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The Technological Trajectory of the Metal Mechanic Industry Based on the Technical and Economic Influence of the Process, Equipment and Material

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Abstract:

The evolution of the metal mechanic industry (MMI) and the hydraulic turbine production are analysed in a longitudinal study covering almost 80 years. To understand the role of the process, equipment and material framed in the industrial tree model and to measure the changes of technical and economic variables by using functional technometric index in order to set their technological trajectory, data of the main turbine producers and time series of industrial sector were collected. Less complex products are a powerful way to understand quality analysis and the diffusion process (no different to co-evolution and coexistence of the process, equipment and materials) under radical technical changes created by latent variables to produce a turning point in the technological life cycle.

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I. INTRODUCTION

The reproduction and expansion of innovations has been a central issue in evolutionary economic research and it is one of the main concerns of this paper. We can distinguish between two types of approaches, the first uses evolutionary dynamics (technological trajectory) as the central framework, and the second analyses the evolutionary selection process to gain an understanding of market mechanisms. The aim of this paper is to follow the technological trajectory version and to answer some of the questions posed by the dynamics of the diffusion process from a qualitative point of view. We follow in the footsteps of P PSaviotti and colleagues that have developed a similar perception of technical process in some well-known articles [1],[2],[3]. Rather than looking at the process of technological change as an outcome, the present article makes an analysis of the technological change from the perspective of production and focuses on the processes which take place in production itself and particularly in obtaining final products.

Many research projects have dedicated a lot of attention to developing models of selection processes, which can be applied to complex production in an evolutionary perspective [4], [5], [6]. However, complex production systems as well as time dependent decisions present problems for making further generalisation since applications to specific industries have not systematically captured the scope and depth of the complexity and as a consequence the combined results have not resulted in a generalized theoretical model. To understand the drive for technological change in products like aeroplanes, cars etc. we must include the materials, the production processes, and the machinery used in the process. This leads us to propose a study of complex production that include machinery, process and materials in order to arrive at a more complete analysis of qualitative change.

Our research uses the concept of functional techno-economic index that reflects the factors that determine equipment or industrial branch evolution and this is the index, with which this research is interested. Rather than measuring changes in technology of products from one period to another, the major purpose is to identify the role played by some critical variables in order to understand the prevalence and importance of a process, an equipment or a material in a specific industry.

The objective of the paper is to gain a better understanding of the technological trajectory (TT) and to answer some of the questions raised by other researches about the role played by TT to explain how technical change appears and the way it is diffused in the economy. The research aims at contributing to the role of innovations in structural change and what constitute the technological impacts on the variables responsible for driving the paths and those responsible to force the changing of paths. The metal mechanic industry (MMI) and the production of hydraulic turbine will be the area to analyse the above questions.

The remaining sections of the article are as follows. In the following section a short discussion of the background of technological trajectories is reviewed in order to justify a qualitative analysis of the industrial tree approach. In the third section the functional relation between the metal mechanic industry and the production of turbines is analysed using the industrial tree approach. In the fourth section, the industry producing hydraulic turbines is assessed on the basis of data collected about the main variables identified in the industrial tree. In the fifth section the concept of latent variables is developed leading to proposals regarding the future of the metal products' industry. Some conclusions form the last section.

II. QUALITATIVE ANALYSIS OF TECHNOLOGICAL CHANGE. A SHORT REVIEW

The concept of technological trajectories is central within the evolutionary perspective. Studies devoted to the analysis of technological trajectories in industry have in many cases resulted in industrial typologies in which one variable has been found to be the determinant of the trajectory. Both, sector and product-equipment analyses have been made.In the first category the classical analysis is Pavitt´s typology of industries [7] and in the second category the Sahal´s analysis of [8], [9] was the pioneer in identifying technological avenues while analysing the determinant variables in the technological trajectory. He added technical data from encyclopaedias on products like locomotives and planes to complement normal statistics. This methodology enabled him to get a different grasp of technological change compared with the pure statistical measurements often used in technometrics. Other applications are found in [10], [11], [12], [13], [14], and [15].

Different approaches have been developed to explain the process of diffusion like for example [16], [17], [18], [19], [20]. The technological trajectories were once thought to be highly useful, but they could not provide a general framework to answer how changes happen in the paradigm. An additional interesting avenue of research can be found in the Technological Life Cycle (TLC). The validity of the TLC have received a lot of criticism through the role of the dominant design as suggested by [21]. The question posed by [22] ofwhy there emerges only one dominant design has succinctly pointed out a weakness in the model. Reference [23] had already pointed at the problems derived from product and process innovation when mass and batches production take place since many intermediate production steps lead to demand discontinuity. In another line of research some researchers see how markets are shaped by shake out processes of firms as a way to explain changes in the industry structure reflected in the TLC.[1]

One way of tackling this problem has been to analyse the quality of the transformation. In this research approach researchers analyse what happen inside production and not simply around it. It enables us to see how raw materials are being transformed physically and not just in terms of their value. Two approaches have been used to capture this process. The first use the product characterisation of technologies and the second is the industrial tree that combines process, equipment and materials (P,E,M). The first emphasizes the close relation between selection and variety.[2] Firstly, variety may involve a more complex analysis than that represented by the characterisation of products on technical and service grounds. It would be advantageous for service characteristics to shape technologies so that no longer the coexistence makes progress during the time life of the product. In other words, service characterisation gives rise to incremental innovation explanations and does not have a significant impact on the process of diffusion, since it will end as soon the service become monotonous. Here, diffusion contents the dynamic of the innovation itself and not the repetition of the service without her modification. We are concerned with the copy of innovations but as well the very important little changes in the technology, *ee* incremental innovations and therefore the way to produce them; implying, the tenuous modification or some of process, equipment or material as will be suggest later. A second issue arise with the magnitude/importance of the variety related to the technologies population and when differences in the technologies explain the turning point. This assumption leaves little room for the possibility that a small population could generate radical changes in technologies. A third problem is the omission of some important inter-intra relations among the process and the materials, which can take command for a new technology. The point to be addressed here is that technical and service variables to represent the technology are not by themselves sufficient to represent any change embodied in the technology since the crucial change may come from other variables which are not completely reflected by the twin characterisation of the product.

