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PRODUCTIVITY, TECHNOLOGY
AND DOMESTIC EFFORTS
IN RESEARCH AND DEVELOPMENT
(the growth-path of a Rayon plant)

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I. MAIN TOPICS OF THE STUDY

In March, 1937, Ducilo S.A. opened its rayon manufacturing plant on the outskirts of the city of Buenos Aires. It was the Argentine branch of the Du Pont de Nemours and Co. group of the United States. This was the first time rayon had been produced in Argentina, sixteen years after Du Pont opened its first rayon factory in the United States, in Buffalo, New York. 1/

Four decades later - - in 1975 - - Ducilo's rayon plant completed its productive life cycle, at a time when rayon was fast losing ground to other synthetic fibers.

During the forty years between the plant's opening and closing, it built up a rich industrial and technological history which not only had an effect on the plant's own long range economic performance but also on that of its suppliers of raw materials, parts and machinery, of its clients, and on the overall engineering capacity of the firm as a whole, which is evidenced by the company's diversification towards other products such as freon and cellophane, and by the completion of various modernization programs over a period of years. 2/

1/ In 1919 there were three alternative rayon-producing processes, none of which belonged to Du Pont de Nemours. Of the three, Du Pont chose the viscose process, which was protected in the United States by two patents owned by the American Viscose Corporation. In order to start manufacturing, Du Pont acquired French technology from Comptoir de Textiles Artificiels (CTA). Somewhat later, it also acquired a license from a Belgian branch of CTA. This is not the first or last case of a large multinational firm having begun operating under license until it could develop its own technology several years later.

2/ In recent years, the engineering team of Du Pont Argentina has transferred technology to other Latin American countries. It has designed, set up, and started factories in Chile, Brazil and Bolivia and has lent consulting aid on nylon to a Mexican-US joint venture in Mexico. In these areas, the Du Pont team has been able to capitalize on its experience accumulated from handling the rayon plant under study here.

Ducilo began operating in 1937 with a labor productivity of 0.82 kg of rayon per man-hour and by the time the plant closed it was producing four times as much, which implies an accumulative growth of close to 3.6% per year. Not only did labor productivity show a marked increase but other indicators also varied significantly over a period of time. Among these are the improvement in quality of the manufactured product, the increasing use of domestic raw materials and equipment, etc. The description of what happened and its explanation in theoretical terms are complex and should be looked at step by step, while bearing in mind a wide range of variables and circumstances, some of which correspond specifically to Ducilo Argentina and her corporate headquarters Du Pont de Nemours; others correspond to the rayon (and other synthetic fibers) market and the greater or lesser degree of oligopolistic competition prevalent on the market; and finally, other variables are inherent to the macroeconomic growth of the country, which, throughout the period of forty years under consideration, had to go through a series of "national plans" which of course affected the behavior of labor and enterprise, as well as the relationship between the company and the government.

In other words, the historical evolution of the industrial plant under study here, is considered to be a result of the interaction of variables relating to the firm and the product in question, of characteristics belonging to the morphology of the rayon and other fibers market, and of general macroeconomic circumstances which affected the various economic agents involved in this area of industrial manufacturing.

Aside from the clarification in the previous paragraph referring to the different levels of causality to be distinguished in this study, we would like to point out at this point in our presentation of objectives that our study is centered around the subject of technological change, its sources or origins, its pace and nature, and its effect on the long range performance of the plant under study. We shall use some of the analytical categories of received theory, such as "major" and "minor" technological changes, "disembodies" or "embodies" technological changes in investment, etc. Also, we shall make use of some analytical categories not often examined in the current debate (e.g. technological changes related to "output mix", to quality of the manufactured product, etc.) Throughout this study we have frequently made use of, and shall quote recurrently, the results presented by S. Hollander in his classic study of 1966, 3/, perhaps one of the most detailed research projects on the macroeconomies of technological change that has been presented to date.

As in the case of Hollander - - who studied four rayon manufacturing plants in the United States, all owned by Du Pont - - this research project is about a subject matter that would seem almost obvious to an industrial engineer, but is certainly not to an economist. We are referring to the fact that technological change - - that is, the modification of a product and/or the manufacturing process - - is a frequent, constant phenomenon in the evolution of any given industrial establishment. Product and process technology of a certain manufacturing plant is far from being "set" and beyond all modification. On the contrary, it changes frequently and for many reasons which we shall look at in detail here, and which are more than just to reduce production costs, the subject matter of most of the work done in this field. 4/

This is the reason why it is not surprising that the accumulated sum of technological changes have normally made up "the" most important explanation for the long range performance of any given industrial plant. These are related to the launching of new varieties of the finished product, the replacement and use of new (and less expensive) raw materials, changes in the basic process used, a more adequate strategy for maintenance of capital goods, improvements in quality, and so forth.

Having stated the subject matter of this study, we shall go on with what is contained in the different sections.

3/ S. Hollander, The Sources of Efficiency Growth, A Study of Du Pont Rayon Plants. MIT Press, Cambridge, 1965.

4/ Practically all of Hollander's analysis is concentrated on the study of unit production cost trends over the years, paying much less attention to various forms of technological change not expressed through costs. In this sense, a broader approach can be found in a recent study of P. Maxwell: Learning and Technical Change in the Steel Plant of Acindar S.A. in Rosario, Argentina, published by BID/CEPAL Science and Technology Research Program, in December, No. 4.

Chapter II gives a brief technical description of the rayon manufacturing process employed by Ducilo. This is presented in order to give the reader an overall view of the plant under study. As we shall see, it is made up of a Chemistry Section, a Spinning Section, and finally, a Textile Sector.

Chapter III is an analysis of the evolution of labor productivity over the years. We can clearly distinguish two stages or periods in the historical development of this firm.

The first of these periods covers the two decades between 1937 and 1958/59. During these years when Ducilo was the absolute leader on the Argentine rayon market and it did not feel pressure from competition to improve its operative efficiency, a steady increase in the physical volume of production was recorded.

From the 1950's on, substantial changes began to take place in Ducilo Argentina concerning technology, management-administration, etc., which ended up bringing about a "new" operative atmosphere where the role played by Argentine technical and professional personnel as well as the interest and motivation provided by the firm to domestic technological efforts grew considerably. All this coincides with morphological changes on the rayon market and with greater competition on the part of Sniafa and Reysol.

Chapter III also discusses the structural "split" mentioned above, evidenced by the indicators of physical productivity. It examines the several sources of origins of the increase seen in labor productivity, mentioning, among others, the following factors: a) increase in spinning speed b) changes in machinery and in the number of spinnerettes c) modifications and changes in the production process d) reduction in the number and kind of varieties of rayon produced as well as the forms of presentations sent to the market e) increases in average denier, etc.

The technological changes carried out over the years are listed in this chapter and an attempt is made to evaluate their relative influence on variations in productivity and costs, what amount of domestic technological efforts were required by each of them, what the external technological contribution was to the firm in each case (coming from corporate headquarters, for instance, or from equipment suppliers), etc.

Chapter IV looks at the different forms of technological change not necessarily expressed by way of production costs or by variations in labor productivity. Falling into this category are those technological changes related to the launching of new varieties and types of rayon, as well as those designed to improve the quality of the different manufactured products.

We have previously stated that the technological effort by Ducilo Rayon has not only had an influence on the long range performance of this firm but has also generated important externalities for suppliers of raw materials, parts, and equipment, as well as for clients, users of rayon and other textiles. These types of indirect effects of a certain firm's technological change are also examined in Chapter IV.

Chapter V attempts to move away from the specific example being studied here in order to draw up a simple behavioral model that would describe the most outstanding characteristics of the general case involved. In this paper, we are talking about a firm - - a branch of multinational enterprise - - that is the leader on the Argentine market of a certain intermediate good.

The technological change and modernization of this firm seems to have been motivated by two types of stimuli. The first of them, endogenous to the firm, is evidenced through a certain flow of "minor" technological changes introduced over the years by the firm's engineering team itself, and through systematic technological efforts designed to improve plant operating standards. The need to lessen the amount of wastage, to improve the quality of the finished product, to maximize working time and operating speed of the equipment, to replace expensive raw materials with other less expensive ones but of different chemical and mechanical specifications, etc. can be mentioned as some of the primary stimuli that led to carrying out permanent technological efforts.

The second group of stimuli is exogenous to the firm, and implies adopting programs of modernization and technological change in answer to events of an external nature. Two types of these events stand out in the history of this firm. The first refers to situations imposed upon it by the legal, institutional, or economic framework within which it had to function after national, political and economic changes. The second group of

external events influencing the technological behavior of this firm comes from its relationship with its home office - - Du Pont de Nemours. The pace of amortization and depreciation on machinery that the home office in the United States determined the time, the size, etc., of the rate of modernization at the Argentine branch, which generally depended on the purchase of second-hand equipment handed down by corporate headquarters. Even though this last situation - - modernizing based on second-hand equipment acquired from foreign firms - - needs to be examined in more detail since it typifies an often recurring situation on the Argentine industrial scene, it is interesting to point out that in this case the equipment handed down by Du Pont in the U.S. was practically new - - one of the cake washing and purifying tunnels had never been used - - enabling the Argentine plant to take advantage of the benefits derived from the early and unplanned closing of the plant at Old Hickory, Tennessee.

Lastly, Chapter VI gives a brief summary of the results arrived at in this research, and discusses their importance in relation to the theory of technological change in developing countries.

II. DUCILO RAYON TECHNOLOGY

A Description of the Rayon Manufacturing Process

Rayon is a synthetic fiber made by taking cellulose and making a series of transformations in it which do not involve any extensive chemical modifications in the molecular chains of the raw material but only make a simple rearrangement of them enabling a spinnable fiber to be formed.

The process consists of three stages. The first stage is chemical and results in the elaboration of a spinnable viscose substance. The second stage is the actual elaboration of the yarn, while the third stage is textile and is related to the different forms of presenting the finished product on the market.

Let us begin with the chemical stage in the manufacturing process. This begins with a mercerizing step - - see Diagram 1 - - which consists in the placement of long-fiber cellulose sheets ^{5/} in a caustic soda bath. The sheets are later pressed to regain a certain consistency and some watery solution is eliminated at this time. Fifty kilograms of dry pulp yield 150 kilograms of moist pulp. After this step, the sheets which are now referred to as alkali cellulose are shredded before going on to the "Aging Bin" where they are kept between six and thirty hours in order to achieve a more definite rearrangement of the length of the molecular chain. This step is important since it has a decided effect - - through time, temperature, use of different catalysts, etc. - - on the parameters of viscosity of the chemical substance to be spun, and therefore, on the quality of the finished product.

The next step, called xanthogenation, is designed to arrive at cellulose xanthate, a substance that can be dispersed in an alkaline solution. Xanthogenation takes about an hour and a half and, like the previous step, is very important in determining several parameters of the viscose to be spun. The load of xanthogen then goes on to the dispersion step in equipment called dissolving tanks where it is churned until it reaches a sticky, viscous homogeneous consistency like honey. Three

^{5/} Other cellulose raw materials - - cotton linters, for example, can also be used after making the necessary changes in the process. See comments on this topic in Chapter IV.

loads from the dissolving tanks then go to the mixer where they are mixed for four or five hours.

At this point we theoretically have a spinnable material. Nevertheless, three more operations are carried out before the viscose is put through a spinning machine. First, the molecular arrangement must be completed which calls for more maturing time. Secondly, the solution must be filtered to take out possible impurities; and thirdly, air bubbles must be removed since they would cause flaws and filament breakage. When these steps are completed, the viscose solution leaves the chemical section and enters the spinning section. (see diagram 1).

The spinning section is made up of a group of spinning machines, each of which has a certain number of nozzles, or spinnerettes, located in a trough containing an acid bath of sulphuric acid, sodium sulphate, zinc sulphate, glucose and water. The viscose solution is alkaline and as it passes through the acid bath, it begins to coagulate and regenerate its cellulosic base. The thickness of the layer that is formed - - measured in microns - - is of great importance to dyeing properties and other quality factors of the finished product. The yarn - - now being formed - - flows along the trough and then passes through a funnel into a centrifugal pot where a rayon cake is formed. Each cake has an outside diameter of 35 cm. After a certain number of hours, the spinning process is interrupted; the cakes are removed with tongs and placed on adjoining tables where gases are first released (carbon sulphide and sulphuric acid).

At this point in the process, the cakes are wrapped in a protective material (rubber or cellophane) and loaded in carts that take them to the purification and washing steps. This job requires a. a second gas discharge b. an acid wash c. a desulphurization treatment d. bleaching and finishing. All of these steps are carried out before the cakes are centrifuged previous to drying. After drying, we enter into the third stage of the process, that is the textile area. (Diagram 1).

Coning is conventional. For many years, a great variety of packages and treatment of the finished product were made up (dull, bright, flamentint rayon, etc), but over the years, this stage was simplified and many final steps (twisting, etc) were left to the clients. 6/ After the textile stage, the products are inspected and then passed on to be shipped.

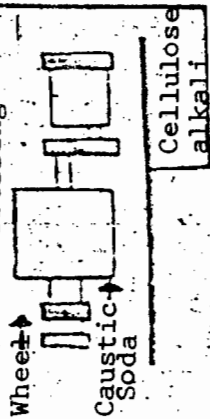
Altogether, the process described took 18 days to complete in its first year of operation. When the plant closed down, it took only 13 days. Each and every one of the phases in the process had been modified and simplified, as will be seen in the following chapters. As the duration of the production cycle diminished, man-hours also declined by nearly one half of those used in earlier productive cycles.

^{6/} See analysis of this topic, its effects on productivity, employment level, etc., in Chapter IV.

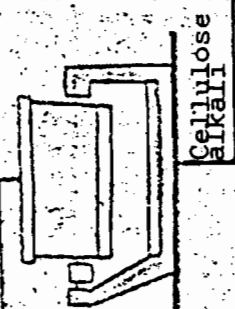
RAYON PROCESS

Chemical Section

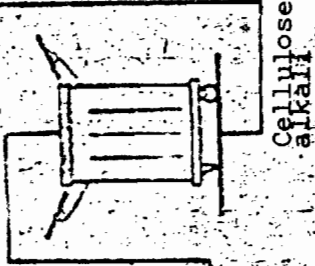
Mercerizing and Pressing



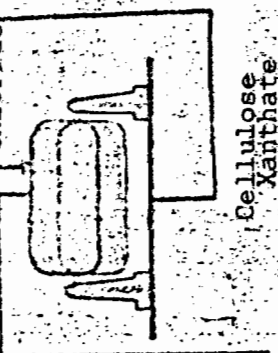
Shredding



Aging



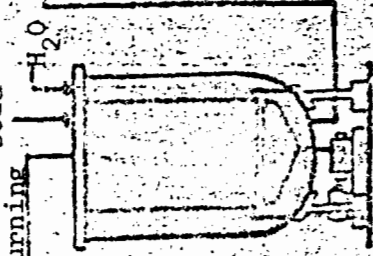
Xanthogenesis



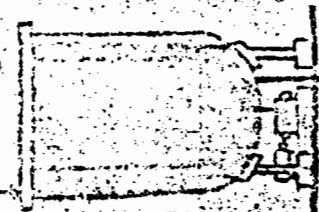
Carbon Chloride

Churning

Caustic Soda

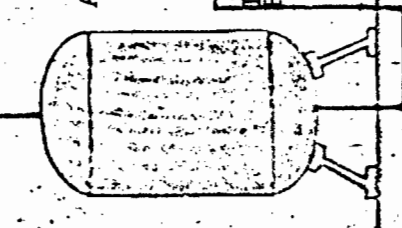


Mixing

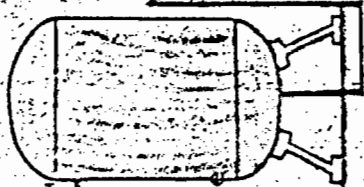


VISCOSE PROCESSING

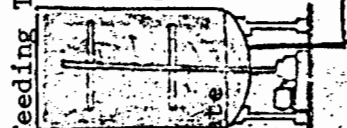
Viscose



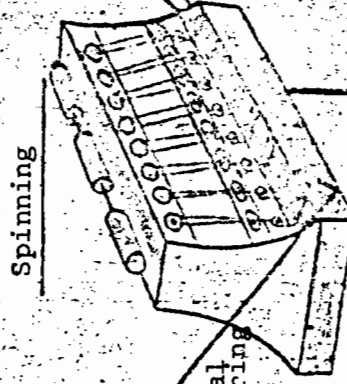
Aging Tank
Intermediate Filtering



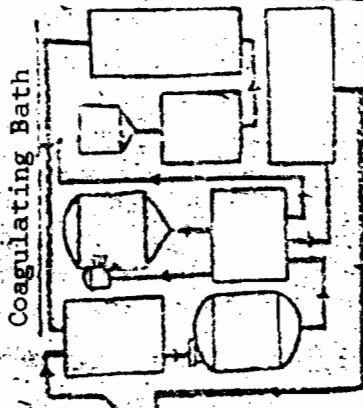
Aging Tank
Intermediate Filtering



Feeding Tank
Final Filtering

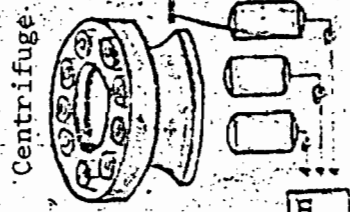
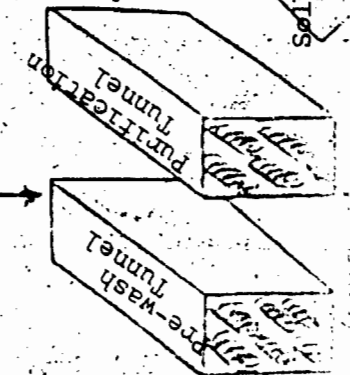


Spinning
Final Filtering

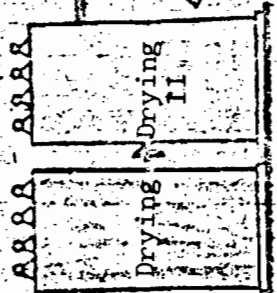


Coagulating Bath

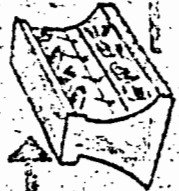
PURIFICATION



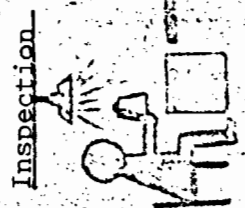
Centrifuge



ARRA - Drying I
ARRA - Drying II



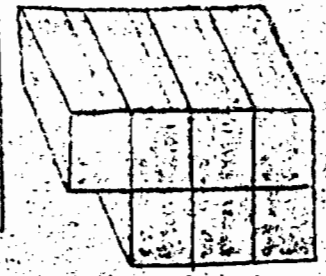
Cones



Inspection

Textile

Shipping



Washing Area

III. LONG TERM ECONOMIC PERFORMANCE

Introduction

By March 1937, the plant under study had been set up. It was a near replica of Plant No. 2 at Spruance, started up by Du Pont in Richmond, Virginia, in 1935 and kept in operation until the late 1950's.

