as well as their heterogeneity, differentiate the model from these approaches since not only are technical variables included, but also economic and cultural-natural variables. These variables are applied to each of the industrial tree components, i.e., processes, equipment and materials. A total index can thus be conceived for the processes (Y_P), the equipment (Y_E) and the materials (Y_M) index. The functional techno-economic index reflects the factors determining equipment or industrial branch evolution. Each index is determined by variables corresponding to the industrial tree's process, equipment or materials (P, E, M), which can be defined by variables:

$$Y = (X_i , Z_i , W_i ,Q_i ,C_i)$$

In which X_i represents the variables with a technological basis, Z_i the variables with a scientific basis, W_i those with an economic basis, Q_i those with an institutional basis, and C_i the cultural and natural variables corresponding to the location. Only the technological, economic and natural variables (X_i , W_i ,C_i) are considered in the application of the model. Thus, according to Sahal, technological advancement is measured by the trade off between different variables, by what is gained and lost via the combination of certain variables. Each

[11] There have many researches interested in capturing technical, economic, characteristics . The measurement approaches are different. Hedonic approaches are based on utility and its relation with the product characteristic in the market . Other studies like Dodson (1970,1985) have put emphasis in the state of art as a convex surface in a space of n dimensions and where n are the technological characteristics and where the curve take the Ellipse form. The generalised distance has been developed by Mahalanobis (1930) and with the concept of discriminant function Fisher (1936) which according to Sahal both approaches are similar to his proposition of technological distances (Sahal 1985,b pag 14-15). This analogue approach, from Sahal (1985a,b, 1975)and Martino (1985), the innovativity activity can be seen as a trade off among several technological characteristic. Sahal worked with the concept of composite approach for measuring technological change based on the wholistic and holistic index. Saviotti and Metcalfe (1984), have studied the relation between methods, technical characteristic of the products and services and its relation with technological regimes.

variable can thus have different attributes, such as design, performance, skill, experience, specialisation, etc.[12]

The function regime can be obtained when two sets of variables are grouped, each representing different moments, but having the same objective. A technometric function can thus be obtained dependent on the number of characteristics (*n* distinctive variables) as well as on the suggestive coefficients that harmonise the distribution. If the analysed variables correspond to a technological evaluation, this regime can be expressed as:

$$Y = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \ldots\ldots\ldots\ldots + \alpha_n X_n$$

in which Y is the technological parameter obtained from applying values α_1, α_2, α_3,....... α_n, , given the regime's variables $X_1, X_2, X_3, \ldots\ldots\ldots\ldots + X_n$. When the weight is obtained through the relation of the total variation and that of each group of variables, the index equals one. In other words a functional technometric index can be find which can indicate which variable have a stronger influence in technical change.

When distinctive economic variables are applied, the equation will be:

$$Y_w = \alpha_1 W_1 + \alpha_2 W_2 + \alpha_3 W_3 + \ldots\ldots\ldots\ldots + \alpha_n W_n$$

In this case W are the economic variables as price, competitive markets, vertical growth, management capabilities, risk. It is possible to obtain a hybrid index by combining technical and economic variables. In that case we are measuring the influence of X or W on the index Y. Because we were more interested in the direction of technical change rather than progress, data of the variables were normalised. See appendix for computation and method.

By combinations of variables, that is technical, economic and natural, a set of index of process, equipment and material can be obtained as show below in Table 1. However, for the analysis of the turbine production, its production characteristics as well as data limitation, the following combination were calculated: a) a functional index of equipment build with

[12] These variables represent a technical and economic concepts which can be understood as n dimension space. According to Sahal (1985a,b) the characteristictics represented by distinctive variables (in fact Sahal considered only technical variables) are distributed normally and the surface is identified by an ellipse S(0) with n dimension and a centroide C(0). At different time to T(0), for example T(1) there is an ellipse S(1) and centroide C(1). Distance between centroides of the ellipses C(0) and C(1) can be considered as a measure of technological change.

technical, economic and natural variables, b) a process and material index build on technical data , c) a process and material index based on economic data.

Table 1

Index	Process	Equipment	Materials
	P_i......P_n	E_j......E_n	M_k.......M_n
Y_x			
Y_w			
Y_c			
	------------	----------	------------
	Y_P	Y_E	Y_M

Variables contained in the industrial tree

From the analysis of the industrial tree of producing turbines Rf (equipment) a group of technical, economical and natural (cultural) variables were found . Table 2 shows the group of technical, economic of the process, equipment, and materials for producing turbines. Those variables were the most representative in terms of having a more important role in defining rate and direction of technical change. For a more complete definition of variables and data information see the appendix at the end.

Table 2

Main variables considered

X1	Compound High : Specific speed	Equipment
X2	Power .	Equipment
X3	Size.	Equipment
X4	Compound Weight-potency : Specific speed	Equipment
X9	Intensity in the design	Process
X10	Intensity in the forming	Process
X11	Intensity of mechanised operations	Process
X12	Other operations intensity. Finishing and transportation	Process
X14	Steel	Material
X19	Soldering	Material
W1	Price per turbine	Equipment
W2	Price of the hydroelectric project and construction	Equipment
W3	Index concentration of group of producers	Equipment

W5	Index concentration by countries producers	Equipment
W6	Production out country origin	Equipment
W8	Design costs	Process
W9	Forming costs	Process
W10	Mechanising costs	Process
W11	Other operational costs	Process
W15	Structural steel price	Material

Note. X represent technical variables and W economic variables. See Appendix for detail.

3. Technological changes in Hydraulic Turbine Production

From data of the main turbine producers and time series of sectors of the metal products industry, machinery, and steel sectors it was possible to fulfil the data demanded by the variables mentioned in Table 2. The information available and the technical and economic information required from the analytical scientific and economic (theoretical and methodology) grounds, come from an iterative process between information´s needs and data´s disposability.[13] Information was organised into a periods and then standardised in order to get a functional technological index.

Before presentation the results of the functional technological index, in the following subsection a measurement of the evolution of hydraulic turbine is made by means of the Compound H-Ns. (see variable X_1 and appendix). In order to asses the difference between evolution of terminal equipment (turbine) itself and the P,E,M ´s evolution for producing the turbine, it was necessarily to work out the techno-economic index of the P,E,M.

Measuring the evolution of the equipment itself: the Francis turbine

The height and specific speed component H-Ns (X_1) reached two peak points between the twenties and the nineties. The peak points achieved appeared in the forties and fifties and later on in the eighties. Statistical analysis of this component X_1 is complex since the various determinant factors differ from one period to another. The processes, equipment and materials vary from one period to the other. There is, however, an important question: the value of the H-Ns (X_1) the component in the forties and fifties does not differ from the value of the H-Ns (X_1)

[13] Two kind of data can be deducted: the data which comes from direct source of the main producers and the data from times series of industrial production sectors of USA economy and Europe countries. See appendix for more details.

component in the eighties. This situation shows that technological evolution measured by the component H-Ns (X_1), may well not be so impressive in its own terms, in its sector or in the analysed equipment itself as when it is compared to other sectors involved in turbine production and to the metal-mechanic industry sector itself. That is to say that in comparing both peaks (40-50s and 80s) minor changes are interpreted, but in analysing all the years involved, changes turn out to be considerable. The hypothesis that is analysed is that the exploitation of economies of scale (and later scope economies), the very well integrated metal industry sector, the development of the product of a technology, reached its highest point in the forties and fifties and was later interrupted by radical changes in processes, equipment and materials as from the fifties until this process ripened in the sixties and eighties which allowed the exploitation of greater natural resources reflected in larger turbines.