Complex artefacts like cars, aeroplanes, motorbikes, helicopters locomotives are final products where substantial parts of the entire economy is engaged. These product categories are produced in complex production systems that include many processes with a large set of interdependencies. It is possible to speak of a degree of complexity and probably the aeroplanes, automobiles, rockets etc. belong to the group of the most complex products [6]. The second approach imply that complexity in production is measured as the amount of process, equipment and material and the many interrelations among them. We do not intent to cover the overall analysis of complexity but one way to understand the degree of complexity is by a process of disaggregation (by its parts) and –partitioning of the equipment, the process or the materials. In our view, it is a solid proposition to make complex more tractable and at the same time permitting us to analyze where does come from such complexity. The breaking out of parts do not just follow an analogical separation but the embodied technological and economic relation which we are looking for. The industrial tree is formed by process, equipment and materials and we claim that it is possible to include many aspects, but more important, the way how they are combined are the way how apparatus or composite materials, or process do have indeed and technical and economic sense. Here it is proposed a -composed less complex products- based on the possibilities to manage the partitioning of a product up and down stream ruled by the industrial tree.

The central aspect of the industrial tree (Rp) have to do with the -intention- to account how and how much a process has been utilized and in the same way for materials and equipment. Particularities and proprieties of those processes are encapsulated and taken as the basis to represent analogies of repetition. The analogy with a tree is that the -trunk- can spread features which are repeated in the overall three: all the branches from the bigger ones to the smaller; and in many ways this repetition of features is similar to the way the ribo-nucleic acid is represented by their helicoidally axes. In the manufacturing industry the process which take place in the transformation of raw material, are all the same (to a certain extent) for various industries, the whole or in parts, and in different places and in big or small economic organizations dedicated to the transformation of such material. Some properties from this approach will hold for accountability of the process which guides the way expansion and diffusion takes place and provide a wide perception to recognise any process which can be substituted for another and in this way allowing to understand the potency of the substitution, whether the determining factor will be a process, a material or an equipment.

III. MEASURING TECHNOLOGICAL EVOLUTION OF THE MMI

The principal goal of this article is the analysis of the transformation of the main process, equipment and material of the metal mechanic industry (MMI) in order to assess radical and incremental technological changes and at the same time evaluate the diffusion process.[3] Because the MMI is so vast, we have decided to measure the rate and direction of technological change in the following way:

a) Simplifying complex production by means of the main features of the process,equipment and materials (P, E, M) in order to carry out a qualitative analysis,
b) the (veracity) technological resume (synthesis) embodied by the (performance) process, product or material (in this case the production of hydraulic turbines)
c) the measurement of techno economic changes in the process, equipment and materials by means of a −functional techno-economic index.

Dualism in Terminal Equipment

Turbines as equipment are the end product of an industrial tree (not allowing a further transformation in itself) 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. From a methodological point of view 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 joining, cutting, and finishing metal. The following diagram describes by explaining the process, equipment and material (P, E, M) required to produce a Francis turbine which can be renamed as those P,E,M of the industrial tree (R_f) of the Francis turbine. This means that in order to produce a turbine it is necessary to have a combination of processes, equipment and material, some of them are required in the present while others needed to be carried out in an earlier period. Introducing the issue of terminal equipment duality R_f becomes a specification and simplification of Rp, for the analysis of the MMI.

In order to simplify and to cope with data only one kind of equipment, some group of processes and one group of materials are considered. In the group of processes, the design process comprises almost all the turbines. There exist 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 includes foundry (casting and smelting), forging, panning as well as welding and soldering. Mechanisation includes boring, brushing, milling, drilling, modelling and 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 together as being part of the same process.

The above scheme represents the *foundation* to analyse the MMI and the technological group of hydraulic turbines and the technological evolution of the process material and equipment to produce turbines. The existence of dissimilarities in the MMI and the assumption of temporality, do not represent a severe constraint to generalize the main representative features of the industrial tree of the MMI to understand the main features of technical change. This will be demonstrated in the following sections.

Functional Technometric Index

Measuring technological evolution has been analysed by many specialists with different approaches adapted to different purposes.[4] Some developments in this field are based on the capture of technical, economic and natural characteristics and events captured in the state-of-the-art as a convex surface in an *n* dimensional space in which *n* refer to the technological, economic, cultural and natural characteristics. The proposed model is an adoption of [8], [9] approachto study innovative activity characterised by a trade off among various characteristics. Reference [8] related with calculating technometric index is well-known because as well the standardised variables permits a more flexible analysis. However, as he limited the scope of the analysis to technical and scientific variables to explain the rate and direction of technical change, later authors e.g. [42] propose to include other variables in terms of product development. The origin of these characteristics, as well as their heterogeneity, differentiates the model from these approaches since not only are technical variables included, but also economic and natural (resources) local variables. These variables are applied to each of the industrial tree components, i.e., processes, equipment and materials. A total index can be conceived for the processes (Y_P), the equipment (Y_E) and the materials (Y_M) index and as well an index for technical and economic explanation of the PEM (Diagram 2). A hybrid of economic and technical index can be represented vertically and economic or technical data, separated, horizontally. The −functional techno-economic index reflects the factors determining equipment or industrial branch evolution. The purpose is to identify the role played by some factors identified in each process, equipment or material of the MMI in the production of turbines rather than measuring changes in technology of the value product from one period to another. The simplification of the analysis through the use of the industrial tree approach and by studying a −composed less complex product make it not necessary to look for a complex and general measurement. Measurements like entropy statistics are suitable for complex technologies products where the relation between variety-selection and technological changes under a general growth theory rather than the structural change is important.[5] However, because we consider structural changes to be important and because the product-technologies are not categorized according to the twin characterisation (mentioned in the previous section 2), measurements using entropy statistics can be avoided if it is used constructed less complex products.