It should be pointed out that Spruance II as well as the Argentine plant began using the so-called "cake-to-cone process" from the beginning, the process Du Pont had been using in its Old Hickory Plant since 1932. 7/ This plant underwent a large-scale modernization between 1935 and 1936 when this technological change was incorporated, which also signified a substantial reduction in manual labor with respect to the original process used at Old Hickory in 1929. 8/

7/ The "cake-to-cone" process enables a) eliminating the wash before preparing the skein and b) preparing the skein before purification and drying, both steps found in the Du Pont technology in its original 1928/29 design. Both steps were very intensive in the use of manual labor and disappeared after improvements in the process were made in 1932. At the same time, the cake-to-cone process allowed for gang doffing of the cakes instead of each one being done at a different time and with an independent shutdown from the spinnerette. Even though this latter change in the process took some time to be perfected, it contributed not only to an additional saving on manual labor (see next footnote), but also enabled reducing the average amount of waste and, so, lowered the cost of production. These process changes were labor-saving and were used in Argentina from the plant's beginning.

8/ In 1932, the unit cost of direct manual labour at Old Hickory was 16.20 cents per pound of rayon. In 1937, this had dropped to 8.60 cents. S. Hollander estimates that more than 50% of the reduction of direct labor costs is due to the introduction of the cake-to-cone process and the reorganization that it produced in removing the cakes from the spinnerettes, or doffing. It is important to note that Spruance II as well as Ducilo Argentina began operating with the new process; that is variations and

Given the technological similarity between the Argentine factory and Spruance II ^{9/} and given also the fact that Ducilo Rayon was Du Pont's first operation in Argentina, it is not surprising that the start-up of the Argentine factory was under the supervision and control of technical personnel from headquarters and that they followed the model of the Spruance II process step by step. One of the first Ducilo Technical Reports reads as follows:

"Having found the write-up of Plant No. 2 at Spruance to be of great value to us, the organization of Ducilo submits the following write-up hoping that it may be of value in subsequent start-ups." ^{10/}

The start-up period reveals no especially significant facts, other than the usual phenomena occurring in this type of activity, that minor technological changes had to be made on the equipment as it was being installed. Generally speaking, such changes consisted in incorporating technological improvements recently adopted by Old Hickory, and not necessarily adopted during the construction of the equipment at Spruance II and Ducilo, even though these already had incorporated technology that was on the whole better than the original process used at Old Hickory.

At this time, the plant had 52 spinning machines.

During its 40 year life cycle the plant under study followed a path that could be described, disregarding annual

to say, that they never used the Old Hickory technology of 1929. Given the different relative prices of capital and manual labor underlying both investment decisions - - Spruance II and Ducilo Argentina - - it is interesting to note that this new labor-saving process was used in both plants.

^{9/} Spruance II began operating in 1935. Originally, it had 60 machines with 100 spinnerettes each and produced 150 denier on the average. It was certainly a more modern plant though smaller than Old Hickory, which began operating with 128 machines and 100 spinnerettes each. See S. Hollander, Op. Cit., pp. 91, 54, respectively.

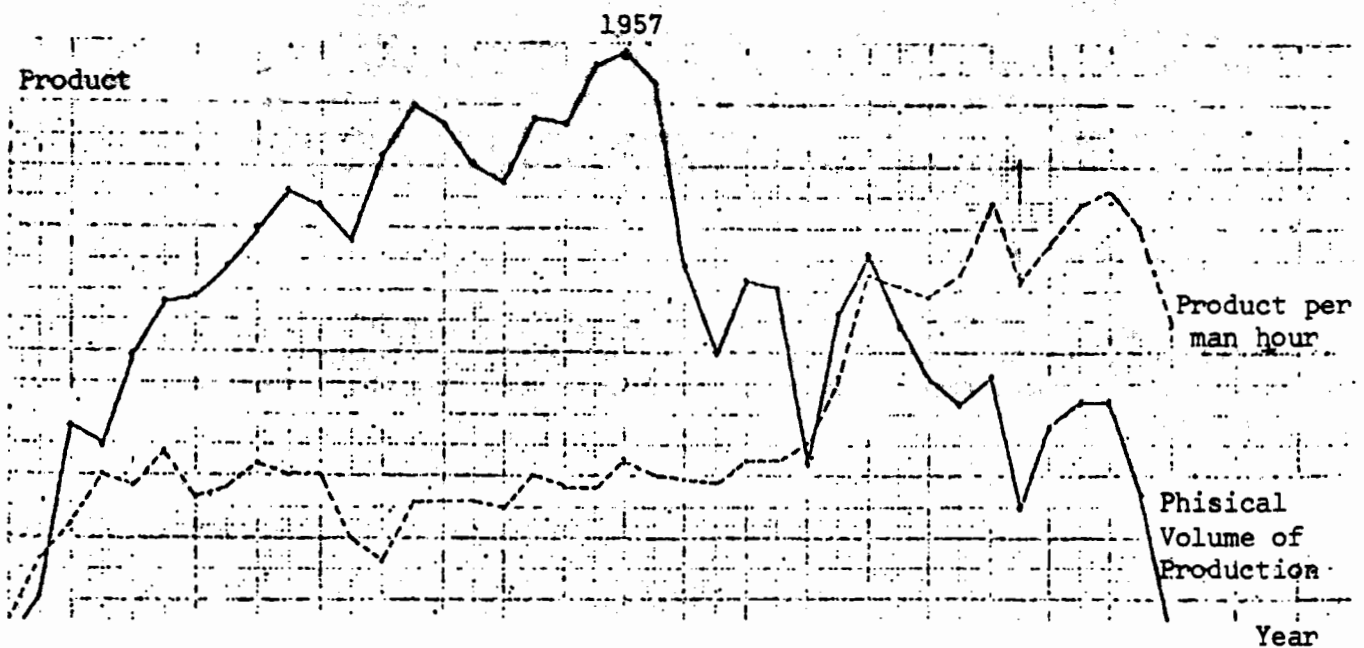
^{10/} "Start-up of Ducilo S.A., Rayon manufacturer." Mimeographed, not published, Buenos Aires, 1937, p.1.

Table 1: Product and labor productivity growth - Ducilo 1937-75

Years	Physical volume of production (a)	Total hours worked (b)	Kg/hour (a)/(b)	Years	Physical volume of production (a)	Total hours worked (b)	Kg/hour (a)/(b)
1937	698 910	851 084	0 821	1957	5 409 818	2 508 521	2 155
1938	1 054 640	761 226	1 350	1958	4 544 163	2 436 157	2 029
1939	2 418 423	1 450 720	1 667	1959	3 740 860	1 875 840	1 995
1940	2 759 104	1 114 988	2 026	1950	3 083 761	1 602 202	1 925
1941	2 968 391	1 537 388	1 937	1951	3 697 496	1 708 687	2 16
1942	3 414 884	1 553 814	2 197	1952	3 689 780	1 095 470	2 16
1943	3 449 414	1 855 857	1 857	1953	2 115 884	922 882	2 292
1944	3 709 895	1 935 187	1 916	1954	3 299 169	1 167 144	2 826
1945	4 017 412	1 808 648	2 221	1955	3 888 553	1 063 033	3 658
1946	4 305 414	2 096 745	2 053	1956	3 245 213	513 251	3 553
1947	4 200 919	2 065 068	2 033	1957	2 800 732	820 406	3 466
1948	3 902 069	2 547 252	1 532	1958	2 605 070	714 170	3 647
1949	4 676 666	3 353 838	1 394	1959	2 841 073	669 011	4 246
1950	5 063 212	2 739 590	1 808	1960	1 746 058	491 532	3 552
1951	4 853 493	2 663 263	1 822	1961	1 925 915	493 569	3 862
1952	4 569 666	2 506 387	1 823	1962	2 109 983	493 896	4 220
1953	4 404 666	2 503 678	1 759	1963	2 110 941	495 196	4 262
1954	4 918 578	2 441 229	2 013	1964	1 859 725	464 146	4 006
1955	4 853 078	2 553 829	1 900	1965	633 969	199 374	3 170
1956	5 356 663	2 687 050	1 993				

Source: Prepared by the authors on the basis of figures provided by Ducilo S.A.

Graph 1: Physical Product and Labor Productivity Growth, 1937-75



adjustments, as an upside down U with a peak in 1957 - - when 5.4 million kilograms of rayon were produced - - and lowest points at its beginning and end, 1937 and 1974, when output was 698,000 and 633,000 kilograms respectively.

The series corresponding to the total annual number of hours worked followed a similar pattern, and it shows that the descent which began in the late 1950s was even more abrupt than that corresponding to the physical volume of production referred to in the previous paragraph. In other words, even when the plant's physical product fell off considerably in the last two decades, the total consumption of manual labor fell at an even faster pace so that the physical product per man hour ended up doubling the historic average of the 1940-1960 period and being almost four times greater than that reached in 1937 when the plant began operating.

The situation referred to in the previous paragraphs is described quantitatively in Table 1 and Graph 1. The information appearing in the table and graph reveals several significant facts which we shall look at now.

First of all, it seems clear that there was a definite "structural split" in the growth of this plant around the years 1958-1960. ^{11/} Even though there were short-term ups and downs which we shall look at later, there was a marked tendency between 1937 and 1958 toward an increase in the physical volume of production, while in the period from 1958 to 1975 there was a significant decrease.

Secondly, the idea of a "structural split" around the 1960s finds support also in the data corresponding to product per man-hour, that is, by the physical labor productivity indicator. After practically two decades of the firm making little or no progress in the area of labor productivity, the period 1960-1975 showed a rapid rate of growth in factory efficiency.

^{11/} The average value of the physical volume of production was close to 3.9 million kilograms yearly between 1937 and 1958 and reached only 2.6 million during the 1960-1975 period.

As we shall see later ^{12/}, this "structural split" shown by the physical indicators of product and labor productivity has a clear counterpart in other levels of the administrative and technological life of the firm which corroborates the strong degree of inter-relationship usually expected in the different operative areas of a firm. We shall see later that at the time of the split, there were several managerial changes and a marked generational replacement began as well as an extensive program for plant modernization which occurred around 1962. The sum of these factors left a strong impact on the total performance of the firm, as can be clearly seen in the information included in Graph 1.

Let us now take a more detailed look at the most outstanding characteristics of both structural periods.

The first period, from 1937 to 1958, reveals several points of interest. In 1958, the physical volume of production had more than doubled that of 1940, that is, when the plant's start-up cycle, begun in 1937, was considered completely finished. The events over the 20 years covered by this structural period can be explained by several variables, some of which are the following: 1) increases in the capital/labor ratio 2) technological changes concerning the production process itself, the output mix, the input mix 3) economies of scale, etc. Let us look at some of the most important "historical events" of this period.

First expansion program at the plant (1941)

In 1941, 12 more spinning machines were incorporated, bringing the number of machines in the plant to a total of 64. Each one had 104 spinnerettes, meaning that at this time, the plant had 6,656 spinnerettes altogether.

High speed spinning (from 1946 on)

From 1946 to the end of the 1950s, a substantial increase in spinning speed was registered, which settled around 145 meters

^{12/} See Chapter IV.

a minute, compared to 83 meters a minute in 1941 and even less in previous years.

Several different types of technological modifications could have caused the rise in spinning speed in producing rayon. This depends mainly on a) the size of the bobbin, b) the speed of the spinning pot c) the friction exerted by the coagulating bath.

Perhaps the most important of the technological changes leading to an increase in spinning speed in this industry was the so-called "tube spinning". This is related to item c) above -- the friction of the coagulating bath -- and can be done without changing the size of the bobbin. This technological change was introduced in Old Hickory in 1950, producing a 40% increase in spinning speed in that plant. The coagulating bath accompanies the yarn throughout its passage through the trough in order to regulate the contact between them. That is, the yarn and coagulating bath circulate on the inside of the tube in this process instead of the yarn going through the trough.

It is important to note that Ducilo Argentina did not use tube spinning around 1948-1949, this being an important part of the explanation for the increase seen in the spinning speed in the period we are talking about. In other words, this technological change was implemented in Ducilo practically at the same time as in Old Hickory.¹³ Technical personnel at the Argentine plant point out that they were entirely responsible for the development of the 89 cm tube. The tube used at Old Hickory was 72 cm and proved unsatisfactory for use in Argentina due to the denier and raw material used. The patents protecting the tube spinning process were obtained in the United States by Du Pont about that time (1950).

Besides tube spinning, the increase in spinning speed is positively related to the diameter of the bobbin and the spinning pot, as well as the speed of the motors. Minor

^{13/} Old Hickory was spinning at a speed of 86 m/min in 1949 going up to 121 m/min in the 1949-1953 period, when tube spinning was introduced. See S. Hollander, op. cit., pp. 54, 64.

technological adjustments, especially in the latter direction, should also be kept in mind in order to explain the increase in spinning speed after 1946/47.

Nevertheless, a greater spinning speed has an implicit cost, since it has a negative effect upon the quality of the finished product, 14/ that being why Ducilo decided to reduce it in 1960, and even more toward the end of the last decade and the beginning of this one, that is in its last years of operation, when quality was one of the main preoccupations of the firm. 15/

Insalubrious working conditions (1947)

Decree 25569 in 1947 modified the standards of salubrious working conditions established in the statutory decree of March, 1930. Ducilo was obliged to increase their number of personnel, especially in the area of spinning and cake washing and purifying.

In these sections of the production process, the new standards required laborers to work 6 hours out of each 8 hour shift, forcing Ducilo to add another full shift. As can be seen in Graph 1, the series indicating work productivity shows that this had a great effect on the firm, especially from 1948 to 1949. 16/ Notice that the level of labor productivity per working hour for the year 1945 was not reached again until the early 1960s, when a vast modernization program was implemented.

14/ The Technical Report "Comparison of performances between spinning productions in open trough and tube machines" reads as follows: (mimeograph May, 1963) "As production levels and sale forecasts do not indicate that (there will be much demand) on a short-term basis, the possibility of transforming tube machines to open trough, due to better quality obtained in spinning at low speed, is being reconsidered." Better quality indicators are a) 50% reduction in major defects b) dye improvements c) greater tenacity, etc.

15/ This effect -- reduction of spinning speed -- is associated with a greater degree of competition prevalent on the market during the 1960s and to the necessity of reaching higher quality standards. This is examined later in Chapter VI of this paper.

Textile simplification from 1950 on

In the early 1940s, Ducilo manufactured the following kinds of end products: a) skeins b) cones c) spools d) bobbins e) chains f) cakes, etc.

This variety of products was, of course, beyond the specific function of manufacturing rayon, and implied a complex range of activities of a textile nature (skeining, finishing, twisting, spooling, reeling, sizing) that were highly intensive in the use of direct manual labor and labor for maintenance of the equipment involved in these activities (cone winders, spoolers, reelers, etc.). Besides this, it also implied a negative effect from the scale diseconomies of short runs and frequent shutdowns and changes in the production program.

Around the mid-1940s, "chain" manufacture disappeared and that of "bobbins" was reduced considerably. The 1950s showed a drastic fall in the manufacture of "skeins", while "spools" completely disappeared in the 1960s. Table 2 below clearly shows the great change occurring over the years in the kinds of finished products.

Table 2: Sales Structure - - Ducilo - - 1941-1967

	Skeins	Cones	Spools	Bobbins	Chains	Cakes	Total
1941	27.44	46.20	14.18	9.87	0.06	2.23	100 %
1967	-	91.20	-	-	-	8.80	100 %

Just as other technological changes mentioned previously, textile simplification had direct consequence on Ducilo's performance and also generated external effects. With respect to the former, the following should be pointed out: a) savings on direct manual labor (which was even greater during the second technological "period" seen here) b) an income from the sale of twisting machines, spoolers, reelers, sizing machines, etc. on the second-hand market.