The dominant trajectory is analysed as follows by means of factors that are involved in the choice of technological direction. This is done through the results of the functional technological index of the industrial tree of turbine production, except that it is first done for the equipment and later on for the processes and materials. See the appendix for a description of the variables.

Equipment

A constant reduction of turbine weight and size measured through the Weight-potency: Ns component (variable X_4), infrastructure costs as a whole hydroelectric project (in constant US $C/kW, variable W_2 which behaves as attraction cost), and firm internationalisation (average production growth rate in MW of the installed turbines out the country home, variable W_6) are the factors that have prevailed in turbine evolution.

The direction of equipment technology is explained by the weight-potency relation (X_4), together with both economic variables: infrastructure costs and firm internationalisation (W_2 and W_6). Although the equipment is represented by the turbine, it is deduced here that, in general, from a technical standpoint, the objective has always been to increase power, and at the same time reduce the size and weight of the machines and apparatuses. A certain prevalence of the economic variables over the technical variables should also be noted although variable w_2 is institutional in nature. In general, other economic variables can also have an influence.[14]

The cost of producing one kW is not of great importance if only equipment (w_1) is taken into account, since although unitary value per turbine ($T/kW) is considerable, it is does not have that much influence in itself. The cost per kW, considering the whole of the hydro-electric project (w_2) is of relevance ($C/kW). The costs of the project in general (here considered attraction costs since they have an influence over other costs) and firm internationalisation (w_6), measured through the degree of concentration of firms and/or competition, are of great importance. Other variables that reflect market concentration in general are not so relevant in this context.[15]

There is an important difference between internal market protection and firm internationalisation. Whereas the former variable, measured by average concentration levels in various countries (w_5), has little significance, thus implying a lesser effect on technological rates and orientation, the growth of the firm outside the country of origin and the constant challenges it faces have been an important feature in influencing technological change (w_6). This latter variable in fact also represents not only taking risk-taking, but also mergers with local enterprises to survive in the market. In fact, firms that did not expand beyond their country of origin had difficulty in remaining in the increasingly competitive markets. Firms that took risks and became international since the twenties are characterised by this feature and by the saturation of the natural resources exploitation that began declining during the eighties. Those firms that moved to international markets survived producing turbines and absorbed others that remained within national markets.

[14] Other consistent sets of variables which show this kind of evolution path are the turbine diameters analyses and the disposability of the turbine (which is a multiplied performance variable). However, it can be stated that x_4 and the size of the turbine measure by its diameter support the thesis of constant reduction of weight in the equipment.
Other variables for the analysis the synergy's which tend to increase the performance do not have an important role. This analysis considered net reserve margin and real power margin which are intended to measure power rates between factory statements and real work and so did not have an influence in rate and direction of technology change. In general, these factors have a certain influence on some service process which are not analysed here. What seems to be more clear is that performance variables rather than design variables have much less influence on increasing machine readability.

[15] It is possible to measure market concentration by a global concentration index and by groups of producers concentration index. The difference resides in the fact that the latter represent a dominant group of firms, and the H index should show a higher concentration. The analysis results show however a low significance level (t) in the second and a good one in the first one. We could say that better condition to promote technological change can be related to the less market concentration.

Processes and Materials

Processes and materials influence producers internal and external. Internal dynamics, are ruled by certain technical variables (in both process and material), whereas external dynamics, that is out side the firm, are ruled by certain economic variables (in both process and material). As opposed to equipment, the greatest incidence in the processes comes from technical factors of the design, conformation, metal cutting and shaving mechanisation, transportation and finishing. Materials on the other hand are more sensitive to economic variables. It can be shown as follows:

a) Through the analysis of technical variables, technological change is explained by metal cutting and shaving mechanisation processes (X_{11}), finishing and transportation (X_{12}) as well as the use of soldering materials (X_{19}).

Two important groups must be mentioned: Firstly there is a group of variables that measures process intensity per work hours. The processes form a group of variables that represent the characteristics of the operations of the equipment processes. Design (X_9) is partly a process that has increased its importance in combination with finishing and transportation (X_{12}). However, the processes of conformation (X_{10}) and metal cutting mechanisation (X_{11}) also present a certain reliability in influence on the rate and direction of technological change. There is, nevertheless, no complete dominion in each of them.

Secondly, there is another type of variables, such as the number of workers per machine, which is a productivity measurement since it implies a decrease in operations as well as operation improvements and may be partially or totally involved in each of the above-mentioned processes[16]. This variable only has importance together with other variables, but it does not have the importance of metal cutting mechanisation, or finishing and transportation which relate to equipment size and increasing potency. That is to say that, together with the variables that have prevailed in equipment, i.e. size and potency, the intensity of the finishing and particularly the transportation processes has been complementary.

The importance of soldering (X_{19}) in a certain way also reflects the performance of the forming processes without metal cutting (X_{10}). Although the introduction of soldering has in practice modified the forming processes, the same product keeps resulting. What has happened is that the reduction of forging operations, and basically of foundry and other operations, such as trimming and rolling, are gradually being replaced by soldering. The joining process has stood out more owing to new materials, such as soldering, which have evolved in order to adjust to the increasing size of equipment thus overcoming problems of metal fatigue and corrosion and decreasing dependence on other processes such as metal cutting and shaving mechanisation and finishing. The importance of soldering can thus be noted in process change, in a continuous balance between processes with and without metal cutting and shaving and the introduction of other new processes.

Of course other materials, such as different kinds of steel, have also evolved, but have not been as crucial as soldering, metal cutting and shaving mechanisation process and finishing process. It can be said that size and power evolution has prevailed, and although the solution of problems such as cavitation and corrosion has also been important, they have been surpassed by soldering. Even though there have been significant advances in metallurgy, in the period comprised between 1950-1980, potency, size and weight still prevail. Materials may come to prevail later on, in the nineties, and in such case, steel and its many applications will also be dominant[17].

Soldering has also evolved not only in the solution of typical resistance problems due to increases in size and potency, but also to less complex techniques for soldering more resistant steels and steel alloys with higher concentrations of chrome and nickel.[18]

b) As opposed to the technical effect, the economic effect is more homogeneous in the sense that all variables participate favourably or unfavourably thus affecting technological change since there is a good association and significance in the set of type W (cost) variables corresponding to the design, conformation, cutting mechanisation and finishing and transportation processes represented by variables w_8, w_9,w_{10}, w_{11}, respectively. In fact, although some of the variables, such as design (w_8), are on the increase, there is a decreasing tendency as a whole. Nevertheless, the economic variables of these processes do not prevail with the same intensity as the technical variables.

---

[16] Variations in the number of workers per machines may imply an increase in the productivity but it can not happen in all the process. The fact that this relation diminish (with less intensity) in this century it does not means than process before mentioned follow also this pattern.
[17] Other steels composed with proportions of Cr, Ni, Mo elements give them special properties in terms of facilitating the metal cutting and shaving operations, etc. In fact there is a trade off between using specific material to reduce cavitation and using hardness materials for ease of use.
[18] Soldering and welding have evolved, in part, through efforts to reduce oxidation and rusting and at the same time to reduce stress fatigue. In addition the combination of Cr and Ni for the process of welding is another factor. However the former has been the dominant trend because it is addressed directly to solve design structural problems.