In the industrial tree approach each index is determined by variables corresponding to the industrial tree's process, equipment or materials (P, E, M), which can be defined by technological, economic, or natural resource variable:

$Y = (X_i, W_i, C_i)$

In this equation $X_i$represents the variables with a technological basis,$W_i$those with an economic basis, and $C_i$the natural resource variables corresponding to the location. Technological advancement is measured by the trade off between the different variables, by what is gained and lost by the combination of certain variables. Each variable can thus have different attributes, such as design, performance, skill, experience, specialisation, competitiveness etc., which can be understood as a n dimension space.[6]

A technometric −function can 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:

$Y = \alpha_1X_1+\alpha_2X_2+ \alpha_3X_3 +...........+ \alpha_nX_n$

in which Y is the technological parameter obtained from applying values $\alpha_1, \alpha_2, \alpha_3,....... \alpha_n$, , given the regime's variables $X_1 , X_2 , X_3 , ... + X_n$. This index explains the profoundness of the technological change. However when the weight is obtained through the relation of the total variation and that of each group of variables, the index value for "Y" equals one. In other words a −functional technometric index can be found which can indicate which variable has a stronger influence on technical change and this is the index that we are interested in. Changes in the variables correspond to changes in Y. The value for Y correspond to the performance of technologies. For calculations it could be represented by the variable which resume the technological change of the turbine Francis (X_1) or another variable which represent technical change or productivity in the industrial sector, ee the Metal Mechanic Industry as a proxy. This last one was preferred to avoid multicollinearity. See appendix B.

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

$Y_w= \alpha_1W_1+\alpha_2 W_2+ \alpha_3W_3 +...........+ \alpha_nW_n$

In this case, the category W refers to the economic variables: price, transaction costs, scale economies, management capabilities, risk or another institutional nature variable. It is possible to obtain a hybrid index by combining technical and economic variables. In that case the measuring imply the influence of X or W on the index Y. See Appendix A and B.

Group of variables of Rp with influence on technological change

From the analysis of the industrial tree of producing turbines R_f (equipment) a group of technical and economical variables were analysed. The variables showed below represent the group of technical and economic characteristics of the process, equipment, and materials for producing turbines. The variables in the table 1 were found to be the most representative in terms of playing a more important role in defining the rate and direction of technical change. Variables denoted with X are technical variables and W are economic variables. For a more complete definition of variables and data information see the Appendix A at the end.

IV. TECHNOLOGICAL CHANGES IN HYDRAULIC TURBINE PRODUCTION

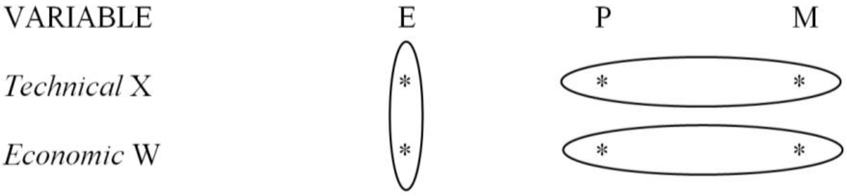
The technological synthesis in the composed less complex product (LCP) can be understood more easily within a process of disaggregation because it consists of fewer parts and as a consequence fewer relations between the parts. The technological synthesis of hydraulic turbines can be summarised and identified through functional groups of variables. A measurement of the evolution of hydraulic turbine is made by means of the Compound H-Ns. (variable X_1 see Appendix A). In order to assess the difference between evolutions of terminal equipment (turbine) itself and the P, E, M's evolution for producing the turbine, it was necessary to work out the techno-economic index of P, E and M.

The height and specific speed component H-Ns (represented by X_1) reached two peak points between the twenties and the nineties. The peak points appeared in the forties and in the eighties. Statistical analysis $X_1$is complex because the various determinant factors differ from one period to another due to the fact that the processes, equipment and materials vary from one period to the other. However, we can note that the value of the X_1 in the forties and fifties does not differ from the value of the X_1 in the eighties as can be seen in the Graph 1. This situation shows that technological evolution measured by the component H-Ns (X_1), may not fully capture all the relevant changes, in this sector or in the analysed equipment itself in comparison with other sectors involved in turbine production and the metal-mechanic industry sector as a whole. The peaks (40-50s and 80s) are similar but behind this similarity a major shift has taken place in the production system. This shift encompasses the exploitation of economies of scale, an increasingly integrated metal industry sector, and radical changes in processes, equipment and materials which allowed the exploitation of greater natural resources reflected in larger turbines. There were two technologies for producing equipment. One utilised cutting metal process, small equipment and steel material. It was mainly developed from the beginning of the last century and reached a maximum during the forties. Another technology developed in the middle of the last century achieving maximum development in the eighties based on welding and soldering process, prices of steel, bigger equipment, and bigger transportation. This last technology will be examined more in detail below.

Explaining the evolution of the equipment itself (Francis turbines) by measuring the equipment, process and material of the MMI

Equipment

The dominant trajectory is analysed through the results of the functional technological index of the industrial tree of turbine production. It is first done for the equipment on technical and economic grounds and later on for the processes and materials together under technical and economic variables separately as can be seen as follow. See appendix B for regression analysis.



A constant relative reduction of turbine weight and size (measured through the Weight-potency: Ns component variable X_4), infrastructure costs measured as the cost of the complete hydroelectric project (in constant US $C/kW, variable W_2), and firm internationalisation (average production growth rate in MW of the installed turbines outside the home country, variable W_6) are the factors that have been found to be important in turbine evolution. The functional relation of the technical and variables shows this.

(1) $Y = -0.59 + 0.55X_4 - 0.33W_2 + 1.3\,W_6$ $\quad r^2 = 0.98$

(83.5) (-3.5) (4.1) (-4.1) (10) $\quad$ e=0.032

The direction of equipment technology is explained by a technical relation weight-potency (X_4), combined with the 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 can also be noted. It is possible to interpret schematically the relative importance of the main crucial variables in relation to H-Ns component value (Graph 1) by assuming a strong influence on the highest values of X_1 and the rest of the variables analysed on the base of the curve. However further analysis is required in order to understand where the curve motion is influenced by such variables and which variables have a strong influence because the regression covers the whole period from 1930-40 and it is possible that the major pressure appears not on the top but on the bottom of the curve.

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 ($T/KW) is considerable, it does not have much influence on the total cost of the project. However, the cost per KW, considering the whole of the hydro-electric project (W_2) is of relevance ($C/KW) as can be seen in Graph 2. 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. The negative value reflected in the equation must be understood by the way normalisation was calculated. In this case the less costly the KW of the hydroelectric project the higher the value.

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 has been an important feature in influencing technological change (W_6).[7] Table 2 shows the firms analysed and their participation in the overall production since 1900.