16/ It is interesting to note that the concept of factory salubrity standards was much stronger in Argentine legislation in 1947 than in the U.S. at that time, so the original technology did not anticipate better systems of purification, plant ventilation, etc.

With respect to the externalities of the textile simplification program, it should be noted that because of it, quite a large group of textile workshops appeared during these years to take up the tasks gradually abandoned by Ducilo.

Customary increase in average denier

During the 1937-1958 period there was a gradual increase in the average denier made by the plant. The denier in the 1940s was 123, the mean for the following decade was slightly above 130.

Diverse minor technological changes were responsible for increasing the spinning denier given the existing equipment. The following were the most important: 1) Changes and adjustments in the dosage pump and in the spinning heads 2) chemical adjustment in the coagulating bath in order to assure a proper reaction, 3) changes in the spinning pots, 4) modifications in the motors.

Only the factory modernization plan of the 1962-63 began to pay attention to technological changes related to numbers 3 and 4 of the list above. During the first "structural period" from 1937 to 1958, the gradual increase in the average denier is due to routine technological modifications related to dosage pumps, the coagulating bath and other similar minor changes.

In short, the first of the two structural periods mentioned here seem to be characterized by a) plant expansion through incorporating equipment (12 spinning machines in addition to those originally stalled in 1937); b) a substantial increase in the use of manual labor per kilogram of rayon produced, induced by the 1947 salubrious working conditions legislation; c) technological changes related to i. output mix, ii. the operating speed of the equipment, and iii. the general operative efficiency of the plant. While the first group of these technological changes referred to the textile simplification effected from 1940 on, the second group was basically associated with the introduction of spinning tubes and the third to general aspects of the plant's operation, e.g. the gradual improvement of the quality of the finished product, the reduction in the quantity of wastes, etc. In the next chapter we shall make a quantitative evaluation of the relative importance of each of these variables.

Let us now look at the second of the structural "periods," that is, the period between 1960 and 1975.

In contrast to the first structural "period" examined previously, this period was characterized by a gradual decline in the physical volume of production and by a faster reduction of the number of working hours employed. This was due to a gradual increase in physical productivity per man-hour worked. Towards the end of the period, the physical volume of production barely reached 20% of the highest value achieved by the series in 1957 and 1958. At the same time, the product per man-hour doubled.

As in the previous case, this one should be studied in terms of accumulation of capital, scale effects, technological changes in the production process, in the output mix, etc. We shall begin by summarizing some of the more relevant "historical events" of the period.

Increases in cone size (1961)

In the early 1960s, the "Lessona No. 50" coners used by Ducilo in its textile section produced two sizes of packages: 1.5 kg for 60 and 75 denier and 1,650 kg. for 100 denier and above.

These sizes, even though there were of an acceptable weight, did not reflect the best that could be reached by the installed equipment. With slight modifications introduced in basically the same machines, Old Hickory was manufacturing cones of up to 3.60 kg in the late 1950s. ^{17/} This, of course, meant great savings on manual labor.

Studies showed that with minor modifications in the equipment, packages of up to 2.50 kg could be produced, which, on

^{17/} Information obtained from the "Technical Report of Plant No. 14, 1961: "Larger size cones in Lessona No. 50 coners," mimeographed, unpublished. Buenos Aires, 1961, p. 2.

the other hand, was apparently the maximum Ducilo's clients could handle with their warping machines.

Ducilo was directly affected by the increase in cone size as were its clients. By producing a greater weight per unit, the number of cones handled was reduced and there was a savings on manual labor. The increase in cone size was also related to the mechanical quality of the finished product (via the spinning speed, which determined the rate or proportion of major and minor defects) and to the quality of dyeing. At the same time, the increase in cone size brought on some difficulties and the need to make some minor changes in packing and distribution. There being positive and negative effects, it became necessary to determine the maximum cone size compatible with maintaining the standards of mechanical and dyeing quality.

With respect to externalities on Ducilo's clients, it should be pointed out that the programs of cone size increase was studied "in house" in the industrial plants of several of them and a 40% increase in warping machine output was recorded.
18/

Modernization of spinning, washing and purification of cakes
1962-1963)

The closedown of the rayon plant at Old Hickory 19/ gave Ducilo, the opportunity to up-date its operative technology by incorporating its used equipment.

18/ In the change from 11/10 to 14/11 cones, the drum loads taken from the warping machine rose from 7 to 10, without noting significant changes in quality and without having to introduce great modifications in the equipment of Ducilo's clients. Op. cit., Larger size cones ..., Buenos Aires, 1961, pp. 12,13. See more on this topic in Chapter IV.

19/ Note that the Old Hickory plant was modernized extensively over the 1950s, assuming it would keep on manufacturing during the 1960s (or at least a good part of it). This forecast was actually incorrect, since Old Hickory stopped production in 1960. Much of the equipment introduced in the 1960s was never completely amortized and had depreciated very little. Some of these machines were purchased by Ducilo Argentina and incorporated in its plant during factory modernization in 1962. Some

The technical modernization program involved the purchase of approximately 7,000 spinning pots of 2 1/2 pounds (instead of 1 pound pots used up to that time), two washing tunnels with three tracks each, evacuation chambers, collapsing machines, bleaching tanks, rust resistant pipes, etc.

Likewise, the closedown of Old Hickory gave Ducilo the opportunity of acquiring second-hand equipment that was practically new (see footnote 19) such as dielectric dryers, steeping and shredding equipment, etc., but Ducilo decided not to incorporate them. While the first decision shows the intention to reduce costs and save on manual labor (and also improve quality), the second shows the intention to continue operating basically with a batch process.

The 1962-1963 modernization program cost about a million dollars -- the reinvestment value of the plant at that time oscillated around 7 million dollars -- and had a pronounced labor-saving effect while also affecting several other performance indicators at the plant under study. With respect to the transfer prices of these assets within the Du Pont group as a whole, it is interesting to note that this operation was one of the first cases where the American appraisal was applied 20/,

of the equipment introduced by Old Hickory in this decade were a) 1.8 pound spinning pots instead of the nearly 1 pound pots used in production in 1952-1953, b) in 1956-1958, dielectric dryers, steeping and shredding equipment, etc. were installed replacing the batch process used until then in different steps of the process.

The Old Hickory plant was closed before expected. This happened when Du Pont had the opportunity to transfer part of their working personnel to the polyester factory just opening up. There seems to be agreement on the fact that Old Hickory did not completely recuperate their investment in modernization effected in the late 1950s.

20/ Several aspects of this modernization program are worth our attention and will be examined later.

Detergents (1963)

When the rayon cakes are removed from the spinning pot (doffing), they contain a large amount of air, sulphuric acid, carbon sulphide, and other gases which must be eliminated in order to allow for an easier and less expensive purification, the latter because a proper evacuation greatly reduces the cycles of purification. The cakes then are put through an evacuation process in a water and detergent solution for approximately 15 minutes. The process is done in a vacuum and . . . "the detergent in the evacuation tank causes the emulsification of the gases which are eliminated in bubbles." 21/

Whether this stage of the process is successful or not depends on a) the minimization of the bubble size, because if they are larger than a certain size, the cake can be damaged, making the inside part of the yarn break away; b) producing little foam so as to avoid dangerous levels of toxic gases in the evacuation area.

Old Hickory, as well as the Argentine plant in its first half of productive life, used the detergent "Dianol 11", made specially by the Quaker Chemical Products Corporation. When Old Hickory was closed, the Quaker Co. discontinued the manufacture of "Dianol 11", and Ducilo began a series of experiments to find a substitute of Argentine origin, if possible. In the course of this program approximately a dozen detergents were evaluated in order to minimize costs and at the same time determine the best concentration of the substitute selected. This experimental detergents program proved successful, as we shall see later.

High solid viscose (second half of 1960)

The research and development program in high solid viscose began in 1962 and consisted of experimental projects in a pilot plant, giving results that were used on the industrial scale in the second half of the decade. 22/

21/ Technical Report of Plant No. 7, 1963, "Evaluation of detergents for cake evacuation," mimeographed, unpublished, 1963.

The spinning of high solid viscose (8% cellulose and 5.5% caustic soda, instead of 7.1% and 6% respectively for the normal process) enabled a large savings in raw materials (caustic soda and sulphuric acid), and also economized on labor in the spinning and textile sections, and reduced consumption of energy, steam, and other minor chemicals.

Three different situations spurred Ducilo to begin looking for a new process that would permit spinning a viscose containing more solids. On the one hand, customs fees on the import of highly cellulosic wood pulp rose extremely in the early 1960s, so it was better to work with pulp of a lower cellulosic content. On the other hand, competition from nylon was growing -- a fiber of approximately 4.5 grams/denier compared to only 1.5-1.7 grams/denier for rayon -- which greatly increased the output of looms in the textile stage following the elaboration of the yarn. 23/ Finally, the advisability of introducing

22/ The first Plant Technical Report in this area dates October, 1963, while the second corresponds to September, 1966. In the latter, it says: "the tests made at Pilot Plant ... indicated that a test on a larger scale should be done to evaluate the final quality of the marketable product." and adds: "Given the relatively small capacity of the pilot plant -- 30 kg/day of yarn -- the following variables cannot be evaluated accurately: 1) spinning performance; 2) textile reeling; 3) mechanical quality, etc. ... so that once the adjustments in the process and the machines have been determined, the other evaluations should be done in large scale tests." Technical Report No. 3, 1965, "Evaluation of high solid viscose," mimeograph, unpublished, Buenos Aires, 1966, p. 5.

23/ Also, throughout the 1960s, Ducilo made a tentative exploration in working with Polynosic yarn, which gives nearly 3.5 g/denier, so its textile output is considerably greater than that of normal rayon. This experiment never did progress, since the idea of producing polynosic yarn was abandoned.

innovations in the process to reduce factory personnel, since the medium-term closing of the plant had already been decided on in the early 1960s, also acted as an incentive. 24/

In summary, the second of the two structural "stages" under study shows a marked increase in the amount of capital per man, related to the factory modernization program of 1962-1963, as well as to the textile simplification which intensified absolute and relative savings on labor. The pace of technological change throughout this period was rapid. Part of the same was "incorporated" to investment in placement, while the technological improvements implemented through changes in the production process, in the materials employed, etc., also proved significant.

Generally speaking, it can be said that the rapid pace of technological progress in this period was what enabled the firm to notably improve its level of labor productivity even in spite of scale diseconomies emerging from the steady fall of the physical volume of production.

This concludes this historical-descriptive chapter. We have noted the existence of a distinct "structural split" in the growth of the industrial plant under study. In the following chapters we shall see the most outstanding characteristics of each one of the firm's development "stages" in more detail and in quantitative terms.

24/ Practically since the closing of Old Hickory, the Ducilo directors were convinced that eventually the Argentine plant would have to follow suit, even though they intended to prolong the factory's useful lifetime for some years in order to reach closedown with the least number of workers possible. That included not replacing retired personnel, incorporating labor-saving technical changes, etc.

IV. SOURCES OF ECONOMIC GROWTH

The purpose of this chapter is to examine in more detail Dueilo's long-term performance, sketched out in previous pages. We shall attempt to evaluate a) which have been the main determiners of the growth seen in physical production volume, factor productivity, etc., throughout the historical growth of this firm; b) what differences can be seen in this sense between the four subsections which compose the plant, that is, chemical, spinning, cake washing and purification, and finally, textile; c) what has been the "technological component" underlying each one of the growth determiners identified -- e.g., what technological modifications had to be introduced in order to increase spinning speed, a variable acting as one of the "sources" of growth observed in the volume of production and in the level of productivity -- and how this set of technological modifications were born and were put into practice in each particular case. 25/

Principal growth determiners

We shall now present a simple analytical examination of the sources of economic growth covering the entire history of Dueilo Rayon. Table 3 shows a different performance indicators for the years 1941 and 1967, which we have chosen to carry out the comparative statistics study explained in the following pages. These years have been chosen because the physical volume of production is relatively the same in both -- 2.9 million kilograms, approximately -- which enables us to eliminate in part the importance of the scale effects which are considerable in rayon manufacturing.

25/ Continuing with the example of increase in spinning speed, this can be achieved through different types of technological modifications which differ in their content of technological and creative effort as well as in their form and area of implementation. One of the possible "technological paths" might be through Tube Spinning, for example. This would primarily affect the spinning section. Increase in spinning speed could also be achieved through technological changes of a chemical nature, which would be another "technological path" leading to the same results. While the first part is predominantly (but not exclusively) mechanical, the second is more chemical. Of course, this does not imply that the paths are not connected.

Between 1941 and 1967 the product per man-hour went from 1.93 to 3.48 kilograms, an increase of 80%. As we shall see, the explanation of what happened is complex because 1) an output mix was spun that was different from the original one (see columns 12-14 of Table) composed only of 'cones' and 'cakes' instead of also including 'chains', 'bobbins', 'skeins', etc. as was done at first; 2) a denier was spun which was much higher on the average than that in 1941 (column 5 of Table); 3) the number of machines and spinnerettes in the spinning section declined greatly (columns 7-8 of Table); 4) machines operated at a greater speed than originally (column 6 of Table); 5) each and every one of the sections in the plant suffered technological changes of differing magnitude saving on labor (columns 9, 15, 17 of Table), as well as on raw materials (column 20 of Table) and capital (column 10).

We shall examine each of these subjects separately. As we can see, both the factory and the finished product, changed considerably between the two years under study, making it necessary to "normalize" the different effects in order to reach a realistic estimate of the increase in productivity and provide an adequate explanation for it.

Output mix and textile simplification

As can be seen in Table 4 below, from a statistical and quantitative point of view, the program of textile simplification was the most important of the labor saving determinants. By eliminating the tasks of skeining, finishing, twisting, reeling, spooling, sizing, etc., it was possible to reduce the total number of direct working hours required in 1967 by 477.6 thousand, the equivalent of approximately 39% of the total number of direct hours utilized in 1941.

TABLE 3 GROWTH DETERMINANTS, 1941-1967

Year	Kilograms Production Index (in Th. lbs) (1937=100)	Labor Productivity (kg/man hour)	Average Denier	Spinning Speed (m/min)	SPINNING SECTION			Relative Weight respect to labor (%)		
					Number of Machines in use	Number of spinnerettes in use	Direct labor (Th. lbs of hours)			
1941	2 934	1.987	115	89.9	57	5 931	226.0	0.0262	18.0	
1967	2 880	2.486	131	96.5	45	4 284	179.4	0.0238	27.9	
Rate of variation					79%	14%	16.3%	-27%	-20%	-7%

Year	Textile Section %		Washing Section		Chemical Section		
	Rate of Shipping	Direct Labor (Th. lbs /hours)	Relative weight respect to labor (%)	Direct Labor (Th. lbs /hours)	Chemical Input 1937=100	Relative weight respect to labor (%)	
1941	46.9	51.8	74.2	152.1	100	115.1	
1967	32.2	293.9	64.2	56.1	114	134.4	
Rate of variation			-60.6%	-63.1%	14%	-17%	10%

Source: Company internal records.

g/ Includes all that is not chemical, Spinning, and cake washing and purification.

TABLE No. 4

LABOR SAVINGS RELATED TO "TEXTILE SIMPLIFICATION"

Total man-hours of direct operation			
Process Area	1941	1967	Difference
1 - Chemical Section	115,108	134,445	19,337
2 - Spinning and coagulating bath	226,003	179,433	- 46,570
3 - Washing and purification	152,133	56,106	- 96,027
4 - Textile Area Maintained (*)	269,080	293,914	24,834
5 - Textile Area Eliminated (**)	477,649	- - -	- 477,649
<hr/>			
Total hours of direct operation	1,239,973	663,898	- 576,075

(*) Coning area. (**) Dyeing, skeining, finishing, twisting, coning, reeling, sizing, etc.

Source: The authors.

In other words, practically half of the increase noted in product per man-hour - - which was 80% between 1941 and 1967 - - owes its origin to the fact that the output-mix at the end of the period differs significantly from the original output mix.

Taken in the strict sense of the word, the program of textile simplification did not mean technological changes in Ducilo Rayon but meant only the elimination of a series of textile tasks which, by passing them on to buyers (who absorbed the dyeing, finishing, etc) and to independent workshops (who worked for Ducilo, received the yarn and returned it after carrying out the tasks) enabled the firm under study to greatly reduce its number of direct employees. 26/

26/ It is interesting to note that originally Ducilo decided to take charge of a wide range of textile tasks not included in the manufacture of rayon itself. There were probably two factors responsible for this. On the one hand, the limited textile experience in Argentina in 1930 when Ducilo began manufacturing, and on the other hand, the low real salary (in relative

Due to the aforementioned, and once the effect of the change in output mix was neutralized, we see that the effective increase in labor productivity which needs to be 'explained' is approximately 40%.

Machinery and Factor Substitution in Spinning

While in 1941, 57 spinning machines with 104 spinnerettes each were in operation, making a total of 5,931 spinnerettes altogether in the spinning section; in 1967, only 45 with 102 spinnerettes each were in operation making a total of 4,288 spinnerettes. In turn, in 1941, the spinning section consumed 226 thousand hours of direct labor, which was reduced to 179.4 thousand hours of direct labor in 1967.