Together with salaries, production costs include the price of steel (w_{15}) which (as part of the materials) certainly has an effect on the way technology changes. Neither labour force productivity nor wages are determinant since the former has a lower growth rate after having reached high growth levels in the thirties[19]. Wages to a certain degree also have been less influential over technology and only combined with other variables had have some effect. Their influence is nevertheless low and in any case it is decreasing costs (in terms of all inputs) and increases in the price of steel which affect innovation rates and orientations. That is to say, on the one hand, there is a situation in which salaries although increasingly (as a group) have less impact reflecting a situation where the greater degree of specialisation comes higher salaries but in which substitution still becomes more attractive and is reflected in a decreasing trend of the participation of wages in value added.

On the other hand as far as profits are concerned, it cannot be stated that there are considerable increases since, in spite of the fact that productivity has grown, its growth rate has not been that intense. In any case, low increases in productivity, lower wage participation, a lack of profit growth and an increase in raw materials have resulted in cost increases in general. Of course, this is based on the more highly concentrated markets of the eighties in which profits were moderated and in part decreased since in the eighties and nineties a large number of firms either disappeared or were absorbed by others. In fact, the importance of materials, specifically steel, had a greater influence over technology and in many cases not only led to a decrease in the amount of materials used, but also to maximum tolerance of equipment in order to save on materials. The price of steel has thus been of great influence together with increasing costs.

Technological change rate and orientation from an external economic perspective is represented by the effects of the costs of metal cutting machinery process (w_{10}), the influence of which is more important and in which greater process mechanisation and automatization are noted.

Group of Dominant Variables

It is not possible to speak of a radical independence of technical variables and economic ones to explain technical change. What we can state however is that there is a feedback process between autonomous and market forces both to create and to exploit innovations. Economic variables, in general, have had an external influence, that is to say that the firms that produce equipment take the market price of inputs and raw materials and have little influence on it.

[19] This is correlated with the workers per machine which start to decline in the forties: it was not possible to follow the pattern of drastic substitution between labour and capital showed in the end of

However, firms do have further control over technical variables and, therefore, have possibilities of influencing technological change. Technological change may emerge from both forces only within the firms that dominate the technical variables while the economic variables prevail in their surroundings. From a technical point of view, process may have a stronger influence upon the creation of innovations.

In general, innovations originating from economic variables are less significant than those deriving from technical variables. Changes influenced by economic variables are rarely radical since these would otherwise transform the firm and even change its activity or the economic sector it belongs to. That is why firms take advantage of opportunities that in many cases become opportunities to develop products, services, etc. What has been noted is an equipment trajectory (T_1), from a technical perspective a processes and materials trajectory (T_2), and from an economic perspective a processes and materials trajectory (T_3).

- The first trajectory, T_1, referred to equipment is explained by weight-potency relation (X_4), the cost of kW of the construction project (W_2) and by the internationalisation of the firm to look for new markets (W_6).
- The second trajectory, T_2, is explained by the intensity operations of the cutting mechanisation processes (X_{11}), the intensity operations of the finishing, transportation and placement processes (X_{12}), and the use of soldering (X_{19}).
- The third trajectory, T_3, is explained by the cutting shaving mechanisation costs (W_{10}), and the price of steel (W_{15}).

Since the subject of this study is precisely equipment i.e. turbines, both processes and materials are analysed in relation to this variable. It is therefore not a question of obtaining a set of technical and economic variables for processes and another set of technical and economic variables for materials, but rather of reaching a set of technical determinants covering processes and materials and a set of economic determinants covering processes and materials. In the former, it has been noted that process aspects prevail, whereas in the latter case, input and output factors prevail. In other words, it is more important to reduce mechanisation times (X_{11}), or conformation times (X_{10}), rather than the cost of finishing (W_{11}). And, in the latter case, the price of steel (W_{15}) is more important than the technical characteristics and properties of various types of steel.

---

last century and the first decades of this century.

Technological change rate and orientation is dominated by these two groups of variables ($x_{10,}$ x_{11} and w_{11} ,w_{15}), together with variable x_4 (the weight - potency : Ns component) referring to a latent tendency to reduce size and increase potency, a trade off between size and weight reduction against limiting potency increase; variable w_2 (price - kW project) associated to pressure to reduce the cost of the project; and variable w_6 referring to the firm's degree of internationalisation (implying that firms grows and that new markets are captured as well as the fusion of international enterprises with local enterprises). This rate and orientation of technical change can be interpreted in part by equipment's dominant trajectories, as well as the technical and economic trajectory of processes and materials.

4. Latent Variables

What is described as a latent variable is the influence of a certain variable over an existing technological dominion. A latent variable is a variable which functions with a large degree of influence over economic activity and is even more powerful than other variables. A latent variable differs from a dominant variable in that the former has no explicit dominion over determinant technological change, which is ruled by a group of variables which may well be weaker on an individual basis, but as a whole achieves a greater degree of harmony thus enabling them to prevail as a determined technological pattern. This is the reason why the concept of latent variables and potential technological pattern has been introduced since they can in a certain time prevail over other technological regimes and thus become dominant[20]. In fact, those mentioned in the previous section are dominant but may be under pressure by other kind of technological regime due to the influence of a latent variable. The following latent variables are mentioned:

a) The design process (x_9) is a unique variable since it has evolved in accordance with turbine development and, at the same time, the evolution itself is the design variable. Detailed analysis reveals an important consistency with conformation process (x_{10}) and the finishing and transportation process (x_{12}).

The importance of the intensity of operations of design process (x_9) is such that it promises to be a potential variable that may eventually come to be dominant. This has been noted since design mostly came out of the experience of factories that produce turbines, an accumulated experience to a large extent based on accumulated empirical knowledge. It is a case in which the fact that learning has taken place through trial and error has resulted in improved turbines. Later understanding of problems related to fluid mechanics, and thus to cavitation and the application of hydrodynamics, have helped develop better designs. More radical changes in this process, however, have taken place more recently following changes in the design process. That is to say that, based on the same principles of hydrodynamics, designs are improved through the finite element method. Instead of having to optimise one option or two, obtained through analytical methods and equation solutions, advantage is taken of supercomputers which enable many more trials often at relatively low cost and generally produce much better design options associated to optimisations in which friction and loss reduction are overcome through design based on the conformation of fragmentation of miniatures of the main parts of a turbine, each of which is maximised. This implies a number of operations that used to be simply unthinkable and that today is making a real difference.

With this new improvement, the design process not only displaces a complete methodology based on infinitesimal calculus and the solution of multiple equations in order to reach one option, or two at the most, but it also has an impact on the labour force (which was already highly specialised) requiring intensive highly qualified human capital. It is a displacement in which the specialist's activity is overcome in different quantitative and qualitative terms through the introduction of design programs. Intensive and specialised use of Cad-Cam itself demands further labour specialisation. It is thus not a traditional type of substitution in which intensive and almost unskilled labour force is replaced by capital and highly specialised labour force. It is also a case of labour force substitution, except that one specialised labour force is being substituted for another, as opposed to the mechanisation and conformation processes in which there can still be an important difference in specialisation degree within the same trajectory.