Processes and Materials

Processes and materials influence producers internally and externally. Internally they are defined by certain technical variables (in both process and material), whereas externally they are ruled by certain economic variables. 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. This can be shown as follows:

a) Technical variables. Technological change in <u>process</u> and <u>material</u> is explained by metal cutting and shaving mechanisation processes (X_{11}), finishing and transportation (X_{12}) as well as the use of welding and soldering materials (X_{19}) as it is showed by the equation (5).

(5) $Y = 1.4 - 0.07X_4 - 0.83X_{11} - 0.29X_{12} + 0.51X_{19}$ $\quad r^2 = 0.97$

(103) (8.3) (1.03) (-4.8) (-1.4) (3.8) $\quad$ e=0.025

Two important groups of variables merit further mention: First, 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}). The processes of conformation (X_{10}) and metal cutting mechanisation (X_{11}) also influence the rate and direction of technological change.

Second, the variable of the number of workers per machine, is a productivity measurement and may be partially or completely related to each of the above-mentioned processes.This variable has importance in conjunction with other variables, but it does not have the importance of metal cutting mechanisation, or finishing and transportation. The importance of material welding (X_{19}) also reflects the performance of the forming processes with the exception of metal cutting (X_{10}). The introduction of welding and soldering has in practice modified the forming processes, but the end product has not changed. What has happened is that welding and soldering are gradually replacing forging operations, and foundry and other operations, such as trimming and rolling. The joining process started out more owing to new materials, in order to adjust to the increasing size of equipment thus overcoming problems of metal fatigue and corrosion. The importance of welding material and the process of welding and soldering can thus be noted in process change.

Of course other materials have evolved such as different kinds of steel but they have not been as crucial as soldering, metal cutting and shaving mechanisation and finishing processes. 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, welding and soldering have surpassed them. Even though there have been significant advances in metallurgy, in the period comprised from 1950-1980,they didn´t have the same importance as they did in other periods. Materials may come to prevail later on, in the nineties, and in such case, steel and its many applications will also be dominant.

Welding 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.[8]

b) Economic variables. As opposed to the technical effect, the economic effect is more homogeneous in the sense that all these variables influence technological change and we can notice a good association 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}. In fact, although the importance of some of the variables, such as design (W_8), is increasing, 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.

Together with salaries, production costs include the price of steel (W_{15}) as part of the materials, which 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. Wages to a certain degree also have been less influential over technology and only in combination with other variables have had 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 increasing as a group have less impact reflecting a situation in which the greater degree of specialisation results in higher salaries which lead to substitution effects resulting in a decreasing trend of the share 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 pronounced. 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 because 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 relative 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. Together with the price of steel (W_{15}) the increasing cost of capital process-equipment given by the supply price of capital goods (W_{14}) has thus been of great influence.

(6) $Y = 0.33+0.24W_{10}+0.39W_{14}+0.28W_{15}$ r2=0.98
(160) (1.2) (1.9) (3.9) (1.3) e=0.018

Technological change rate and orientation from an external economic perspective are 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 automation are noted.

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 is that there exists a feedback process between the economic agents that carry out inventive activities and institutional 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. But some of the economic variables are more institutional than a pure market mechanism and the role of institutions among other things impact on the maturation of markets. However, firms do have better control over technical variables and, therefore, have possibilities of influencing technological change. Technological change may emerge from both kinds of forces, but within the firms dominates the technical variables while the economic variables prevail in the firms' environment.

Dominant variables are those variables, which prevail (in periods) in certain process, equipment or material. It could be said that technological trajectories can be explained by the prevalence and dominance of certain variables. In this way it is possible to speak of three trajectories:

- The first trajectory, T_1, refers to equipment as explained by the weight-potency relation (X_4), the cost of kW of the construction project (W_2) and by the internationalisation of the firm when it expands into 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 welding (X_{19}).
- The third trajectory, T_3 , is explained by the cutting shaving mechanisation costs (W_{10}), the price of steel (W_{15}) and the price of capital process-equipment (W_{14})

To put the above results in the context of firms, industry and technology the following elaboration can help to understand the role played by each dominant variable. Firms focused only on turbine production without putting attention to other external activities can find it tobe increasingly difficult to compete with firms with a broader strategic scope. These firms are both engaged in the production of turbines and are in parallel engaged in heavy machinery. Some of those firms appear in the table 1 and 2. For the MMI it is more difficult to assess the uniqueness of a certain variable to influence the technology trajectory, for example, X_4 also plays a role in the Technological group. The MMI contains many activities, which are related to several influences. Indeed the MMI is a complex industry, which is not subjected to further reduction and consequently there are many influences as can be seen when looking both at the technical variables and the economic that together impacts on the technological trajectory. The Technological group of producing turbines are more influenced by economic variables such as the integration of the turbine with the hydro electrical project where many other firms and industries are involved and also with the price of specialised equipment to form and cut steel.

V. LATENT VARIABLES

A latent variable is the potential influence of a certain variable over an existing technological dominion. This type of variable functions with a escalating degree of influence over economic activity and may potentially be more powerful than other variables. This type of variable contrasts with the dominant variable that already has an explicit and proven dominion over technological change along the technological trajectory. Those variables that we analysed in the previous section are dominant but may be under pressure by latent variables when we move to another kind of technological regime. The following latent variables can be mentioned:

i) 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 of the process of design (in general). 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 shows promises to be a potential variable that may eventually turn to be dominant. Learning has taken place through (planned) trial and error processes that has resulted in improved turbines. The development of the understanding of problems related to fluid mechanics, and thus tocavitation and the application of hydrodynamics, has helped develop better designs.[9] More radical changes in this process have taken place more recently as designs have been improved through the finite element method.

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 also has an impact on the labour force requiring even more highly qualified human capital. It is a reconfiguration in which one type of specialist activity is substituted in different quantitative and qualitative terms through the introduction of design programs that demand another type of highly skilled labour. Intensive and specialised use of Cad-Cam itself demands further labour specialisation. It is thus not a traditional type of substitution in which the intensive use of almost unskilled labour force is replaced by capital and a highly specialised labour force.