In other words, while the number of spinnerettes in use declined approximately 27% in 1967, the amount of direct labor declined 46,570 hours or 20%. This means that the capital/labor ratio decreased approximately 7% in the spinning section.

In this case, we are faced with two different factors which should be differentiated. On the one hand, there is a decrease in the amount of capital and work being used in the spinning section. On the other hand, this obviously is not the only thing that occurs; simultaneously with the above, there is a distinct substitution of capital for labor, a phenomenon which is related to the change from 1-pound pots to 2 1/2 ones imported from Old Hickory in 1962-63. Because of their larger size, much less doffing (cake removal) labor was required, which explains the significant savings on labor shown in the statistics.

With respect to the first of the effects - - the decline in the intensity of capital per man-hour in spinning - - it is clear that had the amount remained the same as in the base year, labor productivity would have been approximately 7% higher than what it actually was. This means that the total increase in labor productivity which needs to be 'explained'

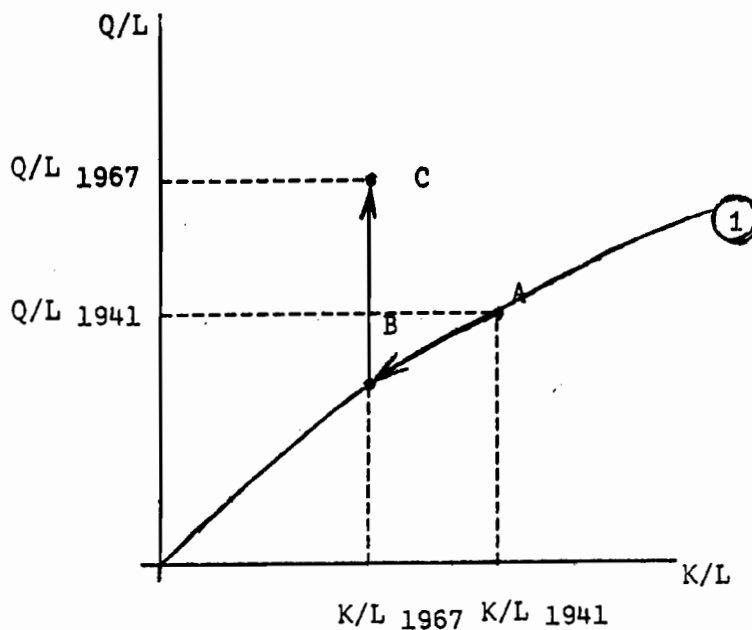
terms. With the growth of industrialization, the development of the textile industry, and the rising cost of labor, textile simplification and changes in output mix become more and more justified.

is now 46%-47% approximately, (see Table 5, p. 36) once we 'normalize' the factors the plant operated with at both times.

In relation to the two effects mentioned -- the substitution of capital for labor in spinning -- notice (col 9 in the table) that labor savings is 20% in a section that, on the average, uses close to 25% of direct labour employed by the entire plant. In other words, the "substitution effect" of capital for labor in spinning 'explains' about 5% of the increase in productivity per man-hour seen between 1941 and 1967 in the plant as a whole. (See Table 5, p. 36).

Graph 2 describes the accumulated effect of factor substitution and "de-cumulation" of capital in the spinning section. While the decrease in the capital/labor ratio supposes a movement from point A to point B along a given production curve, the change in pots and the technological change that followed caused the passing from B to C, which should be seen as the introduction of a new 'production function' in spinning.

Graph 2
Capital "de-cumulation" and factor substitution in spinning



Concerning the nature of this technological change, the evidence in Table 3 (col. 8, 9, and 10) suggests that as a whole it was relatively capital-saving 27/ even in spite of the fact that it drastically reduced the amount of labour employed in spinning in absolute values, and 28/ notably reduced the number of workers needed to operate the plant. This shows that any given technological change can displace labour from the production process (and even drastically, as in this case) and still have a capital-saving bias in relative terms.

Spinning Speed

Table 3 shows that another of the important factors accounting for the increase in productivity between 1941 and 1967 is the increase in spinning speed, which varied 16.3% between these two years (col. 6). This indicates that about 35% - - 16 percentage points of 46 for the actual increase in labor productivity calling for an explanation, - - comes from the fact that the machines were operating at a greater average speed in 1967 than in 1941. (See Table 5) 29/

The programs designed to raise spinning speed were especially important throughout the first of the technological "periods" identified earlier and right after the war until

27/ The units used here are physical, so in order to draw a more definitive conclusion concerning the final nature of technological change in the spinning section, we would have to know the price of new pots as well as the resale value of the old one-pound pots.

28/ W.E.G. Salter examines several examples of technological change often associated with a relative labor-saving bias pointing out that they often also save on capital in absolute terms. See Productivity and Technical Change, Cambridge University Press, 1960, p. 33

29/ Note that in 1967 the spinning speed - - 96 m/min - - was already much less than the maximum reached by this variable - - 145 m/min - -. Spinning speed was of greater relative importance as an explanation for growth during the first "period" mentioned here, but loses some of its importance in this exercise in which points corresponding to both "periods" are being compared.

the 1950s. In 1946/47, for example spinning speed was more than 145 m/min, practically double that of the early 1940s and 50% higher than in 1967, year used as a basis for comparison.

The main explanation for the behavior of Ducilo in this area - - that is, a high and rising spinning speed during the first two decades of productive life and a gradual slowdown to much slower speed during the second technological "period" - - should be looked for in market phenomena and in their relationship to the quality of the finished product. While we see that Ducilo was operating in a 'buyer's market' immediately following the war, where the installed capacity was usually in full use and when there was no difficulty in marketing the finished product, almost regardless of its quality and/or price, we see a different picture in the 1960s. In these years, competition was tougher due to the opening of plants which were not in operation at the end of the war, on the one hand, and on the other, because of the growing penetration of other synthetic fibers which supplanted rayon in several end uses covered by it in the 1950s. This gradual shift to a 'seller's market' and the concomitant loss of rayon as a textile fiber made Ducilo concentrate its efforts on quality aspects, a variable in which it had traditionally been leader on the market.

Of the several paths followed by Ducilo to improve yarn quality throughout the 1960s, one that was especially important was the reduction of spinning speed 30/ which explains the behavior pattern of the firm as far as speed is concerned.

Aside from the behavior of Ducilo concerning spinning speed through the two different growth "stages", it would be wise to ask now that the different technological changes put into practice by the firm over the years to first increase, and later reduce, the operative pace of its spinning equipment.

30/ In the 1970s, an attempt was made to produce polynosic yarn, the latest in quality on the rayon market. Foreign technical assistance was sought (CTA, France), but the program was never put into practice. In polynosic spinning, spinning speed is reduced substantially in exchange for a great increase in quality.

The most relevant technological modification to be mentioned in relation to spinning speed is undoubtedly the so-called "tube spinning" which will be examined in more detail later in this chapter.

Having talked about the increase in spinning speed and the role that it plays as a partial "explanation" for the increase in labor productivity from 1941 to 1967, we shall now look at other explanatory factors.

Factor Substitution in Washing and Purification of Cakes

Unlike what happened in the spinning section, in the area of cake washing and purification there was a significant increase in the capital/labour ratio. This was due to the installation of two washing tunnels with three tracks each in 1962, plus other collateral equipment, bought second-hand from Old Hickory after its dismantling in the early 1960s. In this case, we are in the presence of a set of technological changes put into practice as part of the modernization investment in the early 1960s. They are clearly labor-saving which explains the 63% fall in the number of direct working hours employed by the section. (See col. 17 of Table 3).

Since the washing section employed 10% of direct labor utilized by the plant as a whole, it is easy to conclude that the technological modernization plan of 1962 enabled a savings of 6-7% on the total number of direct labor hours employed by Ducilo Rayon, or similarly, enabled the increase in productivity per man-hour in a similar proportion.

Remembering that the increase in productivity needing to be 'explained' is 46%, this set of technological changes in the washing area became responsible for approximately 14%.

Increases in Denier

Table 3 (col. 5) shows that the average denier rose about 14% between 1941 and 1967. Spinning a heavier denier does not involve a greater use of direct labor; rather, the same amount of labor produces more kilograms of rayon. If production had

done in 1967 with the denier of 1941, the same amount of labor would have produced fewer kilograms of rayon. Therefore, the increase in kilograms obtained by manufacturing a heavier item should be computed as an increase in labor productivity, about 14% as we said before. In relation to the total to be 'explained' -- 46 percentage points -- the increase in denier accounts for close to 30%. (See Table 5)

Table 5 below summarizes the different "explanatory" factors for the observed increases in labor productivity.

Table 5
Variables which "explain" the increase seen
in labor productivity

	%	Relative importance
1. Increase in output per man-hour 1941-1967	79.0	
Less:		
2. Textile simplification	- 40.0	
Plus:		
3. Adjustment for capital/labor ratio	7.0	
Subtotal to be explained	46.0	
4. Spinning speed	16.3	35.4
5. Increases in denier	14.0	30.0
6. Substitution of capital for labor in washing and purifi- cation	6.5	14.2
7. Substitution of capital for labor in spinning	5.0	11.0
8. "Unexplained" residual	4.2	9.4
	<u>46.0</u>	<u>100 %</u>

Source: Prepared by authors on basis of data provided by the company.

The estimates in Table 5 lead us to conclude that three large groups of causal factors, of different origins and of different main characteristics, seem to have acted as the most important determinants of the observed increase in labor productivity.

The first of them -- and quantitatively the most important -- is associated with 'major' and 'minor' technological changes carried out by the plant's engineering team itself. It appears through 1) the increases achieved in spinning speed and 2) the increase in average denier. On the whole, these are technological changes that are "disembodied" and implemented on the basis of capital goods already installed, slightly modified. 35% of the change seen in productivity was achieved by the first of the variables and 30% by the second, which shows that 2/3 of what happened in the area of labor productivity between 1941 and 1967 corresponds to this group of causal factors.

The second group of causal factors affecting labor productivity is, in actual facts, alien to events of a technological nature and has to do with the change in the output mix marketed by Ducilo. This change is related to what we call "Textile Rationalization program," which was nothing but a vast labor-saving operation carried out through the gradual abandonment of a series of textile operations not specific to the actual production of rayon. This second group of factors depends more on external variables particularly macroeconomic ones than on circumstances inherent to the firm itself. In analyzing this topic, we have been led to observe that other firms similar in size to Ducilo frequently seem to have begun operating on the local scene with a larger labor crew than what was actually required by the technology and the capital goods originally installed. At the same time, it seems that in many cases, firms opted for self-supplying themselves with a wide range of goods and services which the industrial structure of the country was not in condition to supply at a reasonable cost and quality. Ten or fifteen years later, due to the growth of the economy as a whole and to the growing relative cost of labor, the original production process became inefficient. This forced many plants to save on direct labor by decentralizing operations of a high unit labor content. The case under study seems to have been one in which both factors -- growth of the textile industry and growing relative costs of labor -- justified the gradual abandonment after the war of many textile operations which were originally

carried out by Ducilo.

Finally, the third group of factors acting upon labor productivity is again of a technological nature but, unlike the first group of factors examined above, this one contains a greater portion of technological changes external to the firm, and it is mainly related to the factor modernization program carried out in 1962-63. We are mostly talking about a group of technological changes "embodied" in the capital goods imported second-hand from the United States, in the early 1960s. As such they are technological changes of a foreign origin and design and need an extensive modernization investment program in order to be put into operation.

In relative terms, this group of technological changes was decidedly more labor-saving than those mentioned before.

We have thus far examined what happened in the area of labor productivity. The figures presented in Table 5 suggest that approximately 2/3 of the increase obtained between 1941 and 1967 originates in 'major' and 'minor' technological changes effected by technical personnel at the plant (chemical and mechanical experimental groups). Such technological changes were generally "disembodied" and were implemented on the basis of available equipment. Simultaneously, we see that approximately 1/4 of the increase in direct labor productivity is derived from 'major' and 'minor' technological changes "embodied" in the plant's modernization investment of 1962-63. In this case, we are speaking about technological changes coming from abroad, and with a stronger labor-saving bias than those mentioned in the previous paragraph (especially in cake washing and purification).

Later on in this chapter, we shall describe in more detail the technological changes mentioned throughout the preceding pages. But before doing that, let us look briefly at what happened in relation to efficiency in the use of physical inputs, particularly pulp and caustic soda, which as indicated in the last columns of Table 3, also suffered significant variations in their "input-output coefficients".

Efficiency in the use of physical inputs

Table 3 suggests at least two important facts related to efficiency in the use of physical inputs. On the one hand, the variation seen in the 'technical coefficients' (physical consumption of pulp, caustic soda, etc. per kilogram of rayon)

poses the possibility that important modifications had been introduced in the production process. On the other hand in this part of the process, unlike those occurring in the spinning, washing, and textile sections, we observe that the absolute and relative labor requirements increase marginally, suggesting the possibility that the technological changes introduced in the chemical area were relatively intensive in the use of labor (saving on specific inputs, particularly caustic soda).

The information presented in Table 6 and Graph 3 below enables us to look at both aspects in more detail.

Table 6

Prices of cellulosic pulp and caustic soda in different sub-periods in the history of Ducilo Argentina (at 1937 pesos)

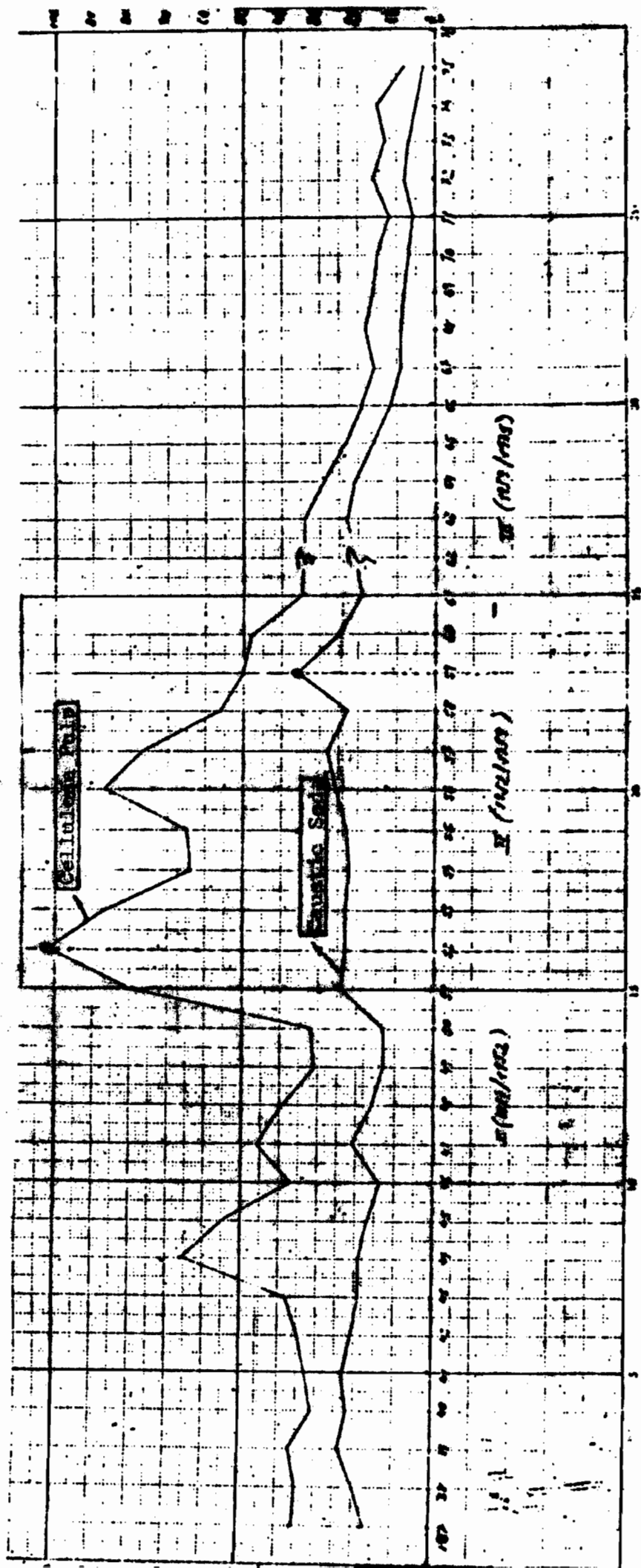
	1937-1950	1950-1960	1961-1974
Cellulosic Pulp	39.3	71.6	19.2
Caustic Soda	18.5	25.3	11.0

Source: Calculated as a simple average of monthly figures deflated with a Ducilo rayon price index.

Two statements of interest can be made referring to the information.

First, the series corresponding to the average price of pulp shows three "stages" when the market underwent serious supply difficulties. The first of these periods corresponds to the war years, while the other two occur in the early 1950s and in 1956-57. In these last two cases, the firm responded to the price increase in pulp through the use of substitutes. In 1951/52 cotton linters were used extensively as a basic raw material, while toward the late 1950s the plant began using pulp of a lesser cellulosic content, which not only was cheaper, but also had to pay lower customs fees when imported (both pulps were imported from Sweden). 31/

Graph 3: PRICES OF CELLULOSE PULP AND CAUSTIC SODA
 (Yearly Averages in 1937 pesos)



As we shall see later, both programs concerning the substitution of raw materials required a great amount of local technological effort since the production process had to be modified and optimized to operate under new chemical and mechanical conditions. This technological effort was provided by plant technical personnel working in the departments of Mechanical and Chemical Experiments.