The benefits of these design yields are inmediate. A different product is obtained owing to better decisions due to reductions in design time and sometimes in costs. At the same time the best design that is studied can be put into practice as a result of modern software and hardware as well as numerically controlled machinery. An improved product is obtained , which results in higher efficiency and better performance.

The effects of this change are beginning to be felt since they have an impact on all the basic and intermediate mechanic industrial branch. This implies a decrease in the price of the products that are obtained and an improvement in the quality of the sector as a whole which

[20] The process of competition among different technologies are not discussed here. In fact it can be a continuation of the latent and subtrajectories approach. For a discussion on technology competition

has an upstream impact on higher productivity and a down stream impact on tremendous substitution in design and part construction.

b) The conformation processes (X_{10}) are another kind of latent and potential variable in which casting some parts of the turbine and joining through milling has actually been replaced by soldering. That is to say that there is competition between two processes in which soldering has a greater impact over the conformation processes and foundry loses its hegemony. The introduction of soldering in the fifties and its evolution through better soldering techniques together with the invention of new soldering equipment and the improvement of soldering itself[21], radically transformed the formation processes in the sixties, seventies and eighties. Time and costs were notably reduced as a consequence.[22]

However, in spite of the fact that this process has considerable importance in itself, it has not managed to prevail over other processes such as metal cutting and shavings mechanisation, and finishing and transportation. In other words, this process has not had such a great impact on hydraulic machines in comparison to previous processes. As this is the case the specific studies on turbines sector and equipment may well be biased since in other metal-mechanic sectors the importance of this process has been evident and may dominate the technological trajectory based on conformation and be less important in the metal cutting and shaving mechanisation. The structures to build large-scale infrastructure and buildings are a good example in which it is very likely that conformation processes may prevail over the technological scenery.

c) Materials. Materials have direct repercussions on two main processes: conformation and metal cutting and shaving. It differs from both above-mentioned latent variables in that these may have both technical and economic influences. In fact what was noted was the dominant influence of increases in the price of steel (w_{15}). Other technical aspects related to steel, such as stress, hardness, corrosion, capacity to be mechanised, also have a certain potential.

From a technical point of view, the group of elements that characterise different types of steel and its alloys are having greater influence since new alloys and materials have endless perspectives. Nevertheless a consequence of the fact that these technical characteristics are latent and hence do not display a dominant trajectory is owing in part to the emphasis on size and potency during the sixties and eighties. Should this emphasis decrease in the future, there

---

see the gas turbine in Islas (1997).

[21] Introducing nitrogen element has been a way to insulate materials from oxygen and in this way improve the process of welding.

would be indirectly a greater chance for the technological advantages of the new alloys dominating over the price variable.

5. Conclusions

i) The influence of turbine size and weight reduction, together with the prices of the project the turbine is related to and internationalisation of firms, are determinants of the technological pattern of both equipment and turbines themselves. Mechanisation metal cutting processes, as well as cost increase, determine the trajectory of the processes which inter-relate with materials determined by soldering compounds and the price of steel. In this context, it can be appreciated that the ruling variables are not exclusively technical nor economic, but rather a cohesive and directed whole that sets out from a technical basis and solves problems related to profit, surviving and growth.

It is rather partial to question whether it is the demand or supply, hierarchical or management risk strategies that determine the emergence of technological change. Analysis based on these kind of statements, apart from being biased toward equipment and even severely limited due to the difficulty in substituting equipment in the short-term, do not consider the influence of processes and materials themselves. The fact that technical variables have strong influence on technical change and that this happen on the grounds of internal decision of the firm (in comparison with external), and in view that external economic variables are influenced by institutional factors like explaining W_2 for example, both, give support to transaction costs rather than market concept explanations. So the relation with the transaction cost approach is even more strong.

The advantage of considering the industrial tree as being composed of P, E, M is precisely to take into consideration processes and materials in production and at the same time to be able to separate autonomous forces from market forces (that is at least technical and scientific). To ignore such accuracy by means of P,E,M, is to reduce the all process of technical change in a wide context. In order to give a way and to favour an analysis from demand side, the economic variables would have to have total dominion over the technical variables and vice versa. This situation, apart from being extremely rare, would not manage to survive neither a long- nor a medium- term period since equipment implies a life of at least between 5 and 10 years. This situation would correspond more to that of non durable products, such as foodstuffs, in which

[22] Arthur (1988, 89) and Foray (1987,89) approaches may help to analyse competition between soldering and forming process operations.

market influence is more perverse than autonomous (technical, scientific, u other) forces, but in this case a long- and medium-term analysis would also be impossible and a trajectory would be even harder to get. This of course leads us to another very intricate discussion related to consumption type and changes in the proportion between durable and non durable consumption, as well as the productive structure, which is not analysed here since it is beyond the possibilities of this analysis[23].

There are enormous advantages in considering technical change based on both upgrading and radical changes on each P,E,M . This analysis of industrial tree can be applied to any sector of the economy from the primary sector to services. The fact that the current economy's most dynamic sectors are analysed, opens an inestimable horizon since it can detect the dominant processes, equipment and materials and thus obtain the ruling variables of a regimen, or trajectory. The basis of the analysis of the industrial tree is not limited to the metal-mechanic sector. Of course it would be appropriate to continue with a related branch, such as the electricity sector. A generators' P, E, M could be studied together with turbines and metal mechanics to thus find an industrial tree that may group both of these equipment families representing large industries. This analysis is likewise not limited to the traditional nor equipment industry, it can cover other materials, the telecommunications industry, electronics and services including information technology. To study these industries through their corresponding industrial trees and their P, E, M, would provide a larger basis for the analysis of structural change in economies.

ii) There are many factors which influence the process of generating innovations: scientific, technological, economic, institutional and cultural factors, among others. The innovations created by these factors, on their own or combined, may be either incremental or radical. The effects are different in each case. What the model detects is that the possibility that the market generates innovation (on the basis) is remote given that production is conceive by means of primary industrial tree and dynamic industrial tree where the central point is to accept the fact that in order to produce a good, first it must be produced and then it must to find its way to the consumer. The basic decision influencing production is thus being moved away from the market. It is not until later, once the market variables have been incorporated, that they do influence production but at the beginning, market variables are originally far from risk-taking decisions and long-term frameworks. However, even though all innovations are generated

[23] The difference between durable consumption and non-durable consumption is crucial to understanding the radical nature of the structural changes. See Jardon (1997) for a discussion on structural change and technological change.

basically by the influence of a certain variable, many of them pass through a economic (and profitability or other) criteria .

This does not imply that all products in the market have been modelled by consumer needs. In the turbine Rp example, demand modelling would apparently be noted since each turbine is different. However, the fact it is different is owing to the design's basic characteristics, whereas an increase in Ns derives from various forces among which some are market forces, such as W_2 that depends on the project's costs, in general, and in any case, is subjected to the influence of institutional forces such as the country's desire to develop, or consumer preference for public goods that are not managed by the private sector. Other variables, such as X_4 and W_6 , are more autonomous since increases in Ns and in potency, as has been seen, were due to factors related to processes and materials, where technical aspects prevail and only the price of steel has a market force. Variable W_6 does not necessarily imply a price reduction, but it does imply a reduction in other factors the firm faces in order to remain in the market, which vary from having a vertical and horizontal growth policy to unfounded preferences for specific places, specific relationship with local industry and, to a lesser degree is based on a decision to make profits.