The benefits of these design innovations are in many cases immediate. 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 the entire basic and intermediate mechanical industrial sector. We can notice a decrease in the price of the products as well as an improvement in the quality of the output of the sector as a whole, which upstream results in higher productivity and downstream results in a tremendous substitution of the manufacturing´s design of the overall parts and equipment in transport and construction industry.

ii) The conformation processes (X_{10}) are another kind oflatent and potential variable in which casting some parts of the turbine and joining through milling has been replaced by welding. That is to say there is a co-existence and a co-evolution of two processes in which welding has a growing impact over the conformation processes and the foundry gradually losing its hegemony but continuing to play an important role. The introduction of welding in the fifties and its evolution through better welding and soldering techniques together with the invention of new welding and soldering equipment radically transformed the overall process of forming in the sixties, seventies and eighties. Time and costs were notably reduced as a consequence.

However, despite the fact that this process has considerable importance in itself, it has not come to dominate other processes such as metal cutting and shavings mechanisation, and finishing and transportation. In other words, this process has so far not had such a great impact on hydraulic machines. Nevertheless in other sectors of the metal-mechanic the importance of this process has been evident for example the structures to build a large-scale infrastructure and buildings where it is very likely that conformation processes can become a dominant variable.

iii) 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 they 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 seemingly endless usages. Nevertheless a consequence of the fact that these technical characteristics are latent and hence do not display a dominant persistence is owed in part to the emphasis in the turbine industry on size and potency during the sixties and eighties. Should this emphasis continue to decrease in the future; there would be indirectly a greater chance for the technological advantages of the new alloys even to restrict its costs.

Latent variables showed by the industrial tree approach constitute a way forward in a dynamic technology selection perspective by interrelating P,E and M and at the same time it shows the process in which one technology become dominant and from here the production of innovations of the path of the technology. In fact latent variables do not explain the way in which new technology overtakes the old. In the first latent variable case, the design process is a consequence of the dynamics of this process, an evolution of design since old methods and equipment are no longer in use, the basic scientific and technological paradigm have not changed. In its place other equipment has been added and this process would become hard to explain using Arthur´s analysis [47]. However, since the beginning of the analysis, regime variables were taken into account, and consequently both Nelson's analysis[18], [48] orSaviotti's variety and natural selection [2], could fit much better because they include technical or other kinds of variables in addition to cost variables. The same could happen with the process of welding and soldering and metal cutting and forming process where clearly there is a co-habitation for staying and living not so different to the point of view that can be found in [22] or [24] in contrast with the market structure alone.[10] There continues a battle for which of these processes that will have a larger diffusion. In other words, the evolution of each process make their way by means of realising and recognising new terrains and inventing and adapting to new circumstances.

VI. CONCLUSIONS

In this article we have developed an industrial tree approach to analyse the evolution along the technological trajectory of MMI in general and the production of turbines in particular. We manage to capture this industry and obtain a composed less complex products. The industrial tree approach proved to be an alternative well equipped to provide a framework to analyse changes in comparison with other techniques developed to analyse complex products.

The evolutionary pattern of the MMI and the technological group to produce turbines and the firms involved, can't be understood without a wider approach to technological change. Market evolutionary principles are not sufficiently strong to explain the evolution of MMI. Instead the co-evolution of certain processes and many of the equipments provide the backdrop to understand the supremacy and predominance of certain designs, processes or products in an industry producing less complex products. At the same time, because there is no signs of obsolescence of the turbine itself and due to the fact that the processes to fabricate it co-evolved, it is difficult to depict the evolution as the pattern of the S curve since neither the equipment nor the process have diminished but continue to evolve adapting to new circumstances. The technological synthesis compound H-Ns (variable X_1) depicted in Graph 1 has showed the consolidation of two different technologies, one reached a maximum in the beginning of the 1930s and the other in the 1980s.

The industrial tree approach has enabled us to track two changes that so far has been largely absent from the analysis of technological trajectories and industry evolution. The first is the observation that behind the cyclical pattern of an industry each downturn and upswing (though seemingly appearing to be similar) profound changes in industry structure can take place. This can either take the form of a reconfiguration of the existing set of dominant variables that largely determine the evolution of the industry. The second observation is the role played by latent variables that appear to be one of the crucial factors in order to understand a shift in the technological lifecycle when earlier dominant variables are being replaced with latent variables that later on will take the position of dominant variables.

In order to understand the interrelation between MMI and turbines, the industrial tree approach has shoved a strong basic relation since process, equipment and materials are the basis of any change. When interpreting the long run of the MMI by means of analysing turbines trends as a way of substituting equipment the techno-economic index is well suited to identify and evaluate the crucial variables and has proved to be a useful technique to measure which variable that has higher relevance. The fabrication and production of turbines is not in isolation of other industries in particular in relation to the MMI which evolve with the new turbines where substitution of process, equipment and material took place. First, it made it possible to interpret the restructuring of the industry and the way economic and technical factors of the new processes, equipments and materials during nearly 50 years spread. Second, it was possible to associate the path of turbine synthesis, the compound H-Ns (X_1) with the most important variables which took place to refine the evolution of the MMI in the period between the 1930 and 1980s where substitution of process and material to conform the equipment of turbine were dominated by technical variables whereas economic factors influenced materials. To understand the period of lower value of H-Ns (X1) in terms of the restructuration of the MMI implied a mixture and cohabitation of old and new processes, and a cohabitation of the modernization of the old process in front of new ones. The developing of new turbines and the new MMI give way to bigger equipment, bigger projects and bigger turbines. That is, that from the 1930s the processes started to increase the size not just of the turbine but also of the transportation of parts and machinery which resulted in the improvements of machinery until we reach the 1980s.