Finally, and also in relation to the use and unit cost of pulp, the technical coefficients in Table 3 suggest that the substitution of high cellulose pulp for one of an inferior quality caused an increase of about 14% in the input-output coefficient of this raw material. Since the difference in price between cellulosic pulps was around 20% ^{32/}, such substitution amounted to a significant reduction in costs.

Secondly, the series corresponding to the price of caustic soda also reveals a marked rise in price of this raw material beginning in 1950. Only in the second half of the 1950s did Ducllo decide to carry out an applied research program designed specifically to save on caustic soda; this program was called "High solid viscose spinning" and its development coincided with the opening up of a pilot plant ^{33/} in order to facilitate the research, as well as the closing of the last rayon-producing factory belonging to Du Pont de Nemours in the United States. The latter gave a greater degree

^{31/} One of the technical reports from the Mechanical and Chemical Experimental Department reads as follows: "Due to customs regulations in force, imported wood pulp is subject to taxes whose amount depends on their alpha-cellulose content ... This means that using pulp with an alpha-cellulose content less than 90% economizes considerably." At this time an extensive research program was carried out in this field whose results were published in "Evaluation of wood pulp with an alpha-cellulose content of less than 90%." Plant Technical Report No. 1, March, 1967. And also "Pulp for the viscose process". Technical Report No. 1, January, 1968.

^{32/} This is an estimate made on the basis of information found in the technical reports mentioned in the previous footnote (see footnote 31).

on freedom to the Argentine technical team, leaving it open to its own limitations and potential. The greater analytical and experimental infrastructure available upon opening the pilot plant strengthened the technical team in their decision to develop their own package of technological know-how, since technical assistance from corporate headquarters was no longer available.

As in the case of cellulosic raw materials, the rising price of caustic soda seen in the 1950s (and its physical shortage toward the end of the decade gave rise to the search for technological solutions on the part of the chemical and mechanical engineering departments. Also, as in the previous case, it became necessary to design, put into practice, and finally optimize a new productive process notably different from that originally installed.

The next section, last in this chapter, takes a brief look at the Argentine technological component introduced by Ducilo over the years.

Pace and nature of Argentine technological endeavors

We have seen in the preceding section that the technological changes coming from the research and development efforts carried out by the plant's Mechanical and Chemical Research Department ^{34/} made a great impact on direct labor productivity as well as on efficiency in the use of the most important raw materials.

This section will examine some of the features of Ducilo's technological behavior, beginning first with a study of the level of expenses for technology and the sources of demand for new technological know-how coming from within the factory,

^{33/} With respect to the use of the pilot plant in the high solid spinning research program, two very detailed reports served as the basis for this analysis. They are 1) Write-up No. 1. on high solid viscose spinning, Plant Technical Report No. 12, October, 1963, and 2) Evaluation of High Solid Viscose, Plant Technical Report No. 3, September, 1966.

and then going on with a detailed analysis of some specific technological programs, their magnitude, and their effects on the company's technical and economic performance.

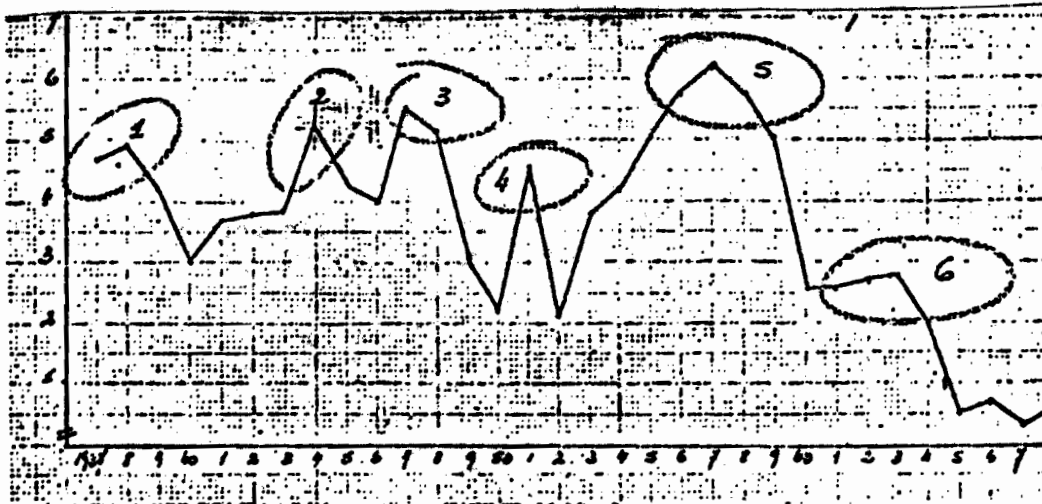
Graph 4 below reflects the evolution of expenses in wages and salaries in Mechanical and Chemical experiments over the years. The series is in 1937 constant pesos.

Graph 4

Wages and Salaries in Mechanical and Chemical

Experiments

(1937 Pesos)



34/ The names of these departments were changed in the early 1960s, when "Mechanical and Chemical experiments" became "Plant Technical Assistance".

The graph reveals several interesting facts. First it is clear that during the lifetime of this plant - - almost four decades - - the yearly expenses in Mechanical and Chemical experiments gradually lost importance, until they practically disappeared toward the end of the 1960s.

Secondly, the decline in mechanical and chemical research - - which seems obvious if we compare the first and last decade of factory operation - - is not really characteristic of the 1937 to 1957 period, when, in spite of annual fluctuations, a minimum level of year technology expenses was maintained of not less than 2.1 (thousands of 1937 pesos), and which averaged around 4.0 (thousands of 1937 pesos). The sudden drop begins only after 1945 and, apart from the short lapse corresponding to the modernization program of 1962-63, plant technology expenses practically disappeared during the course of the 1960s.

Thirdly, it is important to note what the different "sources" of demand for "in house" technological efforts were over the years. Using the figures in Graph 4 they can be summed up as follows:

1. Start-up stage
2. Expansion of installed capacity, (incorporating and adjusting 12 more machines in the spinning section).
3. High speed spinning and transformation of open trough to tube spinning". (Mechanical aspects of the production technology)
4. & 5. Changes in chemical aspects of the process.
 - a. Replacement of pulp by cotton linters.
 - b. Replacement of high content cellulosic pulp for another of lesser quality.
 - c. Decrease in the 'input-output coefficient' of caustic soda.
6. Substitution of capital for work. Installation and start-up of new cake washing and purification tunnels and 2 1/2 pound pots, purchased second-hand after the closing of Old Hickory.

In other words, the graph shows that matters such as a) the start-up of the plant and the initial optimization of the process, b) the expansion of installed capacity, c) the changes in the process (whether these occur by changes in the raw material used, by alterations in the machinery or other such circumstances), d) the modifications of available capital goods, e) the substitution of capital for labor, etc. are all situations that call for a certain amount of ad hoc technological know-how which must be produced strictly according to need and which, therefore, requires experimentation, trial and error, and research and development done at the plant itself.

Fourthly, apart from the aforementioned, the graph also discloses another fact related to the nature of the mechanical and chemical experimentation program of this firm. We are referring to the clear trouble-shooting nature of the technological efforts carried out. As can be seen the firm tended to respond to urgent requirements in the process or production line, by increasing its "in house" technological efforts, but they were not equally interested in maintaining a steady level of technological efforts over the years. Rather, they reduced them as time went by. We feel that the explanation for this behavior can be found in the fact that Ducilo rightly expected rayon to be a product with a limited lifetime being faced with the rapid upsurge of nylon and other synthetic fibers.

The rayon plant seems to have been somewhat of a training ground for the extensive technical and professional team formed by the firm over the years. The growing loss of interest in rayon led to the transfer of technical personnel, once trained, to other factories in the Ducilo group, particularly those of nylon and cellophane paper.

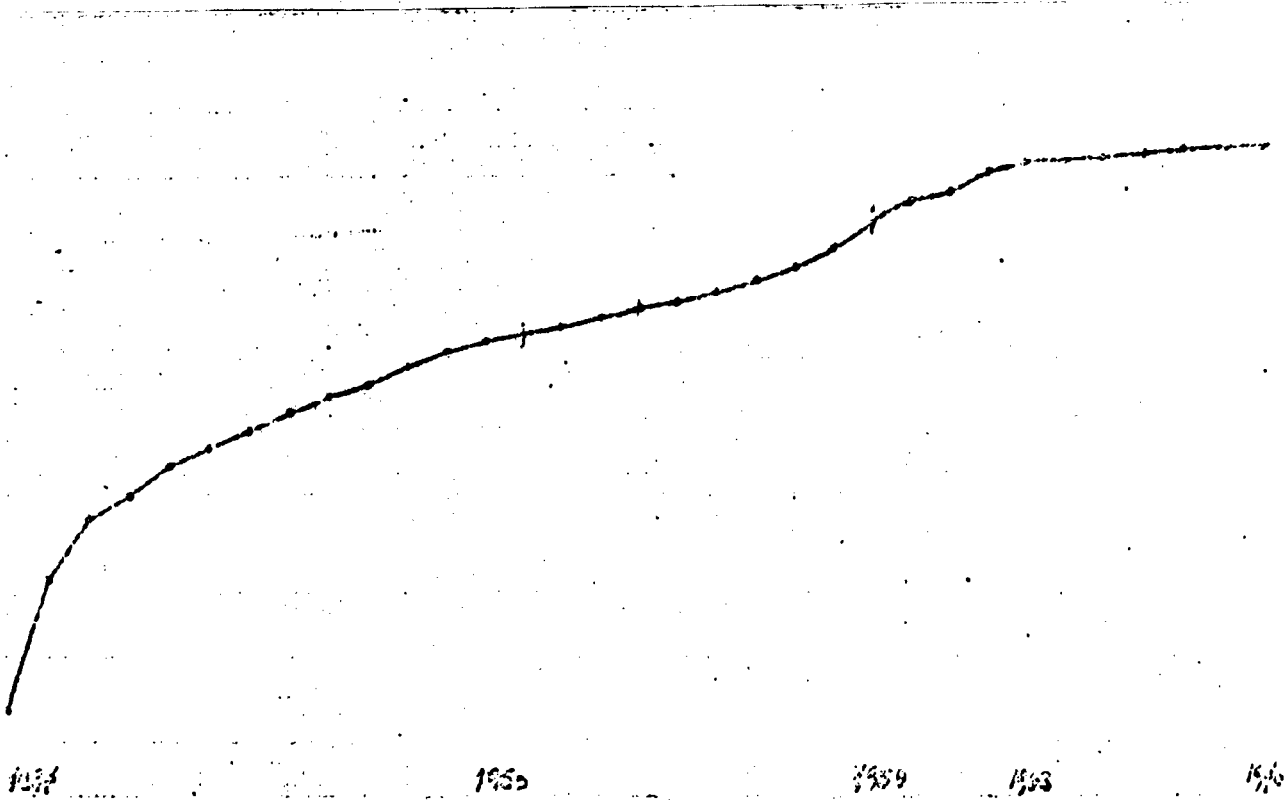
The changes in the process, substitution of raw materials, installation of new machinery and their tune-up, etc. normally brought about the need to partially reconstitute the technical team of the rayon plant, which was done on the basis of a special task force made up of professionals and technicians from other operative units. When the problem was solved that they were called to work on, they returned to their former positions, which explains the oscillating nature of the technological expenses described in the graph.

Before going on to an analysis of some specific technological programs, let us examine one more point. Looking at expenses in research and development over the years, we have a typical asymptotic curve, characteristic of situations where a saturation effect can be detected with regard to the flow technology basically intended to improve and optimize a factory which is essentially given. Due to the restrictions imposed by the available capital equipment - - which would only admit a finite number of adjustments - - and, in this case, due also to the growing lack of interest in rayon as a topic for study and experimentation (given the imminent closing of the plant, which was originally decided upon at the end of the 1950s), it is logical to expect a flow of accumulated expenses for research and development similar to that described in Graph 5.

Graph 5

Accumulated Expenses for Research and Development

(in 1937 pesos)



It is interesting to note that the logistic function involved in Graph 5 shows a certain historical discontinuity around the period 1958-1960, when there is an inflection and a short up-going trend covering the five-year period from 1958 to 1962.

It is also worth noting that this discontinuity has a clear counterpart in the history of this firm. It coincides with a very profound change in its managerial staff, and with the hiring of new technical management which favoured the growth of domestic engineering capacity. This fact, which appears even more clearly in other Ducilo factories, has only marginal importance in the rayon plant which was already entering into its final stages of operation.

Having finished the aggregate analysis of the flow of technical expenses, we shall now examine some specific technological programs.

1. Tube Spinning

In 1941 Ducilo was working at full capacity with all the equipment installed in 1937, which meant operating with open trough at 200 Godet revolutions per minute at the spinning midpoint of the machine. ^{35/} That gave 96.5 meters of rayon per minute, an output considered normal by Du Pont.

Given the existence of unsatisfied demand, Ducilo was faced with two alternatives: 1) to expand capacity by installing new spinning machines and/or 2) to increase spinning speed in order to obtain greater production volume from the installed equipment. It decided to follow both avenues.

Friction caused by the coagulating bath on the yarn being formed in the trough was one of the principal technological limitations hindering the increase in spinning speed at this time. The idea of replacing open trough spinning with a system where the coagulating bath circulated along with the yarn on the inside of a glass tube, allowing more speed without altering the

^{35/} Since there is a difference in speed between the beginning and the end of a cone, we use the conventional term, "midway point".

time period in which bath and yarn were in contact, ^{36/} seems to have originated around 1944-45 in Du Pont, U.S. ^{37/} The domestic development of the idea - - and all the mechanical and chemical experimentation involved - - was done at Ducilo in 1945-46. What does this mean?

The open trough machines had to be modified by installing a lead zig-zag, new guides, and finally, glass tubes of approximately 1/2 cm in diameter so that the yarn and the bath could circulate through it. The investment required for this modification in the equipment was around 10% of the value of a new machine, and enabled increasing production to about 300 Godeet revolutions per minute (which would signify about 145 meters of rayon in the same amount of time). In other words, output was increased by 50% compared to open trough spinning.

The length of the glass tube determines the length of the course and therefore the duration of contact between the filament and the bath. This length of time and therefore, the length of the tube should be adjusted according to the denier being spun, the raw materials used to make the viscose, etc. That is why the developments made in the U. S. calling for a tube of 72 cm. proved inadequate for local competitions and the Mechanical and Chemical experimentation team thought it more appropriate to use a tube of 80 cm.

The transfer to tube spinning entailed six months of work for approximately half of the Mechanical and Chemical Experimentation team, which at this time consisted of 30 people. First they worked experimentally with two or three spinnerettes of a given spinning machine, testing a) the type of trough (course), b) type of coagulating bath, and c) the type of viscose. After choosing the optimum combination on a pilot scale, they had to make the detailed "blue-prints" for modifying the troughs and also had to draw up standard instructions for preparing the viscose and coagulating bath in the 'proper' optimum conditions.

^{36/} Several yarn properties - - especially its dyeing capacity - - depend crucially on the length of time of contact (and therefore, on the length of the tube) between the yarn and the bath.

^{37/} S. Hollander says that by 1945 Du Pont had already patented the tube spinning method in the U.S., although he does not speak of the origin, development costs, etc., of this new technology.

Having completed the experimental stage, spinning on a semi-commercial scale was begun, putting the production under physical and chemical tests with customers. The Mechanical and Experimentation Department had to work in close collaboration with sales Technical Service, who was directly responsible to the clients.

It is important to note that the tube spinning is negatively correlated with quality, and so Ducilo decided to greatly reduce its spinning speed in the 1960s and go back to working on the basis of open trough. This undoubtedly called for a new adjustment and optimization of the process.

A second technological program which called for a great experimental effort on the part of Ducilo's engineering team was the so-called High Solid Spinning.

2. High Solid Spinning

The research program in high solid viscose spinning dates from the early 1960s, the two main technical studies on the subject dating 1962/63 and 1965/66.

The main objective of this experimental research program was to reduce costs by decreasing the input-output coefficients of caustic soda, a raw material which by the end of the 1950s had not only become more expensive but also was difficult to get.

Technically speaking, the aim of the R & D program consisted in reducing alkalinity and increasing the cellulosic content of the viscose, without altering the mechanical and chemical quality of the rayon produced. Besides lowering costs by saving on caustic soda, the technique of high solid spinning has several other advantages. Among them are 1) reducing the capital services used in production, especially the vaporizer and crystallizer, this also implied lower energy consumption, 2) reducing labor requirements in the textile area, due to the decrease in the number of "doffings" (cake removal) required for a given output, 3) reducing the input-output coefficient of sulphuric acid due to a lesser alkalinity content in the viscose.

Now then, a technological change of the kind examined here -- like those associated with changes in the type of pulp employed in the elaboration of the viscose -- presupposes a complete change in the process, especially in the chemical section. The pressing relation, the time for impregnation, the

time for aging, the proportion of carbon sulphide to make cellulose xanthate (see diagram of rayon process, p. 10) etc. must all be varied.