The need certain firms have of expanding beyond their country of origin has been a factor of greatest importance to remain in the market, since it implies many factors that oblige the firm to acquire skills to explore new businesses, develop management knowledge and skills to survive in situations that may differ from those of the country of origin. The transformation into an international firm and the operations an enterprise must get involved in so as to be able to work in other countries is not discussed in detail here.[24] However, some results can be deduced that are related to different postures. The traditional focus of the growth economy, analysed by Vernon on the differential cost between producing in the country of origin and abroad, has less relevance. It cannot be applied, even in with regard to product standardisation.[25] Exploitation features, the countries' resource potential, and enterprise management are even more important than standardisation. When the market is determined by the amount of natural resources, by the advantage the local producer has vis-à-vis the natural

[24] International operations of companies are well documented on studies ranging from an economic growth theory of firms, evolutionary methods and internationalisation, corporatist analysis, management and behavioural approaches. See for example: Vernon (1966), Johanson and Wiedersheim (1975), Buclet and Casson (1979), Welch and Luostarinen (1988), Bartlett (1981).
[25] However, the standardised product concept could have an important role if it is considered Standardised turbines for certain heads rank and flow together with a certain of flexible form production.

resources of the country of origin, and the negotiation capacity to go to other countries, these can all help explain the internationalisation of operations.

As can be noted there is not a single exclusive logic which explains international operations through one theory only, since different facts can be deduced from the above that are taken up, in a coherent manner, by other approaches such as the evolutionist, industrial economy, enterprise and management organisation and location economy models. The world factory concept should be added within the globalization scheme since for some sectors the evolution of production has led to fragmented production throughout different regions in its different stages (conception, design, manufacture and consumption).[26]

iii) Technological Change: An Advancement or a Regression. This analysis cannot be isolated from the impact of conceiving technological change in terms of equipment yields and in terms of processes and materials. Technological change is typically conceived as deriving from process and product development. It is first of all possible to have a certain process producing a certain product, to then make changes in the process and obtain the same product either in larger amounts or at a lower cost. Although this is the typical case, it does imply certain difficulties. The difficulties derive from the assumption that a change in the process implies an improvement in production. A change in the process is simply not conceived without repercussions in the final output and even less as a regression. This partly occurs because measurements are so global that technologies going in the opposite direction, in an unexpected direction, are hardly recognised. What is more important is that there are technologies which in turn are being pulled along by another group of technologies which survived not because they are better than the others but because they depend on the dynamic trend of other dominant technologies. This certainly has repercussions on employment and income distribution since a technology in itself can be valued better from the point of view of employment, distribution or in terms of the equipment itself, but it may be poor or it can not survive with the dominant technology. Such may be the case of variables W_1 and W_2 .

When the product changes, but the process does not change, or both change, the difficulty in analysing them increases since, apart from the aforementioned situation, it includes modifications to the product that affect the production chain upstream and downstream. In the former case, when the process does not change with the neo-classical framework it becomes difficult to evaluate changes. However, the mere fact that technological change in the product (which can be either in equipment or materials) is conceived, implies that part of the traditional

[26] See Gereffi (1989,1992,1995) for a discussion on globalization and the new division of labour.

analysis is being abandoned. In the studied case, the H - Ns component is precisely a variable that measures turbine evolution on its own terms separate from equipment productivity. Although price reduction per kW/machine is noted in the analysis, it is not associated with an increase in the H-Ns component.

In the latter case, when both the process and the product change, it is difficult to know whether changes in the process without repercussions on the product or product modifications have greater influence since either situation may be involved. That is it includes any of the situations mentioned above.

Other studies have focused on evaluating intersectorial technological flows in order to analyse the contents of technological change in materials, parts and equipment.[27] Although the analysis that is made acknowledges a change in equipment itself through an improvement in materials or the introduction of electronic parts, for example (a common case), if the investment in research and development is valued, one becomes aware that intra-process analysis is not effected. As opposed to this approach, the industrial tree (Rp) opens the possibility of analysing technological change in its basic components (i. e. equipment, processes and materials) through technological, economic and natural resource factors affecting innovation. Thus, apart from analysing the so-called embodied component, it provides a basis to evaluate change in processes, materials and equipment not just through economic but also technical variables.

From the above, it can be concluded that although conventional analysis does evaluate changes in productivity factors, it omits change itself from equipment, processes and materials, and although intersectorial technological flow analysis includes technological change within raw materials and equipment, they both fail to make a complete evaluation. The former does not consider technological change on its own terms and the latter does not consider the operational changes that take place in the processes.

A shift in economic appraisal of technological change can be noted in all this. That is to say that in spite of the fact that there has been an advancement in the understanding of technological change in itself and in economic evaluation[28], we are now currently facing group-immersed technologies. It no longer suffices to analyse technologies in isolation since, although their understanding give concrete results they may be unilateral from technical as economic level, given that the same technological dominant group would well cancel out individual effect. At the same time, evaluating technologies in unilateral form to resolve

---

[27] See for example Scherer (1982) for intersectoral technology flow. See Cohen (1995) for a review.

problems such as income distribution and employment would be very limited .[29] The lesson derived by analysing technological change through the industrial tree and measuring technological advancement is that in the presence of a scientific and technological revolution, such as those produced by electronics, information technology, new materials, market globalization, and a change in the role of the State, it is indispensable to understand the impact technological change has on productive structures and that this impact may be explained, at least primarily, through a more structural approach.

Appendices

i) Description of the variables of process, equipment, and materials.

Information. The analysis was based on information from statistics of those firms which produce turbines, magazines, technical reviews, statistics published by private associations, statistics of the metal products industry, machinery, heavy industry, interviews with specialised personnel in the industry and information obtained directly from turbines and parts producers. The main producers were grouped as follow:

Table 3
Participation of the production of turbines by group of producers
(as % of MW installed)

MANUFACTURER	**1901-30**	**1931-50**	**1951-60**	**1961-70**	**1971-80**	**1981-93**
Group 1	56.73	48.92	47.6	53.4	51.32	60.61
Group 2	0.66	7.92	12.5	9.73	6.7	8.11
Group 3	19.55	20.14	10.7	8.71	10.16	0.72
Group 4	7.90	6.5	4.0	0.08	0.25	0.03
Group 5	1.80	12.9	2.13	8.32	2.6	0.61
Group 6	12.9	0.38	14.5	16.3	19.5	9.2
Group 7			0.04	0.02	0.01	7.3
Others					0.07	0.13
s/n	0.10	0.03	0.04		0.01	
Total	100	100	100	100	100	100

Group 1 : A Chamber, E-Wiss, Neyrpic, Toshiba, Voith, Hitachi, Kvaemer, Mitsubishi. Group 2 : Hydroart, Nohab, Vevey, Voest, Fujii. Grupo 3 : Boving, DEW, KMW, English-Elec. Group 4 : Riva, Tampella, Tosi Group 5 : Baldwin-Lima, Boving-KMW, Creusot-Loire, Mil. Group 6 : Russe, LMZ, Building(LMZ), KTZ, Lijostroj, Skoda, CKD-Skoda, Temaire skoda, RomeNegro. Group 7 : DFEM, TP,E,M, Tiajin, DEMW, Dengyosha, Temsan.
Note. The Table do not show fusion's and firms which any more exist.
Source: Based on direct information from the companies.