Diagram 1

Processes	**Equipment**[11]	**Materials**
(P_i) *Design*	**(E_j)**	**(M_k)**
		Steels
Conformation		Welding compound
Mechanisation	Equipment: Turbine	Lubricants
Finishing		Other
Transport		
Installation and testing		

Marketing/service

+Table 1Variables considered

X_1	Compound High: Specific speed	Equipment
X_2	Power.	Equipment
X_3	Size.	Equipment
X_4	Compound Weight-potency: Specific speed	Equipment
X_9	Intensity in the design	Process
X_{10}	Intensity in the forming	Process
X_{11}	Intensity of mechanised operations	Process
X_{12}	Other operations intensity. Finishing and transportation	Process
X_{14}	Steel	Material
X_{19}	Welding and soldering	Material
W_1	Price per turbine	Equipment
W_2	Price of the hydroelectric project and construction	Equipment
W_3	Index concentration of group of producers	Equipment
W_5	Index concentration by countries producers	Equipment
W_6	Production out country origin	Equipment
W_8	Design costs	Process
W_9	Forming costs	Process
W_{10}	Mechanising costs	Process
W_{11}	Other operational costs	Process
W_{14}	Capital-goods price (operational supply cost)	Process/Equipment
W_{15}	Structural steel price	Material

Diagram 2

Process **Equipment** **Materials**

P_i......P_n E_j......E_n M_k.......M_n

Index

$Y_{x\ (tecnic)}$

$Y_{w(economic)}$

------------ ---------- ------------

$\mathbf{Y_P}$ $\mathbf{Y_E Y_M}$

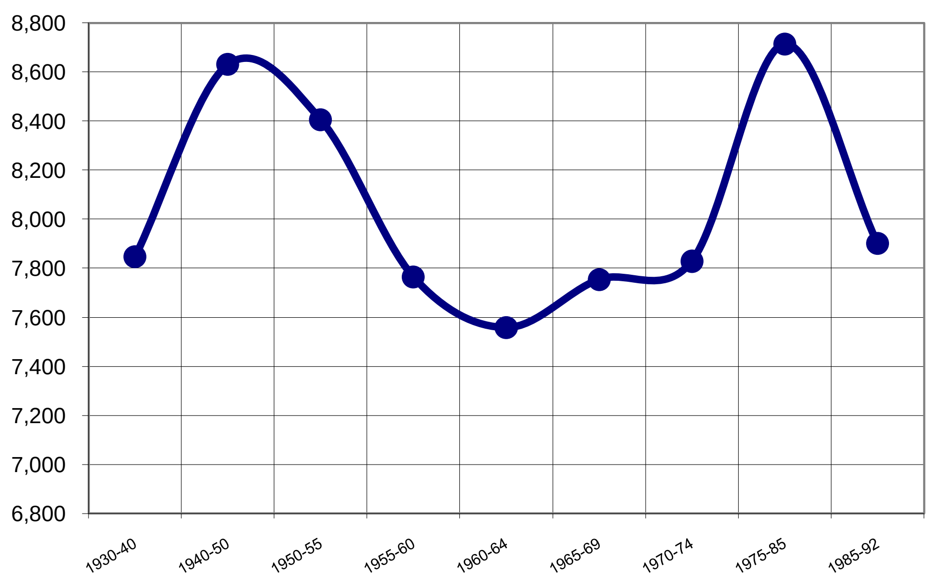
Table 2 Share of the production of turbines by group of producers (as % of MW installed)

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
Other firms					0.07	0.13
s/n	0.10	0.03	0.04		0.01	

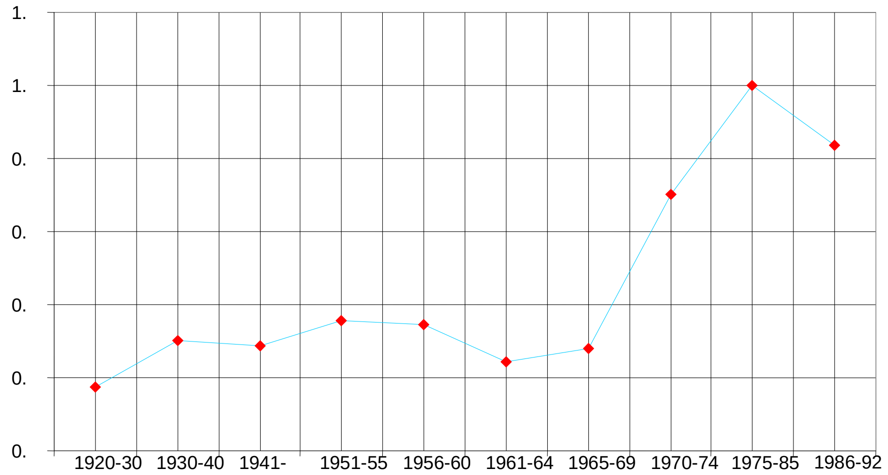
Group 1: A Chamber, Echer-Wiss, Neyrpic, Toshiba, Voith, Hitachi, Kvaemer, Mitsubishi. Group 2: Hydroart, Nohab, Vevey, Voest, Fujii. Group 3 :Boving, DEW, KMW, English-Elec. Group 4: Riva, Tampella, Tosi Group 5 : Baldwin-Lima, Boving-KMW, Creusot-Loire, Mil. Group 6: Russe, LMZ, Building (LMZ), KTZ, Lijostroj, Skoda, CKD-Skoda, Temaire Skoda, RomeNegro. Group 7: DFEM, TP,E,M, Tiajin, DEMW, Dengyosha, Temsan.
Note: The table do not include fusions and firms that have disappeared.

Source: Based on direct information from the companies.

Graph 1
H-Ns Component Value (1920-1990)



Graph 2
Index Cost Mw-Hydroelectric Project (1920-1990)



Appendix A

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

Variable	Coverage	Years	Data analysed
X_1	World &western	1920-1992	Universal & western
X_2	World & western	1920-1992	western
X_3	Regional & country	1930-1990	Mexico and western
X_4	Regional & country	1930-1990	various countries
X_9	Local & producer	1930-1990	various
X_{10}	Local & producer	1930-1990	various
X_{11}	Local & producer	1930-1990	various
X_{12}	Local & producer	1930-1990	various
X_{13}	USA & MMI	1930-1990	statistics
X_{14}	Local & steel ind	1930-1990	survey
X_{19}	Local & steel ind	1950-1990	survey
W_1	Local & producer	1930-1990	producers
W_2	Regional & EUA &México	1930-1990	specific studies
W_3	World & western	1930-1990	western data

W_5	World & western	1930-1990	universe &western
W_6	World & western	1930-1990	western
W_8	Local & producer	1930-1990	various
W_9	Local & producer	1930-1990	various
W_{10}	Local & producer	1930-1990	various
W_{11}	Local & producer	1930-1990	various
W_{14}	USA & Capital goods	1930-1990	statistics
W_{15}	USA & Steel ind	1900-1990	statistics

Notes:
- World. Referred to the technical data of the all installed Francis turbines in the world
- Western. Referred to the technical data of the Francis turbines installed and produced by western companies. Except for Japan´s companies It does exclude Asia and Russia companies.
- Regional. Referred to a region were turbines were installed. It could be Europe´s countries, USA, Japan, México, Brazil and other developing countries. Data observation was constrained and could be an average
- Local. It is referred to specific location of a country. Economic and some technical data were constrained.
- Producer. It is referred to a manufactures of Francis turbine or MMI industry, or Steel industry.
- Surveys and specific studies. Data published by companies of the technological sector, MMI and Steel industry. Also it includes specific studies on dams produced by governments and companies.
- Various. It is referred to data from statistics, surveys, producers and interviews with experts of the Francis turbine industry and MMI.
- Prices were deflated to US$ of1982 according to industrial and whole index.