As in the case of the experimentation related to the use of new kinds of pulp, the only way of generating technological know-how needed for the program of high solid spinning was through trial and error on a pilot plant scale, searching for an 'optimum' combination close to (or better than) Du Pont quality standards. Given the relatively small capacity of the pilot plant - - 30 kilograms/day of yarn - - once the adjustments in the process were determined in the chemical section, tests had to be run on a larger scale (using the factory itself for experiments), in order to be able to evaluate the performance of spinning, textile reeling, and other factors which require larger samples.

It is important to point out that the high solid spinning program used certain information coming from the technical files of Old Hickory 38/, but that program should be considered as a genuine result of Ducilo's engineering team, since little or no technical participation from the corporate headquarters was received.

'Tube spinning' and 'high solid spinning' were two of the important experimental research programs carried out by the professionals and technicians at Ducilo. Both had an important effect on the firm's performance. Nevertheless, it is important to observe that the group of Mechanical and Chemical Experiments (later called group of Plant Technical Assistance) completed more than a hundred research and development projects between 1959 and the closing of the factory, period for which we have been able to obtain the pertinent statistical material.

38/ This can be deduced from the bibliography consulted by the Mechanical and Chemical Experiments personnel which is mentioned explicitly in the technical reports already referred to.

V. QUALITY, NEW PRODUCTS AND EXTERNALITIES

I. Introduction

In this chapter, we shall look at three topics which are often left out in contemporary aspects of technological change. This omission is not because they are considered unimportant topics, but because of the serious theoretical and quantitative analytical difficulties which have to be faced to study them in detail. We are referring specifically to 1. Quality, and its changes over the years, 2. the introduction of 'new' products, and 3. the flow of externalities which the technological changes of a certain firm have on third parties, and which are not correctly expressed in the normal market relations which exist between different manufacturers and/or between these and the consumers.

The technological change at Ducilo Rayon was strongly related to each of these topics. As far as quality is concerned, we shall see that this variable played an important part - - especially during the last two decades of its operative lifetime - - in the confrontation with Ducilo's two most immediate competitors, Sniafa and Reysol. One of the Plant Technical Reports states: "Nevertheless, since the end of 1967, the dyeing performance of Sniafa and Reysol began to improve - - drawing close to the dyeing levels of Ducilo's product ... The market situation has been changed to the point that Ducilo may try to improve its standard of dyeing in order to compete in quality. 39/

We see that the 'quality' variable - - and the technological efforts connected with its improvement - - became a central theme of firm strategy, even if it does not necessarily relate to the cost-price relationship, which is the main area of concern to students of technological projects.

Somewhat the same occurs with the introduction of new products, a subject very unsatisfactorily treated by theory to date. I. M. D. Little in his Critique of Welfare Economics writes: "The introduction of new products is somewhat more serious." In fact, this subject can hardly be analyzed. 40/

39/ "Chain stripping", Plant Technical Report No. 1
May, 1969, p. 2.

Just as in quality, the introduction of new projects - - and the technological effort to develop them - - should be considered as a crucial aspect of firm strategy, especially on a market of oligopolistic characteristics where price competition is not the main (or only) variable determining the relative participation of firms in total supply.

Finally, externalities. Here we shall consider two types of spillovers from Ducilo Rayon's technological efforts. They are a. technical assistance to suppliers, manufacturers of equipment, parts, etc. and b. technical assistance to clients. We feel that technological efforts carried out by the Mechanical and Chemical Experiments department of Ducilo Rayon have given rise to important externalities in both areas.

The fact that we attempt to discuss these topics in the following pages does not mean that the available information permits us to make more than a few preliminary statements. We are aware of the fact that more detailed research work is necessary, but the topics mentioned seem important enough to warrant at least an introductory treatment.

Quality

The quality of rayon is measured on the basis of 5 different variables, which are 1. tenacity; 2. Elongation; 3. denier; 4. mechanical quality (yarns) and 5. dyeing properties. The firm's strategy on quality is based on three basic considerations a) the theoretical standard, in this case set by the Technical Standards of Du Pont, b) market needs, and c) the quality of competing products.

The above suggests that the firm's strategy on quality is essentially a dynamic one. Obviously it is not the same to operate on a competitive market with technically sophisticated firms, or to monopolize the entire demand being even protected from imports by high customs duties. The consequences for quality strategy are also not the same when we compare producing for a market which is

40/ I.M.D. Little: Critique of Welfare Economics, Oxford University Press, 1960, p. 39.

not very fussy as doing it for a market which is able to discern differences in quality. Also, the previous paragraph reveals the complexity of the topic by showing us five different variables affecting the final quality of rayon, each of which depends in turn on a variety of chemical and mechanical factors.

Due to the first of our previous points, that is, the essentially dynamic character of the strategy on quality -- it is not surprising that the technological efforts designed to improve quality, although present throughout the history of Duclon Rayon, become more important toward the late 1950s when competition became stiffer and, at the same time, changes in the process became more important through eliminating high speed spinning, and the introduction of the high speed spinning process.

As far as the second point mentioned above -- quality being a complex topic since it is determined by five different variables -- it is not surprising that the firm only arrived at an explicit theory on what determines the quality of their product in its third decade of operation, formally expressing the different relative weight of each of the variables on a global quality index, at the beginning of the 1960s 41/

41/ Only toward the early 1960s -- after more than 20 years of operation -- we read in one of the Plant Technical Reports: "The accumulated experience in applying the present method of calculation -- the Weighted Quality Index -- allows us to make the following observations: a. There is no relationship between the quality indices of the various characteristics (tenacity, elongation, denier, creel, and dye). That is, small fluctuations in tenacity or in denier affect the index used up to now (the unweighted) more than larger fluctuations in dyeing or creeling." If we see that nearly 60% of the complaints received from clients come from dyeing problems and another 20% from defects in mechanical or creel quality, it is obviously unsatisfactory to operate with a non-weighted index as a working procedure. b. "Relative weight is not given to the different characteristics which affect the final quality." Supposing that the probability of clients' complaints is related to the historical mean indices of complaints -- see previous paragraph --, it is reasonable to say that an unweighted quality index is a less efficient indicator than the weighted method of calculation designed and put in practice in the early 1960s. This discussion can be seen in "Rayon Quality Index," Plant Technical Report No. 19, December, 1961.

Aside from the aforementioned points - - that is, that the theme of quality became much more important in the late 1950s, when the market became more competitive, and that only in the 1960s did the engineering team draw up a formal model of quality determinants - - the information available reveals other interesting facts. Among them are the following: a. Even in spite of the fact that the statistics are fragmentary, a secular tendency toward improving quality can be observed over the years. Since the variable "dyeing" carries the higher weight in an aggregate index of quality, it is interesting to note that the percentage of production with more than 6 colors - - the variable used by Ducilo to evaluate dyeing quality - - was 16.2 in 1963 42/ and fell to 8 at the end of the decade 43/, the theoretical optimum being 5. Likewise, the indices of tenacity and elongation show a tendency toward improvement, especially during the 1960s. 44/

b. Traditionally on the local market, the quality of Ducilo was always considered to be above the average quality of its nearest competitors, Sniafa and Reysol. A mid-1960s report provides the following indices: 45/ 46/

	Defects per kilogram	Dyed % greater than 6 T	Weighted index theoretical optimum = 100
Ducilo	1.8	7.	88.5
Sniafa	1.5	25.	72.0
Reysol	2.4	12.4	81.0

42/ "Whither Rayon", September, 1964, p. 29.

43/ "Chained Rayon", Plant Technical Report, No. 1, May, 1969, p. 3.

44/ "Evaluation of viscose with a greater cellulose/alkalinity ratio, Plant Technical Report, January, 1969, p. 7.

45/ "Whither Rayon", Op. Cit. p. 29

46/ Ducilo's prices also were systematically higher than those of competitors. We must add, however, that thanks to its better quality, this firm sold its products more easily than Reysol or Sniafa.

c. The flow of technological knowledge produced by the department of Mechanical and Chemical Experiments for the purpose of improving the different variables associated with product quality was extremely significant over the years. From the set of Plant Technical Reports that we were able to examine throughout our research, 42 of them are directly connected with the quality variable. Others affect quality in an indirect way, that is to say, that even when the immediate objective or motive for carrying out the applied research and development program was not to improve the quality of the product.

In summary, a) the quality of Ducilo rayon made systematic improvements over the years, b) these were greater in the late 1950s, when competition became stronger and when the engineering team at Ducilo gained a better understanding of the basic theory underlying quality c) a strategy on quality necessarily implies a concomitant strategy of experimental research work and development of new technological know-how. Even when theory to date is devoted mainly to examining the cost-price relationship and the incidence of incremental technological change on such relationship here the quality variable also plays a central role in any company behavior, and that this firm undoubtedly had a strategy to that effect, which in turn implied a strategy as far as domestic technological creation is concerned.

Let us look next at the introduction of new products.

3. Introduction of new products

The introduction of new products -- in this case new varieties of basically the same product -- shares some of the behavioral features associated with the topic of quality improvement. ^{47/} As in the case of quality, the introduction of new products is one of the ways with which the company builds its competitive strategy in an imperfect market where various other considerations, aside from the price, are involved in the consumer's decision to buy. Also, like changes in quality, the introduction of new products requires the "production" of technological know-how to develop them, as well as an explicit firm strategy in this sense.

It is important to note that Ducilo's behavior in the area of new product introductions differs from that of its competitors. While these concentrate their activity on a few items of widespread demand -- 9 varieties in the case of Sniafa and only 7 varieties offered by Reysol ^{48/} -- Ducilo produced 32 varieties covering a wide range of deniers and presentations (bright, dull, flametint) not offered by Sniafa and Reysol.

This had at least three immediate consequences. First, Ducilo was negatively affected by having to make shorter turns, which involve more machine stopping, more labor costs in doffing, etc. Secondly, this strategy also implies that Ducilo enjoyed monopolistic conditions in several 'supermarkets'. ^{49/} Lastly, Ducilo's strategy of greatly diversifying the number of varieties offered constituted a permanent source of demand for "in house" technological efforts. The Department of Mechanical and Chemical Experiments was the operative unit in charge of this task over the years. Between 1959 and 1974 - - period throughout which we have been able to examine the Plant Technical Reports produced by that department - - a total of 14 out of 117 are concerned with new products.

As our last point in this chapter we shall discuss the topic of externalities derived from this plant's technological efforts.

4. Externalities derived from the technological know-how generated by Ducilo

Of the various types of external effects which derive from the flow of technology produced at Ducilo, at least two deserve analysis. They are a. technical assistance to suppliers, manufacturers of parts and equipment, etc. and by technical assistance to customers. We have been able to detect significant effects in both direction, originated both in efforts to create new technology by the Department of Mechanical and Chemical Experiments and of the Sales' Department with support from the research and development group.

^{47/} What a 'new' product is, is certainly a complex question. Even when rayon can be a cloth for upholstery as well as one for making undergarments, the degree of substitution between both is extremely low. Presumably this implies that the name 'new' can be validly used when it refers to a product which meets a need that cannot be met by items already on the market.

^{48/} See Table III 'Rayon deniers offered on the local market', Whither Rayon, 1964. p.26.

^{49/} This partially explains why this firm opted, to a good degree, for the strategy 'live and let live' when Reysol and Sniafa arrived on the market.

a. Suppliers

Every firm has a more or less explicit strategy for maintaining its capital goods. Maintenance involves repairing deteriorated equipment and replacing those pieces that must be replaced due to natural wear or breakage. 50/

Now then, any maintenance strategy -- and especially in those cases where the equipment to be maintained was originally imported -- posed a series of interrogatives concerning the sources of supply of necessary parts and pieces to accomplish it. In this specific case either the parts and pieces could also have been imported or they could eventually have been manufactured locally. What were the determining factors for one option gaining preference over the other?

The end objective of maintenance is to try to maximize the number of hours the plant is in operation. From this point of view, each unplanned stop (or a stop somewhat longer than planned) means additional costs which the firm must try to minimize. In this respect the lack of a replacement part is much more serious than its actual price.

Having stated the above, and remembering the relative complexity of the import mechanism -- Ducilo personnel estimated that the time necessary to order, receive and pick up a part from customs amounted to around 6 months -- and it is not surprising that Ducilo's strategy on maintenance involved a growing replacement of imported parts with locally designed and produced equivalents (or nearly equivalent). Having started fully relying on imported parts in the 1940s, all spare parts were made in Argentina by the latter half of the 1960s.

Spare parts can be manufactured domestically in a workshop owned by the firm itself or contracted out to third parties. Generally speaking, the second of these options was the one followed by Ducilo, tending to utilize its own workshop only in cases of emergency or to manufacture those spare parts of very sporadic or non-recurrent demand.

50/ Under this point, we could make a distinction between export maintenance and preventive maintenance. The latter implies the existence of a relatively more sophisticated engineering team than the former, inasmuch as it involves detailed programming. The plant under study had an efficient preventive maintenance program from its initial years.

Even though some of its spare parts suppliers were large firms such as Pirelli, Schkolnik, Rigolleau, etc. it is also possible to find a large number of smaller ones, formed in many cases by ex-operators of the Ducilo plant who put up small workshops with Ducilo as their only (or main) client. Dudulec, Moronese, Newbound, and others belong to this group.

The decision to buy Argentina and the choice of supplier generally called for close collaboration between the Purchasing Department and that of Experimental Mechanics, which was in charge of supplying to the small firm the original Du Pont "blue print" and of closely supervising the operation when it involved changes in the original design, which happened fairly often.

Changes in the original designs were caused by having to replace raw materials, by the advisability of changing the design, etc. Some examples in this respect are the spinning machine stabilizers which were originally made of stainless steel and were locally made of epoxy-coated iron, the adapters and yarn holders which were originally made in lead and were here changed to plastic, rotating bath tracks which were changed from glass to alclad, etc.

Aside from the replacement of raw materials in spare parts manufacturing, it is also important to mention their frequent redesigning in order to increase resistance (useful lifetime), or to improve performance. Press filters, doffing gears, EB 19 motors, etc. are examples of this kind of situation.

Besides the externalities involved in the transfer of technological know-how from Ducilo to these firms, we have also been able to detect some special situations where Ducilo provided financing for new equipment, taking out an insurance bond or some other type of guarantee to cover the down-payment.

In summary, the maintenance strategy carried out by Ducilo, produced important external effects on quite a number of industrial workshops which arose for the nearly sole purpose of meeting Ducilo's demand for replacement parts which substituted those previously imported.

b. Technical Assistance to clients

We have detected at least two types of externalities on clients emerging from Ducilo's technological efforts, and a third effect, although not necessarily has to be considered an externality it all the same does warrant mention.

The first important effect has to do with observed increases in productivity achieved by Ducilo's clients as a result of technological efforts carried out by this firm, which induced subsequent modifications in the client's routine in operation. In one of the 1961 Technical Reports the importance of the change from 1.6 and 1.65 kg cones to 2.5 kg cones is evaluated in the following way: "The increase in cone weight is an advantage to our factory internally as well as to our clients. In the factory, machine performance rises and more yarn weight is obtained per unit, along with less handling. Our clients obtain a rise in output from the machines that prepare the yarn before weaving, such as for example, a rise of 40% in warping. 51/

It should be mentioned that the increase in prices introduced by Ducilo when 1.5 and 1.65 kg cones were replaced by the larger 2.5 kg cones did not absorb the productivity improvement obtained by the firm's clients, there being here an important externality for them.

A second effect, which we shall call indirect since it is not associated with technological changes introduced by Ducilo, has to do with those situations where the Sales Department with support from personnel of the Department of Mechanical and Chemical Experiments, had the chance of giving free technical aid to clients so they could improve their own operating routine.

We come across situations of this sort when examining the tasks carried out by the Sales Department. In visits to their clients' industrial plants, Ducilo's sales personnel could identify operations where the equipment was not being used in the most efficient way.

In several cases, and with the help of the engineering team of Ducilo Rayon, it was feasible to propose adjustments and modifications in the technology of the client firm, this being a clear cut externality for the latter.

Finally, a last effect, which does not necessarily fall into the category of an externality since the difference in prices between Ducilo and its competitors could be considered to partly pay for it, lies in the flow of technical information from the firm to its clients through the Sales Department. Such department distributed without charge, a monthly bulletin containing technical information concerning each of its marketed products, and normally

51/ Plant Technical Report No. 14, August, 1961. "Larger size cones in cones lessons No. 50", p. 2.

including technical suggestions on how to treat the product in the client's plant. ^{52/}

As in the previous case, we have here an example of an indirect effect emerging from Ducile's technical efforts. It involves certain minor forms of technical assistance to clients which did not call for monetary returns on their part.

Although briefly this chapter has examined, three topics often left aside in studies on technological change. The material presented here shows that, beyond the cost-price relationship normally explored in the literature, technological change is strongly related to a) changes in quality and b) to the introduction of new products. At the same time, we have seen that the technological efforts of a certain firm produces "forward" externalities in its client firms and "backward" externalities in its equipment and spare parts suppliers.

The next chapter - - sixth in this study - - presents a simple model of firm behavior designed to further explore the main features of the case under study.

^{52/} For example, Bulletin R-5 of September, 1966, discusses "Rayon 125-5 flat filament yarn", and after giving the basic data on the product, contains a section called "Conditions for processing it" where it explains how the product should be treated in order to achieve the greatest possible output in the textile stage.

VI. A SIMPLE MODEL OF COMPANY BEHAVIOR

The analysis and statistics presented in the previous chapters will permit us in the following pages to construct a simple model of company behavior that will be used to throw some light upon the interrelationship between micro and macro-economics, as well as between economic and technological aspects in the evolution of the company under study.