---

[28] Even so the fact that technical and economic obsolescence has occupied a central position in economic analysis through discussions about capital.

In some cases the information came from the beginning of the century, from the twenties and also before and after of the fifties. The following Box 1 contain the variables analysed. See Jardon (1996) for further details.

Box 1

Description of variables

Equipment

X_1. Component of the height (H) and the specific speed (Ns). It is given by the sum of the distances between the origin (0,0) and the component (H-Ns), from a adjusted regression function Ns=f(H).

$$X_1=\sum_{i}^{h} ((Ns_i-Ns_0)^2 + (H_i - H_0)^2)^{½}$$

The specific speed Ns. The specific number of revolutions permits a classification of the hydraulic machines because, under geometric and similarity criteria, the turbines can be compared by their specific speed (Ns) without taking into consideration their size. The Ns is very useful because it allows a synthesis of the machine.[30] It is considered a design variable[31]. $Ns= nP^{0.5}/H^{1.25}$.

The analysis of the turbines produced by different firms in the world shows a correlation between height and specific speed in different periods. The analysis of regression showed a good correlation coefficient.[32]

X_2. Power . It is the sum of all potencies and divided by the number of units by periods. The power is given in Mw and all the turbines greater than 15 MW manufactured for different locations in the world were analysed.

X_3. Size relation. This is based on:

$$X_3= (\sum_{i}^{h} (\text{Estimated Diameter / Real Diameter}) -1) / n$$

[29] There are many studies on this subject but particularly the work of A. Sen (1969) and technology choice for developing countries Steward (1983), Giral (1990), Goonatilake (1984,88).

[30] The specific speed of revolutions is a result from different turbine producers which have made laboratory test with samples models and prototypes. Tests are based in the concept of adimension numbers to permit comparisons. Reynols number is one of them which can help to compare dynamic similarities. Many tests and prototypes are very difficult to develop owing to values which should be obtained at very high speeds, 25000 rpm, and at the same time to carry out the whole test would be very costly. In order to find turbine dimensions results and in order to simplify the assays, all the tests start by supposing null viscosity effects and the assumption that a geometric similarity implies a mechanic similarity.

[31] Another way to calculate the Ns is by considering the flow: (Q in m^3/seg). $Ns=nQ^{0.5}/H^{0.75}$

[32] For the periods 1960-74 y 1974-84 Siervo y Leva (1976) and Lugaresi y Massa (1987) found similar results.

Where i referred to the analysed turbine and n to the number of turbines in a period of time. The diameter is given in metres. Ns and the turbine diameter relation have been studied by several specialists observing that the evolution of the turbine throughout Ns is positively correlated with decrease in diameter and with and increase efficiency. Thus a higher values of Ns the diameters have been reduced and also the efficiencies have increased.[33]

X_4. Compound of the relation weight-potency and the specific speed (Ns). It is given by the product of the sum of the distances between the origin (0,0) and the points ((weight/Pot),(Ns)) from an adjusted regression function Ns= f(weight/Pot).

$$X_4 = \sum_{i}^{h} (((weight/Pot)i - (weight/Pot)_0)^2 + (Ns_i - Ns_0)^2)^{½}$$

where the weight is given in tons, the power in MW.

W_1. Price of kW per turbine. It includes the main components but not the generator . The cost is given as an average of USdlls of 1982 per kW installed. ($T/kW).

W_2. Price of kW of the project and construction. It refers to the cost of the hydroelectric project (infrastructure). It is given as an average US dlls of 1982 per kW installed ($C/kW).

W_3. Global concentration Index of the main producers per time periods. It is calculated according to the Henrdilfal Index.[34]

W_5 Concentration average in several countries producers including the producer country origin by time periods.

$W_{6.}$ Rate of growth of the average of the production out the country home in Mw of turbines installed by time periods.

Process

X_9. Intensity in the design. Average change in time taken to design a turbine.

X_{10}. Intensity in the forming. It measure the average change in time to form the turbine by process like founding, forging, bending, cutting, soldering but do not taking into considerations metal cutting and shaving operations.

X_{11}. Intensity of mechanised operations. It measures the average change in time of metal cutting and shaping mechanised operations.

X_{12}. Other operations intensities. It measures the average change in time of finishing, transport, fixing, testing operations.

X_{13}. Number of workers per machine.

W_8 Design cost. Average change in cost of design of a turbine as a proportion of direct cost.

---

[33] Siervo and Leva (1976) and Lugaresi and Massa (1987) . Both analyses show the size of the turbine studying the tangential velocity coefficient (Ku) defined by $Ku = 3.1416 D_3\, n\, 60^{-1} (2gHn)^{-0.5}$. Where Ku is the coefficient of velocity, D3 is the turbine diameter outlet, n the revolutions per minute, g the gravity speed and H the design height.

[34] The Henrdilfal index was calculated on $HI = n\boldsymbol{S}^2 + 1/n$. Where n is the number of firms and $\boldsymbol{S}$ the variance.

W_9. Forming cost. Average change in cost of forging, cutting, founding, bending, soldering (operations) a turbine as a proportion of direct cost. These operations do not include metal cutting shaving operations.

W_{10}. Mechanising cost. Average change in cost of metal cutting and shaving operations as a proportion of direct cost.

W_{11}. Other operations cost. Average change in cost of finishing, transport, fixing, testing operations as a proportion of direct cost.

W_{14}. Cost index. Index of producing capital goods in United States.

Materials

X_{14}. Steel proportionality modulus.

X_{19}. Soldering coefficient.

W_{15}. Structural steel price index.

ii) Functional technometric index IDETEIC (technical, economics, institutional and cultural and natural index)

Some of the variables analysed were a complement of others. To start with, not all the information obtained was homogeneous. There were differences between the technical and the economic data and it was necessary to evaluate the data and to analyse times series in order to be able to conduct out the analysis starting from the twenties and thirties. For accuracy an consistence in the analysis it was necessary to consider small groups of variables and to relate them to an economic and technical causality.

The data and statistics analysis were based on :

1) Functional index analysis Y was based mainly on Sahal and Esposito studies. From the former, the concept of technometric function was considered and from the latter, the development of the product and the inclusion of not only technological variables but also economic variables was taken into account. A holistic index and not a total index was calculated. The first measures deep technological changes and the second the progress. The data for the analysis correspond to the variables analysed and was converted into a period and then divided by highest (or lowest) change in order to homologies and normalised the information.

In order to find the best combination to get a lineal equation several regressions were made.

$$\mathbf{Y= a_1+a_2X_1+a_3X_2+a_4X_4......a_nX_{n-1}}$$

Regression analysis were based only on technical, economic and cultural variables grouped on process, equipment and materials. Owing to differences in the data, the criteria to analyse the main trends was dominated by variables which were more reliable in terms of the data and which corresponded at the same time to issues in the production of turbines.

The criterion used to relate the variables was based on technical, an economic grounds and a mix of both. At the same time the equipment variables were analysed first and process and materials variables were together analysed afterwards.

From the beginning, the analysis was guessed since there were certain coherence in the way of relating the variables together owing to technical and economic knowledge of the industry sector. The values of Y were based on the rate of growth of productivity and efficiency in the metal product sector in the US economy.