Description of variables

Equipment

X_1. It is a constructed variable base on the 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 an adjusted regression function Ns=f(H). n refers to the number of observations.

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

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.[12] It is considered a design variable[13]. $Ns= nP^{0.5}/H^{1.25}$.

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.[14]

First, the data analysed was based on the overall Francis turbines installed in the World since 1900-1992 by all kind of producers and second, an analysis was based on turbines manufactured by western firms included the production carried out by developing countries. Source: Direct data from the main producers.

X_2. Power. It is the sum of all potencies of the turbines divided by the number of units by periods. The power is given in MW of all the turbines bigger than 15 MW.

The data analysed were based on Francis turbines installed and produced by western firms.

X_3. This is a constructed variable: Size relation. This is based on:

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

Where i is 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 an increase in efficiency. Thus the higher values of Ns the diameters have been reduced and also the efficiencies have increased.[15]

The Real Diameter data were measured from turbine installed in several México´s dam developments. Estimated Diameter was calculated from general data of producers. Number of observations were reduced to the installed Francis turbine in México since 1930.

X_4. This is a constructed variable. 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.

Data. Weight of the turbine was estimated from Francis turbines installed in México´s dam developments. The specific velocity comes from X_1 calculations. Number of observation depended of the data collected from installed Francis turbine in México since 1930.

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

Data source comes from the main producers, buyers, and contracts found in death files. Observations were limited for each period since it depended of the price of the turbine sold. There was strong information confidentiality.

W_2. Price of KW of the hydroelectric project and construction. It refers to the cost of the hydroelectric project (infrastructure). It is given as an average US Dollars of 1982 per KW installed ($C/KW).
Data source: Specific studies on EUA, Word Bank, IBD and Mexican dam developments. Observations number were limited but without a confidentiality constraint.

W_3. Global concentration Index of the main producers per time periods. It is calculated according to the HenrfindahlIndex.
Calculations were made on the basis of Western producers of the installed Francis turbines. It excludes China and Russia (USRR).

W_5 Concentration average in several countries including the producer country origin by time periods.
Calculation came from installed Francis turbines in developed and developing countries. It does not include China and Russia (USRR).

W_6. Rate of growth of the production average of Mw of turbines installed out the country home (in time periods).
Data belongs to western manufactures of Francis turbines and statistics surveys of western industry.

Process

X_9. Intensity in the design. Average hours worked to design a turbine obtained as a proportion of total hours worked to produce a turbine.
Data information come from an written questionnaire send to the main manufacture companies of Francis turbines, interviews with personal expertise, special studies from [54], [55]and similar studies of the Machine tool industry. Data was limited because of confidentiality.

X_{10}. Intensity in the forming. Average hours worked to form the turbine by process like founding, forging, bending, cutting, soldering but do not taking into considerations metal cutting and shaving operations. Average hours worked as a proportion of total hours worked to produce a turbine. Data source the same than X_9.

X_{11}. Intensity of mechanised operations. Average hours worked of metal cutting and shaping mechanised operations. Average hours worked as a proportion of total hours worked to produce a turbine. Data source the same than X_9.

X_{12}.Other operations intensities. Average hours worked for finishing, transporting, fixing, and testing operations. Average hours worked as a proportion of total hours worked to produce a turbine. Data source the same than X_9.

X_{13}. Number of workers per machine.
Data source. Specific studies from capital goods and the MMI industry in EUA. Also [56] and [27]. Data limited.

W_8 Design cost. Average cost of design a turbine measured as a proportion of total direct cost.
Data source is the same than X_9.

W_9. Forming cost. Average cost of forging, cutting, founding, bending, soldering (operations) a turbine measured as a proportion of direct cost. These operations do not include metal cutting shaving operations. Data source is the same than X_9.

W_{10}. Mechanising cost. Average cost of metal cutting and shaving operations measured as a proportion of direct cost. Data source is the same than X_9.

W_{11}. Other operations cost. Average cost of finishing, transport, fixing, testing operations measured as a proportion of direct cost. Data source is the same than X_9.

W_{14}. Cost index. Index of producing capital goods in United States since 1900.
Data source. EUA statistics of capital goods industry and [56].

Materials

X_{14}. Steel proportionality modulus.
Data source. Surveys

X_{19}. Soldering coefficient.
Data source. Surveys. Producers, interviews with personal expertise

W_{15}. Structural steel price index.
Data source. EUA series statistics.

General Data source

The data were collected from the main turbine producers related to the installed Francis turbines in the world, from interviews and questionnaires to the producers and to expertise consultants in Europe, Japon, USA, Mexico. Data was required to construct time series of metal products industry, and machinery and steel industry from 1920s to 1990s. Two kinds of data can be deduced: the data which comes from direct source of the main producers in industrialised and developing countries and the data from time series of industrial production sectors of the US economy and European countries and from specific studies and articles related with the machine tools and MMI industry. Information from statistics of those firms which produce turbines, magazines and surveys, 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. Some of them are the Comisión Federal de Electricidad (CFE) various numbers [57], [58], [59], [60], GEC AlsthonNeyrpic[61], GE[62], Materials [63], Historical Statistics, USA, various numbers[64], Hydroelectric Plants Costs [65], INEGI various numbers [66], NAFINSA-ONUDIvarious numbers [54], [55], Neyrpic[67], OECD [68], SECOFI-PEMEX [69], tahlschlussel-Taschenbuch[70], Statistical abstract various numbers [71], Sulzer Escher Wyss [72], VDMA [73], Voith[74]. The main producers were grouped and presented as in table 1.