The objective of this chapter is to examine the growth pattern of Ducilo Rayon over the years in order to understand some of the more outstanding decisions taken concerning modernization, productivity, permanence and departure from the market, etc.

First of all, we shall summarize the most significant conditioning factors in this case, pointing out three levels of analysis: a) the firm, the product, and the relationship with corporate headquarters; b) the market; c) the macro-economic conditioning factors.

A. The firm, the product and the relationship with corporate headquarters

In every situation there is a set of strictly microeconomic factors that condition and determine the objectives and restrictions a firm operates under. Several factors inherent to the particular case of Ducilo, to rayon as a textile fiber, and to the relationship of the firm with its headquarters must be kept in mind in order to understand what occurred. Among them are the following:

A. 1. The product

1. From the demand point of view, rayon experienced two clearly different situations during Ducilo's lifetime. While a strong surplus demand for rayon was seen in the 1940s and immediately following the war, after the 1950s, the product was in evident decadence and began to disappear. It was gradually replaced in its main uses, by nylon and other synthetic fibers, particularly in later years when these were able to incorporate certain physical properties (fiber breathing, softness to the touch, etc.) which had been the principal advantages of rayon as a textile fiber.

2. From the textile production point of view, and given the growth in substitute products technology and the relative prices of capital, labor and main raw materials (cellulose), rayon became a growingly 'inefficient' product for at least two reasons:

a) it only produced 1.5 to 1.7 g/denier compared to 4.5 g/denier for nylon, which implies a much lower output per unit of input from the looms in the stage following yarn elaboration, b) rayon is a product which uses rather intensively both labor and scarce raw materials, which had risen in price considerably over the years, making rayon an increasingly non-competitive product compared to synthetic fibers (e.g. nylon or polyester).

Such situations acquired greater significance from the 1950s on. Rayon has now been relegated to minor markets (lining for example) and is relatively expensive.

a. 2. Corporate headquarters

1. Du Pont closed its last rayon-producing plant toward the end of the 1960s. Before this date, in 1957 approximately, the firm mistakenly decided to modernize the Old Hickory plant extensively, only to discover a few years later that it was wiser to close that plant and transfer its workmen and technicians to another manufacturing line to produce polyester, which they were then able to market some years before expected.

Due to these circumstances, Ducilo was unexpectedly faced with the supply of second-hand machinery at throwaway value, even though it was practically new equipment technically and mechanically speaking.

2. The technical staff involved in the start-up of the rayon plant in Argentina did not come from the higher ranks of the company in the U.S. It had little interest in developing Argentine engineering competence. Only several years later, in the 1950s, together with an overall reorganization involving the general management as well as diverse technical-administrative departments of the different plants, did a change in hierarchy occur. The new general administrator sent by Du Pont to take charge of the local operation was from the higher ranks within the organizational structure of the company and the subject of domestic technological efforts was completely revised.

3. From the end of the 1950s on and coinciding with the closing of Old Hickory, Du Pont suggested to the Argentine branch that they close the rayon plant. With the exception of Canada, this was the only branch manufacturing rayon and headquarters was very reluctant to admit an extension of the useful lifetime of the Argentine plant.

A. 3. The Argentine company

1. Ducilo Rayon was the first of the plants to be

opened by Du Pont in Argentina and as such enjoyed certain advantages in terms of being an excellent training center, but had to accept the cost of a growing "decapitalization" in terms of professionals and technicians. In the 1950s the nylon plant was already the main source of attraction for professional personnel, who generally worked first with rayon and then were transferred to other technical areas of the firm.

2. From the mid-1950s on, the team of technicians - - especially those belonging to nylon and only to a lesser degree to rayon - - rapidly grew up on the basis of locally-trained professionals coming from the Chemical Engineering School in the province of Santa Fe, a renowned educational center in chemistry.

3. The closing of Old Hickory in 1960 created a real conscientiousness and a sense of technical responsibility in Ducilo's engineering team, which understood then that they had their own technological solutions to the successive problems arising from the need to change raw materials, redesign and improve the production process, modernize old equipment, etc. in the rayon production line.

In summary, when we examined the sphere of factors which we have generically grouped under the title of 'the firm, the product, and the relationship of the firm with corporate headquarters' we find: a) a declining product; b) a home office which by closing a production line recently modernized in the U.S. was in condition to provide practically new machinery to its Argentine branch at scrap value; c) simultaneously, the managerial group originally in charge of the Argentine branch did not come from the highest ranks in headquarters, and only in the 1950s - - when it was clear the rayon plant had to be shut down fairly soon - - a new technical management of great strength and prestige within the Du Pont group, took hold of the running of the local subsidiary; d) the former point is associated to the fact that the firm showed an increasing interest in filling its decision-making positions with a new group of young local professionals, very keen in developing a rather strong technological base.

B. The rayon market

1. Toward the middle of the 1950s, the rayon market became a sellers' market instead of a buyer's one. This was obviously connected with a change in the competitive atmosphere prevailing in it.

2. During the first 10 to 15 years of operation, Ducilo Rayon enjoyed a monopolistic situation. In the course of the 1950s, and after the incorporation of several other firms (Sniafa, Reysol, Rodhia), the market situation changed evolving toward a case that we could depict as an oligopolistic leadership surrounded by various competitive offers.

3. Save exceptional situations, we did not find a market where price competition was the rule. Competitive forces expressed themselves in terms of quality, variety of items offered, etc. Ducilo acted as a leader in practically all the most important dimensions of the market.

4. While Ducilo offered a wide range of deniers and lusters (bright, dull, flametint, etc), Sniafa and Reysol only worked a reduced number of items (denier 100, 120, 150 and 200) where most of the market's demand was concentrated.

C. Macroeconomic conditioning factors

Finally, let us refer to some macroeconomic factors that have significantly affected the behavior of the economic agents on the rayon market. The following fall into this category:

1. The rapid rise in labor costs as well as in the price of the main raw material (cellulose);

2. The accelerated pace of technological change in other textile fibers, rayon substitutes. The physical, chemical and mechanical properties of nylon, first, and later, of polyester and other synthetics were greatly improved, making it feasible to use them in fields traditionally left to rayon. At the same time, their relative price fell steeply.

3. 1947 legislation on insalubrity affected labor costs in the spinning section considerably, in Ducilo as well as Reysol (firm joining the market in that year), by obliging them to add another complete shift, working four 6 hour shifts (but paying for 8 hours; that is, full time), plus one supplementary shift of substitute personnel.

4. The post-1957 atmosphere greatly favoured and subsidized factory modernization as well as the incorporation of foreign capital goods.

Each and every one of the factors mentioned briefly in the above paragraphs -- the strictly microeconomic ones as

well as those referring to the rayon industry or the national macroeconomy - - played a specific role in Ducilo's evolution. Along with other daily circumstances, they influenced the sequence of company decisions we are interested in illuminating out here. In the next section, we shall attempt to examine what happened, using the instruments provided by the economic theory of oligopoly.

The history of Ducilo Rayon and economic theory

The first 12 years of productive life in Ducilo Rayon are not analytically complex. During these years Ducilo enjoyed a complete monopoly situation on this product on the Argentine market. At the same time, a strong excedent demand for it prevailed, due to the shertage during and after the war.

A high protective tariff - - more than 200% - - allowed the firm to set prices much higher than the international ones, which assured high absolute profits (and also relative, with respect to what a similar plant would have earned in Europe or the U.S.). 53/

Unit production costs fell radoidly following the start-up period of a plant conformed by 52 spinning machines originally brought from abroad. (See Graph 6, the section up to 1939). The basic objective of these years was simple: To produce more rayon. Price and quality were two considerations that were taken into account but they were not a cause for preoccupation. Du Pont standards guaranteed the latter while monopoly, the high protective tariff, and surplus demand reduced importance to the former.

The logical response to this was to increase installed capacity and operating speed of the available equipment - - which was achieved in 1941 and 1947 respectively through the purchase of 12 more spinning machines and through the change from 200 to 300 Godet revolutions per minute (96.5 to 145 meters of rayon per minute) made possible by adopting the tube spinning process. As can be seen, the technological change involved in tube spinning was introduced to meet the need of expanding the output yield of installed capacity. Tube spinning was the principal engineering endeavor of the period.

The first two important "worries" in Ducilo Rayon's history occurred well into the 1940s. The first was the appearance of Reysel in 1947 as a seller of rayon, (only in 1950 did

it finish its start-up period). The second source of difficulties was the new salubrity legislation, passed in 1947.

While the second factor also affected Reysol and therefore did not alter the relative positions of either firm in terms of costs and productivity, Reysol's entrance to the market is an important change that should be examined more thoroughly.

Reysol was also the branch of a foreign company (Mate-razzo, Brazil), which used only European technology, basically coming from Snia Visosa, Italy. The plant had 24 spinning machines, that is about half the original size of Ducilo in 1937, and just a little more than one third the size of Ducilo after its expansion in 1941. During its first years of operation, Reysol worked at speeds of nearly 90 meters of rayon per minute (tube spinning was never used by Reysol in textile rayon), which shows that the productivity gap between Reysol and Ducilo - - which had already made the transfer to tube spinning at this time and worked at about 145 meters/minute - - must have been substantial. Although it is true that this was partially compensated for by the fact that Reysol produced an average denier higher than that of Ducilo, it is still reasonable to suppose that there were important differences in the performance of both plants at that time.

The 1947 salubrity legislation strongly affected both firms by forcing them to create an extra shift in the spinning section (see Graph 6 Appendix I of this chapter, the part between 1945 and 1949). At that time, Ducilo's unit direct labor costs suffered a 30 to 40% increase with respect to 1945, as shown in Graph 6 (Appendix I of chapter) and Table 1, Graph 1 (Chapter III, p. 14), where the phenomenon is shown in terms of labor productivity per working hour. 54/

53/ Strictly speaking and even using the full tariff - - that is to say, adding the average production cost plus the full tariff, Ducilo did not set the maximum price the market was able to absorb. This can be deduced from the fact that there was both a strong excedent demand and a lack of imports, which can only be explained by the abnormal supply conditions prevailing during the war.

During the early 1950s, the entrance of Reysol -- which absorbed between 20 and 30% of domestic demand -- led Ducilo to diversify the items it offered on the market, while Reysol concentrated its activities on three or four items of widespread demand. This shows how technological change (related to the introduction of new varieties) is directly connected with market competition. Throughout the 1950s, however, a new set of circumstances, outside the realm of Ducilo, led it to modify several aspects of its technical-economic behavior. Some of these circumstances were: 1) the appearance of nylon and its rapid expansion as a substitute for rayon; 2) Energy shortages in 1951/52 made it necessary to reform machinery (burners, boilers) in order to be able to use by-products of agricultural raw materials as sources of energy; 3) the need to use cotton linterns as a basic raw material, called for a major effort to modify and optimize the process; 4) When Sniafa entered the market as a rayon producer, the balance reached after Reysol's entrance was altered again, reducing Ducilo's relative participation once more; 5) During the second half of the decade, the fast-rising price of caustic soda (and its shortage) led again to the necessity of modifying the productive process and improving the technology for recuperating that raw material; 6) The growing labor difficulties on a national level resulted in the strike of 1959 which paralyzed the plant for several months. When the plant was reopened, it was significantly reorganized, with a strong reduction in labor utilization.

Let us look at some of these factors in detail.

Sniafa entered the market in 1950 with a plant of 26 spinning machines whose capacity fluctuated between 2,000 and 2,200 tons annually. In other words, this firm started up a factory marginally larger than that of Reysol, which was operating at full capacity by this time.

Sniafa also decided to specialize in a few deniers of widespread demand -- particularly 125, 150 and 200, bright and dull lusters -- and, since its operating speed reached approximately 85-90 meters of rayon per minute, it must also be considered as having a lower productivity per man hour than Ducilo.

^{54/} For the same number of total hours worked, more people had to be hired in spinning and in the textile section.

Nevertheless, this last statement calls for an important qualification related to the salubrity legislation of 1947:

Sniafa, thanks to a late entry and to more modern equipment, managed to avert it, thereby avoiding its negative impact on labor costs and productivity.

Let us examine this point further. Ducilo, during these years, worked at 145 meters of yarn per minute (nearly 50% more than Sniafa or Reysol) but, at the same time, felt the full impact of the 1947 salubrity legislation which forced it to employ 30% more labor per unit than that required by the technology used at Sniafa. It then seems reasonable to assume that a certain productivity differential existed between the plants (Ducilo and Sniafa), even though it was not as great as suggested by the differences in spinning speed. Likewise, it is to be expected that Reysol, spinning at approximately the same speed as Sniafa but, (like Ducilo), affected by the salubrity legislation, was the firm which had the least productivity per man hour of the three.

Due to these differences in productivity, and to the fact that it started up much earlier, it is not surprising that Ducilo acted as the market leader on the Argentine market. This leadership can be seen in quality as well as in prices. 55/

55/ A report of a few years later shows that while Ducilo reached a weighted quality index (obtained from the weighted average of mechanical, physical, and dyeing characteristics) of 88.5, Sniafa only reached 72 and Reysol, 81. (While in defects per kilogram, Sniafa and Reysol were practically the same as Ducilo, in dyeing properties, both firms were much lower, this being the explanation for the weighted index which shows Ducilo in a much better position than its competitors).

Suppose now that the central objective of the leading firm is to choose a price that maximizes its own benefits, taking into account the supply curve of the minor firms, which indicates the amount they would be willing to sell at each particular price set by the leader.

In graph 7, the curve DD refers to total rayon demand. The curve SS represents the aggregate supply of the minor firms, which the leading firm knows about and takes into account; at the price OS' - - which in this case would have been below the mean cost of Reysol, (which Ducilo probably could have set, thanks to its higher productivity) - - the smaller firms would have been ousted from the market. ^{56/} For prices higher than OS', the smaller companies could enter the market equaling the price with their respective marginal costs. When the price reaches OG, the smaller firms cover the entire market. In this way, the demand curve of the leading firm is set by GED, which is arrived at by subtracting, for each price, that part supplied by the smaller firms from the total demand.

Given then the demand curve GED the leading firm derives its marginal earnings curve, GNEM. It maximizes benefits producing the amount at which marginal costs equal marginal earnings, which in this case occurs at point R, determining the quantity OX to be sold by the leading firm at price OP. At this price the firm will produce PZ = OX while the smaller firms will produce PZ' = OX', which together with the former satisfy the total demand; that is, PA = OX + OX'.

Returning now to Ducilo and the rayon market in the 1950s, this kind of comparative statistics exercise allows us to examine several of the situations of interest occurring in that decade. It is obvious that the monopolistic situation of the first operative decade could not remain for long. Protective

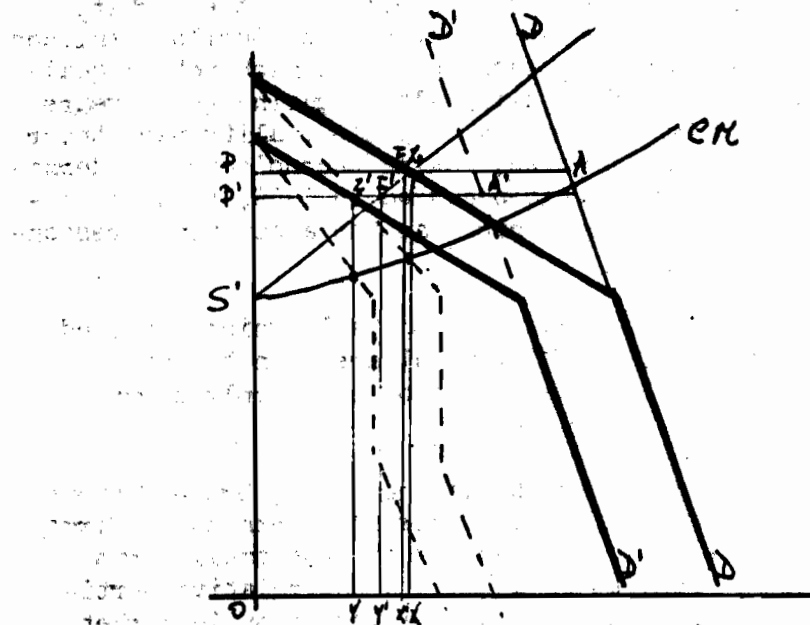
^{56/} OS' is then an 'entry-preventing price' which has the peculiarity of keeping smaller firms out of the market since they are not able to cover the minimum average variable cost of their respective productions. The conditions in which the leading firm could find it advisable to set a price below OB' and eliminate smaller producers from the market have been discussed by P. Sylos Labini in Oligopoly and Technical Progress, Harvard University Press, 1961.

tariffs and the presence of excedent demand induced other firms to invest in new rayon manufacturing plants. ^{57/} At the same time, the appearance of nylon as a direct substitute caused a reduction of the total demand for rayon.

Let us look at both situations, beginning with the continuation in demand caused by the appearance of nylon. In terms of the previous graph, the introduction of a substitute has to be interpreted as a displacement of the demand curve, which would move from DD to D'D' as shown below in Graph 8. The overall market falls from PA to P'A'.

Graph 8

Rayon demand fall upon the appearance of nylon



While in the initial situation, the leading firm produced $Ox = PZ$ and the smaller firms, $OX' = PF = ZA$, after the fall in demand it produced $OY - P'Z'$ and the smaller firms $OY' - P'F' = F'A'$.