2) Test depended on type, quality, quantity, information and the estimators programs availability .

a) F and t   test for all estimators. b) The preparation of the data out of future disturbances was the basis of the analysis. In that way multicollinearity could not be important because even if it was present in the data the important analysis consisted   knowing the degree or acceptance level. In some cases this problem was analysed with 3 variables and from there combinations with other variables of the economic group, and technical group were analysed observing differences among the correlation coefficient in the regressions. c) The analysis of the information was likewise utilised to make tests in order to specify errors . From the beginning a mix of economical and technical variables was avoided and only when it was otherwise impossible and when there were the suspicion of a serial correlation the standard error was analysed. d) The omission of relevant variables to some degree was discarded not because information was poor in terms of observations but rather because the number of variables analysed did not fail. In fact, the correlation coefficient thus obtained show at first that this problem was not relevant. However, the inclusion of irrelevant variables   could have a further effect.   Certain incompatibility of the data specially with some groups of information which should be analysed with other kinds of model such as an non lineal model   was omitted because the number of variables included in the regression was restricted by the number of grades of freedom, and another model to cover the limitation of the linear one imply a further data analysis which in turn goes beyond the scope of the study.   e) An heteroscedasticity problem was discarded. First, only turbines greater than 15 Mw were analysed because this gave more homogeneity to the data. Secondly, for certain types of regression, only data from Western firm were analysed. Third, the data analysed have the same objective and parallelism: production of turbines and parts. Finally, the data analysed did not consider dissimilarities among the units and only in the equipment analysis was a combination of variables first in terms of technical variables and then in terms of economic variables.

Some of the more important regressions analysed are:

(1) $Y = -0.59 + 0.55X4 - 0.33W2 + 1.3\ W6$ r2 =0.98
(83.5) (-3.5) (4.1) (-4.1) (10) Et=0.032

(3) $Y = 0.91 + 0.82X_3 - 1.1X_4 + 1.0\ X_5 - 0.6X_6$ r2= 0.95
(13.9) (2.3) (4.3) (-4.4) (4.6) (-1.8) Et=0.067

(5) $Y = 1.4 - 0.07X_4 - 0.83X_{11} - 0.29X_{12} + 0.51X_{19}$ r2=0.97
(103) (8.3) (1.03) (-4.8) (-1.4) (3.8) Et=0.025

(6) $Y=0.33+0.24W10+0.39W14+0.28W15$ r2=0.98
(160) (1.2) (1.9) (3.9) (1.3) Et=0.018

(7) $Y=0.15+0.14\ X_4+0.59X_9+0.28X_{12}$ r2=0.94
(56) (1.2) (1.17) (3.7) (2.3) Et=0.039

(8) $Y= 0.84+0.14X_4+0.44X_9-0.56X_{10}$ r2=0.96
(77) (3.2) (1.4) (3.4) (-3.08) Et=0.031

(9) $Y= 0.3+0.12X_4+0.43X_9+0.24X_{19}$ r2=0.97
(112) (3.1) (1.3) (4.2) (4.06) Et=0.031

References and Bibliography

Abernathy, W.J. and Clark, K.B. (1985), "Innovation: maping the winds of creative destruction", *Research Policy*, Vol 14, Num 1.

Abernathy, W.J. and Utteback J.M., (1078), "Patterns of Industrial innovation" *Technology Review*, 80, (7).

Alexander, A. and Mitchel B. (1985), "Measurimg Technological Change of Heterogeneous Products" , *Technological Forecasting and Social Change*, 27, 161-195.

Allegre, J. and Roche, N. (1989) 'Conception et realisation des grands alternateurs", , No. 410.

Archibugi D. (1988), "I n Search of a Useful Measure of Technological Innovation" , Technological Forecasting and |Social Change 34, 253-277.

Arthur B. (1988), "Self-Reinforcing Mechanisms in Economics", in *The Economy as an Evolving Complex System*, (ed) P. Anderson, K. J. Arrow, D. Pines, Vol V Addison-Wesley Publising Co.

Braley, R and Gasnier, S. (1982) "Fabrication mecano-soudee de composants de turbines Francis de grandes *Revue technique*, No. 1, France.

Buclet, P. and Casson, M. (1979), "A Theory of International Operations", (reprinted) in Buckley P. y Ghauri P (ed) *The Internationalisation of the Firm*, (1993), Academic Press, London.

Casagrande J., Couston M., Diana J., (1991), "Operating experience of the Tucurui Francis turbines", in *Water Power and Dam Construction*, February.

C.F.E, (1993), *Potencial Hidroeléctrico Nacional*, Gerencia Técnica de Proyectos Hidroelectricos, México.

C.F.E,. (1982), "Anteproyecto Definitivo Coainala, Chis", (Comec)

C.F.E., (1989), Costos y parámetros de referenncia para la formulación de proyectos de inversión en el sector

C.F.E. (several years), *Indices para ajustes de precios*, Subdirección de Programación, CFE., México

C.F.E., "Centrales Eléctricas, Subestaciones y Líneas de Transmisión".

C.F.E., "Informe de Operaciones"

C.F.E., "Proyecto Eléctrico la Angostura". (A. Ulloa G.)

Casacci, S., Bosc J., Moulin C.and Sauron A., (1977), Conception et construction des turbomachines hydrauliques de grandes dimensions", in *La Houille Blanche*, No 7/8.

Casagrande, J. , Couston, M., and Diana, J. (1991), "Operating experience of the Tucuruí Francis turbines", in Water Power & Dam Construction, February.

Cohen, W (1995), "Empirical Studies of Innovation Activity", in Stoneman P (ed), (1995), *Handbook of the Economics of Innovation and Technological Change*, Blackwell, Oxford.

Cohen W and Levin R (1989), "Empirical studies of innovation and market structure", in R Schmalensee and R Willig (ed) *Handbook of Industrial Organisation*, Amsterdam NH.

De Parres ,J. (1966), *Máquinas Hidráulicas* , México,

Dodson E.N., (1970), "A General Approach to the Measurement of the State of Art and Technological *Technological Forecasting and Social Change* .

Dodson, E. (1985), "Measurement of State of the Art and Technological Advance", in *Technological Forecasting and Social Change*, 27. 129-146

Dosi G.,(1982), "Technological paradigms and technological trajectories. A suggested interpretation of the determinants and directions of technical change", *Research Policy*, 11.

Dosi G. (1988), "The Nature of the Innovation Process", in Dosi G *et al*.

Dosi, G. *et al* (1988), *Technical Change and Economic Theory*, Pinter Publisher, London.

Dutrenit G. and Capdeville M. (1993), "El perfil tecnologico de la industria mexicana y su dinamica innovadora en la decada de los ochenta" , in El *Trimestre economico* Vol LX (3), N 239.

Ehrnberg E. and Jacobsson S. (1993), "Technological Discontinuity and Competitive Strategy-- Revival Through FMS for the European Machine Tool Industry?", in *Technological Forecasting and Social Change* , 44, 27-48.

Eremeef L., Larroze, P., Lathuile C., Philibert R., (1983), "Calculus hydrodynamiques dans les *Revue technique Neyrpic*, No. 2.

Esposito E. (1993), "Technological Measurement: a composite approach", in *Technological Forecasting and Social Change*, 47, 1-17.

Ferguson, E. (1964), "The Origins of Steam Engine", in *The Rise of Scientific Technology*.

Fisher R.A.(1936), "The Use of Multiple Measurements in Taxonomic Problems", *Annals of Eugenics*, I, 179-188.