Appendix B
Functional techno-economic 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 and convenience it was necessary to consider small groups of variables and to relate them to an economic and technical causality. Periods were arranging according to the data availability and in general for technical variables of type X data cover almost universe but for data type W and some X the opposite was the case. So in order to follow a regression analysis it was necessary the mixing of variables with different coverage; data were arranged by periods from 1930 to 1992 and for each period an average value was calculated and standardized.

The data and statistics analysis were based on:

1) Functional index analysis Y was based mainly on Sahal and Esposito studies. A holistic index and not a total index was calculated. The first measures deep technological changes and the second the progress. The type (a, b, c, d) of the data to be analysed was adjusted into an each period and a ratio was obtained by using the highest (or lowest) and at the same time homologising and standardising the information as follow:

$\mathbf{X_{ij}/\not{X}_{ij}\ , W_{ij}/\not{W}_{ij}\ ,\ C_{ij}/\not{C}_{ij}}$

Where X, W and C correspond to technical, economic and natural variables (i) and (j) correspond to the period analysed. $\not{X}$, $\not{W}$, C are the maximum or minimum values of each variable.

In order to find the best combination to get a lineal equation (semi log and log log) several regressions were made in order to fit the following equation:

$\mathbf{Y= a_{1+}\ a_2\ X_2 + a_3X_3 + a_4X_4 ...... a_nX_{n-1}}$

WhereX represent technical variables.

Regression analysis was based on different technical, economic arranged on process, equipment and materials. 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 as was showed in section 4.

From the beginning, the analysis was guessed since there were certain coherence in the way of relating the variables together owingto technical and economic knowledge of the industry sector. The values of "Y" were based on the rate of growth of productivity in the metal product sector in the US economy and some cases it was used the variable X1. However this last one were used as way to monitoring collinearity. The same value of Y was used by the process, equipment and material and once it was adjusted the overall variable were normalized in order to get a functional index.

2) Test depended on type, quality, quantity, information and the estimator's programs availability. Around 60 equations were analysed by means of the combinations of the variables. Some textbooks were referred [81], [82].

i) F and t test for all estimators. (e) correspond to the standard error

ii) In general in the overall analysis the preparation of the data before to submit it to a regression analysis was the basis to avoid uncomfortable future disturbances. In that way multicollinearity could not be so important (or relative) since in the special case where it showed its presence in the data, the relevant analysis consisted in understanding 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 partial and total correlation coefficient.

iii) The analysis of the information was likewise utilised to make tests in order to specify errors. From the beginning a mix of economic 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.

iv) 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 a non-lineal model was omitted because the number of variables included in the regression were restricted by the number of the degrees 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.

v) Theheteroscedasticity 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)	e=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)	e=0.025
(6)	Y=0.33+0.24W10+0.39W14+0.28W15	r2=0.98
	(160) (1.2) (1.9) (3.9) (1.3)	e=0.018
(7)	$Y=0.15+0.14X_4+0.59X_9+0.28X_{12}$	r2=0.94
	(56) (1.2) (1.17) (3.7) (2.3)	e=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)	e=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)	e=0.031

Foot Notes

[1]However [24] discussed the aeroplane´s industry which is different tothe industry´s structure reflected in the TLC can´talways be proved in whole of industry since more complex production process displays different patterns.

[2] A first version of the twin characterization of technologies is in [24], and then in [2], [25] and some application in [3].

[3] The MMI is and industry with a long history with many transformations. See for example [26], [27], [28], [29] for metal mechanic and [30] for the processing industry.

[4] Other studies [10], [11] 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 [31] and with the concept of discriminate function elaborated by [32] which according to Sahal both approaches are similar to his proposition of technological distances [9: 14-15]. In an analogue approach, from [33], [8], [9] and Martino [34], the innovative activity can be seen as a trade off among several technological characteristics. This author worked with the concept of composite approach for measuring technological change based on the holistic index. References [35], [36], [37] have studied the relation between methods, technical characteristic of the products and services and its relation with technological regimes. A review of measurements is found in [38], and [39] and [40] for a survey of evaluation and measurement on R&D and patents. Reference [41] had made a full review including the -ideal technometric measurement.

[5]Several authors have developed the measurement of entropy statistics and some researchers have used to compare changes in variety and the process of changes in technologies. See [4], [1], [5]. Results have showed a relation between a measure of variety and some kind of technical change. The measurement is general since it can't explain more than a change in the measurement associated by the events in the industry. On the other hand entropy statistics have been criticised for only applying continuous data with no disruptions. See [41].

[6] These variables represent technical and economic concepts which can be understood as n dimension space. According to [8], [9] the characteristics represented by distinctive variables (in fact this reference considered only technical variables) are distributed normally and the surface is identified by an ellipse S(0) with n dimension and a centroid C(0). At different time to T(0), for example T(1) there is an ellipse S(1) and centroid C(1). Distance between centroids of the ellipses C(0) and C(1) can be considered as a measure of technological change.

[7] For further analysis of internationalization firm see [43].

[8] 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 technical structural problems.

[9]The design of hydraulic turbines had a long history. See [44], [45][46]

[10] Market structure formed after shake out process in certain periods of time [49], [50] can´t always explain the overall industry structure because it lacks the inclusion of institutional forces.

[11] The equipment required to produce a turbine is related to practically every other industrial process. Hence there is computing equipment, (including hardware and software), the foundry (ovens, melting pot, forms, centrifuge), laminating and forging (laminated, rolled line trends, 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, trucks, pushing and pressing machinery, crane, industrial tractors), finishing (oven tanks, transporting devises).

[12] The specific speed of revolutions is a result from different turbine´s producers which have made laboratory test with samples models and prototypes. Tests are based in the concept of a-dimension 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 the turbine dimensions and in order to simplify the analysis, all the tests start by supposing null viscosity effects and the assumption that a geometric similarity implies a mechanic similarity. See [51].

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

[14] For the periods 1960-74 and 1974-84 Siervo and Leva see [52] and [53] found similar results.

[15]Reference [52] and [53] both analyses show the size of the turbine studying the tangential velocity coefficient (Ku) defined by $Ku= 3.1416D_3 n 60^{-}(2gHn)^{-0.5}$. 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.

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