Foray, D. and Massard N. (1987), "Conceptualisation de l'industrie et des mouvements d'industrialisation: *Analyse de Systemes*, vol XIII, No. 3, sept 1987.

Foray, D. (1989), "Les modeles de competition technologique. Une revue de la literature", *Revue de D'Economie Industrielle*, No. 48, 2 trimestre, 16-33.

Freeman, C. (1974), *The Economics of Industrial Innovation*, F. Pinter, London.

Freeman, C.,Clark, J. and Soete, L.(1982), *Unemployment and Technical Innovation*, F. Pinter, London.

Freeman C. and Perez C. (1988), “Structural Crisis of Adjustment: Business Cycles and Investment *Technical Changed and Economic Theory* (ed) Dosi G. et al , Pinter Publishers. London.
Giral J. (1990), *Planeacion Estrategica Integral*, Limusa, Mexico.
GEC Alsthon Neyrpic (1988), Turbinas-bombas, Neyrpic.
GEC Alsthon Neyrpic (1990), Turbinas Francis.
General Electric (1992), *36 th GE Turbine State of Art Technology Seminar*.
Gereffi G. (1989), “Development Strategies and the Global Factory” *The Annals of the American Academy of Political and Social Science*, Philadelphia, Vol 505, Sept.
Gereffi G. (1995), “State Policies and Industrial Upgrading in East Asia”, , No especial, No.71. Paris.
Gode, E. , Cuenod, R., (1992) , *Numerical Simulation of Flow in a Hydraulic Turbine*, Sulzer Escher Wyss.
Goonatilake S. (1988), “Inventions in developing Countries” , in *Impact on Science and Society*.
Goonatilake S. (1984), *Aborted Discovery*, Zed Books, London.
Gordon T. and Minson T. (1981), A Proposed Convention for Measuring the State of Products or Processes, *Technology Forecasting and Social Change*, 20,1-26.
Griliches, Z (1990), “Patent statistics as economic indicators: a survey” , *Journal of Economic Literature*, 28, 1661-1707.
Griliches, Z. (1995), “R&D and productivity : Econometric Results and Measurement Issues”, in Stoneman P , (ed)
Hanley, D. (1980), *Introduction to the Selection of Engineering Material*, Van Ustrand Reinhold.
Harder, E.,(1982), *Fundamentals of Energy Production*, J Wiley S.
Hebden, J. (1983), *Application of Econometrics*, Philip Allan, Oxford.
Higgins, R. (1978), *Ingeniería Metalúrgica* (tomo 2), ed. Continental, México.
Historical Statistics , Colonial Times to 1970. EUA.
Historical Statistics of the United States , Selected Commodities, Steal Rails (1880-1970), Gas & Electricity (1931-1970).
Historical Statistics of the United States, . Wholesale Index, BLS, Pearson.
Historical Statistics of the United States: Two centuries of census, 1790-1990, Compiled by Donald B. Dodd, Greenwood Press, 1993.
Hydroelectric Plant Costs-1978” (1979), 20th Ann, Suppl. Washigton, D.C. Supt of Documents.
Industrial Outlook EUA. Several years.
INEGI , *La Industria Sidergica en México México.*
INEGI, Censos de Poblacion.México.
INEGI, Censos Industriales, (several years), México.
Islas J. (1997), “Getting round the lock-in in electricity generating systems: the example of the gas turbine”, *Research Policy* 26, 49-66.
Jardon U.J.(1998), “The evolution of hydraulic turbines”, To be published.
Jardon U.J. (1997), “Estructura productiva y cambios tecnologicos. Un analisis basado en el arbol industrial
Jardon U.J. (1996), *Estructura productiva y cambios tecnologicos: un analisis de la industria hidronergetica*, tesis doctoral, DEP-FE, UNAM , Mexico.
Johanson, J y Wiedersheim P.(1975), “The Internationalization of the Firm- Four Swedish Cases”, Journal of Management Studies, October .
Kazanas, Baker, Gregor, *Basic Manufacturing Process*, MacGraw-Hill.
Kendrick J.M.,(1980), *Understanding Productivity*, John Hopkins Universiy Press.
La Technique de Léquipement des Chutes”, La Houille Blanche
Lenz, R. (1985), “A Heuristic Approach to Technology Measurement”, *Technological Forecasting and Social Change*, 27, 249-264.
Lissone F and Metcalfe J (1996), “Diffusion of Inoovation Ancient and Modern: A Review of the Main *The Handbook of Industrial Innovation*, EE, UK
Lugaresi, A. y Massa, A. (1988), Kaplan turbines: design trends in the last decade, en *Water Power & Dam Construction*, Mayo.
Maddala, G. y Miller E. (1991), *Micro Economía*, McGraw Hill, México.
Maddala, G. (1977), *Econometrics*, Mcgraw-Hill Kogakusha LTD Tokio.
Mahalanobis P.C. (1936), “On the Generalized Distance in Statistics” In *Proc National Institute of Science*, India, 2, 49-55.
Martino, J. (1985), "Measurements of Technology Using Trade Off Surfaces", *Technological Forecasting and Social Change* 27, 147-160.
Mataix, C. (1982), *Mecánica de Fluidos y Máquinas Hidráulicas*
Megnint L., Neyrpic et les machines hydrauliques. *La Houille Blanche*.
Mowery and Rosenberg N., (1991) , *Technology and the Pursuit of Economic Growth*, CUP, Cambridge.
Nafinsa (1968), Aspects of Turbine Manufacture, mimeo Nafinsa.
Nafinsa (1977), *México: Una Estrategia para Desarrollar la Industria de Bienes de Capital*

Sen A. (1969), Choice of Technic, Blackwells.
Siervo, (de) F. and Leva, (de) F. (1976), “Modern trends in selecting and designing Francis turbines”, *Water Power & Dam Construction*, Agosto.
SPP-PNUD, "El Modelo Insumo-Producto". México.
Stahlschlussel-Taschenbuch, (1995), Verlag Stahlschlussel Wegst GmbH, Deuchland.
Statistical Abstract EUA. Several years.
Steward, F. (1983), *Tecnología y Subdesarrollo*, FCE, México.
Sulzer Escher Wyss, (1988), Lista de referencia. Escher Wyss
Utterback, J. and Burack E. (1975), Ïdentification of Technological Threats and Opportunities by Firms, *Technological Forecasting and Social Change* , 8, 7-21.
VDMA (1991), German Turbines, VDMA, Frankfurt.
Vernon (1966), “International investment and international trade in the product cicle”, *Quarterly Journal of Economics*, Vol 80.
Viejo Zubucaray, M. and Alonso (1977), *Energía Hidroelectrica*, Limusa.
Voith, (1995), The Company, Voith.
Voith, (1989), Turbinas Francis. Voith

Weeg, D. (1992), *Applications of Hydraulic Turbines*, mimeo, Voith.
Welch, L. and Luostarinen, R. (1988) “Internationalization: evolution of a concept”, in Buckley P. and Ghauri P (ed) *The Internationalization of the Firm*, (1993), Acdemic Press, Londres.
Wyss E. "Turbinas Pelton", Catálogos
Zaidman, B. and Cevidalli, G. (1989), “The Technology Efficiency Index: A Method for Measuring Process *Technological Forecasting and Social Change*, 35, 51-62.