^{57/} Reysol was built in 1947 and began producing rayon in 1949 while Sniafa entered the market in 1950.

Although the relative participation of both kinds of firms should not necessarily be altered, it is clear that under such circumstances some or all of the firms would have to operate below capacity.

This was in fact what happened, except that the demand fall was assimilated differently in the two segments making up this market. While Ducilo reduced its spinning speed appreciably, but maintained the majority of its machines in operation, Reysol, as well as Sniafa, stopped a significant number of spinning machines (approximately 50%, in the case of Sniafa) but continued to spin at the same speed as before.

Ducilo's reducing its spinning speed and returning to open trough spinning allowed the firm to improve the quality of its product considerably. Obviously, this had its effect on the market, since it became evident that even at higher prices, Ducilo displaced competition in different end uses, because of its much better quality. Reysol's product had serious difficulties during these years with dyeing, so that the improvement in Ducilo's quality made their relative position on the market worse, making technological modernization unpostponable for them. This occurred in 1959, when the entire washing section was replaced, which was the area mainly responsible for quality deficiencies.

The technological modernization of Reysol, which involved an investment of close to half a million dollars, can be seen geometrically in Graph 7 as a displacement of the supply curve of the smaller firms sector. 58/

Given the rest of the elements in the model, Graph 9 shows us that both situations - - the entry of new small competing firms or the introduction of technological changes in the small firms already in existence - - results in a fall in the relative participation of the leading firm as well as in a reduction in market price for consumers, (or a fall in the relative price of the product in an environment where the general price level was on the rise.)

58/ The entry of Sniafa to the market can also be seen in geometric terms as a displacement from f1 to f2.

The decision might seem strange, since the leading firm surely had the possibility of obtaining greater benefits (in absolute value) than those derived solely from the fraction of the market available after taking into account the supply from the competitive sector. It could have tried to acquire a larger portion of the market, but in order to do this the leading firm would have to lower its price below the variable cost of the smaller firm forcing them to leave the market. This could have caused a 'price war', which would have been rather long-lasting (especially if faced with a branch of a multinational group such as in the case of Reysol or Sniafa) and, given the rather unattractiveness of the rayon market, it is understandable why Ducilo was uninterested in carrying out such a policy of confrontation and decided instead to 'live and let live'. So this model proves useful; the leading firm takes into account the supply of the group of smaller companies and only then asks itself what price it should set in order to maximize its earnings on the portion of the market which at this price is not covered by the smaller firms.

From the mid-1950s on, the increasing difficulty of rayon to compete with other textile fibers (nylon which reached spectacular rates of expansion in a few years) is apparent. The nylon producing plant at Ducilo became important in the mid-1950s and there was widespread feeling within the company that the rayon line should be closed within the near future. 59/

Throughout the decade of the 1950s, there was a marked tendency toward increasing operative efficiency within the framework of an essentially given factory. Textile rationalization - - which freed more than 1/3 of the total direct labor hours - -, the improvement of systems for recuperating raw materials, the adaptation of the process to the use of cotton linters and pulp with lesser cellulose content, etc. were some of the technological programs attempted during these years when maximizing output for an essentially established factory was sought.

In terms of our geometric model, this situation can be

59/ It is important to note that the closing of a plant of this nature is a decision that takes two or three years to implement, since it must be carried out with a minimum of problems concerning clients, the transfer of labor to other production lines, etc. The internal reports of the firm reveal that the final closedown took more than two years and was very carefully planned.

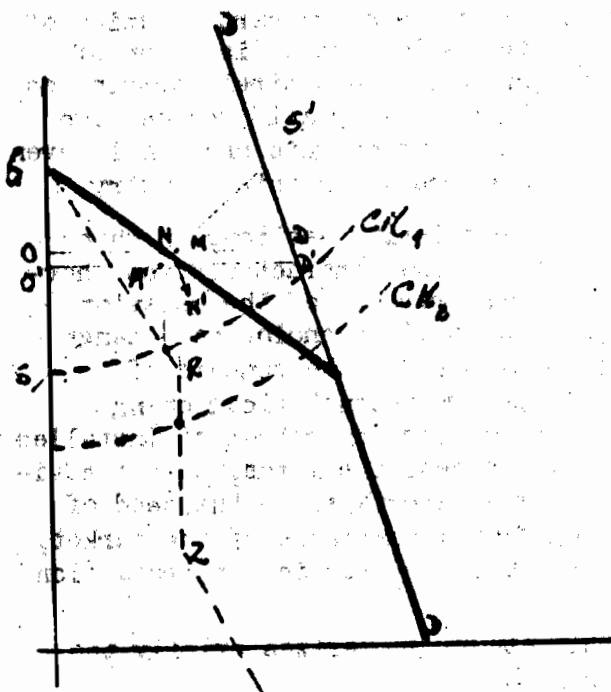
seen as a gradual displacement of the marginal cost curve of the leading company, given the other conditions.

Nevertheless, toward the end of the decade, several separate events came together to recreate an apt environment for large factory modernisation (see the section between 1962 and 1967 in the curve of direct average costs, presented in Graph 6 of Appendix I in this chapter). Some of these events were: a) the premature closing of Old Hickory freeing semi-new machinery that Ducilo could get at a price slightly above scrap value, b) the 1959 strike imposing a thorough top-level reorganization. The new managerial team set up work, analytical, and engineering standards never seen before in the company. c) At this time, Ducilo had access to a large supply of young technicians and professionals capable of carrying out the factory modernization program and revising the operating standards of several departments in the firm.

Together, these three events made Ducilo decide to prolong the lifetime of the rayon production line another decade. It was still clear to the general management that the plant should close it in the near future, but the presence of a protective market and the acquisition of semi-new machinery at scrap value assured a high potential profitability which seemed wise to take advantage of.

Graph 10

Technological change in the leading firm



$\frac{NO}{OD}$ - Relative participation of Ducilo before modernizing in 1962-63

$\frac{N'O'}{O'D'}$ - Relative participation of Ducilo after modernizing factory.

At this time, the marginal costs curve of the leading firm suffered a significant displacement downward, as reflected in the curve GM_2 in graph 10. The global market was marginally widened -- the price elasticity of demand played a crucial role here -- and the relative participations of the leading and the smaller firms on the market were modified again. While the leading firm originally produced ON and the smaller firms OM, and together they supplied a market equivalent to OD, after the technological change in the leading company, the global market grew to O'D', O'N' being the supply of the latter and O'M' that of the smaller firms.

It is important to observe that from 1964 on, and as expected from the geometrical analysis of Graph 10, the relative participation of Ducilo rose again until it reached 40% of the market, having been 36 to 37% before the 1962-63 factory modernization.

Throughout the last decade of productive life -- 1964-1974 -- a new element became of crucial importance, we are referring to scale diseconomies -- and their negative effects on labor productivity and direct production costs -- resulting from the gradual fall of the physical volume of production. Over these years, the physical output of the plant fell below what was considered to be an acceptable operative level, given in the dimension of the plant and the 'production function' involved in the process installed.

This led the team of technicians at Ducilo to seek a new 'package' of technological changes -- a new 'production function' -- able to compensate for the adverse impact of a falling production level. 'High solid spinning' was the technological answer to the set of circumstances described. Note that the downward displacement of GM_2 -- in Graph 10 -- could very well have occurred in the RZ section of the marginal revenue curve leaving unchanged the relative participation of the firms in the market. 'High solids' is in fact a situation of this type, where the new 'production function' -- entirely originated in domestic research and development efforts -- greatly reduced the direct costs of production allowing the firm to operate profitably even on a scale traditionally considered anti-economic in this industry.

We conclude here this analytic descriptive section, in which we have been able to point out certain principal characteristics (having to omit others, of course) of the rayon market, of the behavior of Ducilo on the market, and the significance of technological change (that of Ducilo as well as of its competitors) in the genesis of equilibrium over the years. We have seen how technological change constituted an answer to the need of increasing the output of installed capacity, to the entry and expansion of competitive firms, to the advisability or inevitability of replacing raw materials, to the need of offsetting scale diseconomies emerging from a shrinkage of the market, to the advisability of substituting capital by labor in the production process, etc.

The next chapter, last in this study, summarizes briefly the results obtained in this research project.

APPENDIX

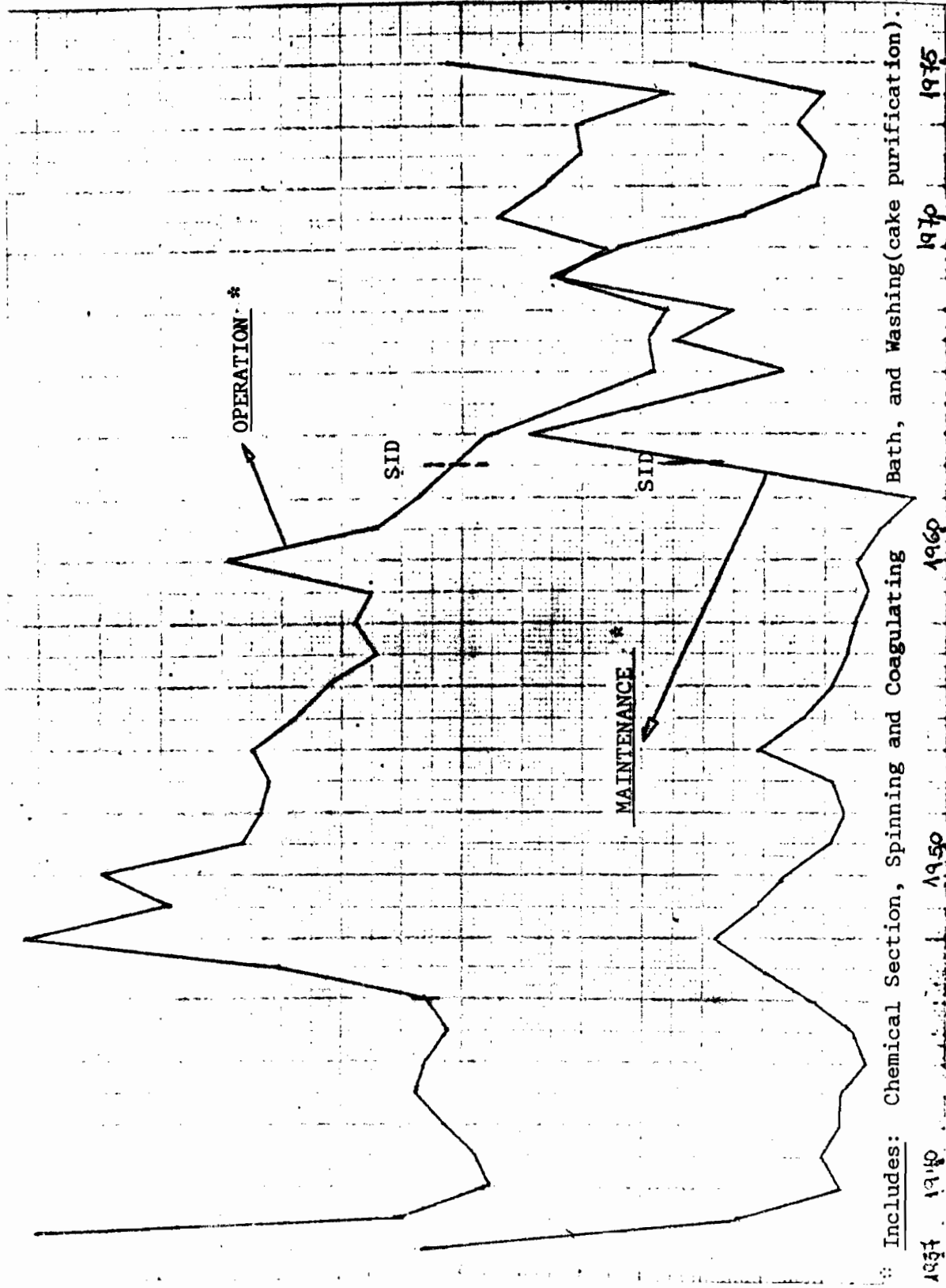
Graph 6: Unit labor costs
(diagram)

Table 7: Unit labor costs

Graph 6

SELECTED UNIT LABOR COSTS

(Constant 1937 pesos per ton of rayon)



* Includes: Chemical Section, Spinning and Coagulating Bath, and Washing (cake purification).

TABLE 7
SELECTED UNIT LABOR COSTS
(Constant 1937 pesos per ton of rayon)

YEARS	INDIRECT LABOR			DIRECT LABOR															
	LAB	C&M Exp.	Tech. Assis.	TOTALS			CHEMICAL SECTION			SPINNING			WASHING						
				Operation	Maintenance	pesos	Operation	Maintenance	pesos	Operation	Maintenance	pesos	Operation	Maintenance	pesos				
1937	4.5	6.7	11.2	27.48	10.59	100	6.14	22.34	1.91	18.04	14.74	53.64	7.28	68.74	6.6	24.02	1.4	13.22	
1938	2.6	4.6	7.2	11.0	5.4	100	2.8	25.45	0.90	16.67	5.0	45.46	3.9	72.22	3.2	29.09	0.6	11.11	
1939	1.1	1.69	2.8	9.5	3.65	100	2.03	21.37	0.57	15.62	4.71	49.58	2.74	75.06	2.76	29.05	0.34	9.32	
1940	1.58	1.30	2.8	9.83	4.10	100	2.11	21.46	0.58	14.15	4.73	48.12	3.04	74.15	2.99	30.42	0.48	11.70	
1941	1.34	1.26	2.6	10.32	3.74	100	2.32	22.48	0.66	17.65	5.10	49.42	2.64	70.59	2.90	28.10	0.44	11.76	
1942	1.11	1.10	2.2	10.75	3.70	100	2.44	22.70	0.61	16.49	5.45	50.70	2.77	74.86	2.86	26.60	0.32	8.65	
1943	1.08	1.11	2.2	10.56	3.32	100	2.33	22.08	0.51	15.36	5.02	47.54	2.51	75.60	3.21	30.40	0.30	9.04	
1944	1.0	0.81	1.8	10.21	3.47	100	2.26	22.14	0.44	12.68	4.77	46.71	2.61	75.22	3.18	31.15	0.42	12.10	
1945	0.89	1.03	1.9	10.64	4.23	100	2.19	20.50	0.54	12.77	4.93	46.34	3.24	76.59	3.52	33.08	0.45	10.64	
1946	0.80	0.92	1.7	13.34	5.06	100	2.35	17.62	0.57	11.26	6.09	55.65	4.01	78.25	4.9	36.73	0.48	9.49	
1947	0.91	1.37	2.2	17.21	5.77	100	3.05	17.72	0.70	12.13	7.98	46.37	4.23	73.31	6.18	35.91	0.84	14.56	
1948	0.87	1.27	2.2	14.75	5.13	100	3.52	23.85	0.75	14.62	6.37	53.19	3.77	73.49	4.86	32.95	0.61	11.89	
1949	0.54	0.87	1.2	16.05	4.60	100	3.62	22.55	0.83	18.04	8.15	50.78	3.17	68.91	4.28	26.67	0.60	13.05	
1950	0.43	0.61	1.1	13.64	3.89	100	2.36	17.30	0.62	15.94	7.39	53.74	2.71	69.67	3.95	28.96	0.56	14.99	
1951	0.56	0.94	1.5	13.21	3.67	100	2.52	18.93	0.53	14.44	7.26	54.47	2.77	75.48	3.54	26.60	0.37	10.08	
1952	0.66	0.46	1.1	13.46	3.92	100	2.41	17.91	0.58	15.05	7.17	54.24	2.81	71.68	3.51	26.55	0.52	13.27	
1953	0.76	0.86	1.6	12.84	4.34	100	2.32	18.07	0.53	13.59	7.15	55.69	3.29	75.81	3.37	26.24	0.46	10.80	
1954	0.77	0.86	1.7	12.84	4.34	100	2.32	18.07	0.53	13.59	7.15	55.69	3.29	75.81	3.37	26.24	0.46	10.80	
1955	0.85	1.05	1.9	11.36	3.55	100	2.27	18.64	0.64	16.62	6.59	54.11	2.74	71.17	3.32	27.25	0.47	12.21	
1956	0.88	1.09	2.0	11.36	3.55	100	2.13	18.75	0.53	14.93	6.14	54.05	2.58	75.68	3.09	27.20	0.44	12.39	
1957	0.92	1.15	2.1	11.79	3.54	100	2.14	18.15	0.54	15.25	6.57	55.73	2.63	74.29	3.08	26.12	0.37	10.46	
1958	0.89	1.18	2.1	11.49	3.31	100	2.12	18.45	0.51	15.41	6.49	56.48	2.37	71.60	2.86	25.07	0.43	12.99	
1959	1.35	1.33	2.7	13.93	3.45	100	2.35	18.87	0.67	19.42	7.8	55.99	2.31	66.96	3.78	27.14	0.47	13.62	
1960	1.32	--	2.2	11.39	3.08	100	1.64	15.89	0.60	19.48	6.82	59.88	2.09	67.86	2.76	24.23	0.39	12.66	
1961	1.62	--	2.3	10.71	2.52	100	1.75	16.34	0.58	23.02	6.54	51.06	1.63	64.68	2.42	22.60	0.31	12.30	
1962
1963	1.56	--	2.9	9.60	8.88	100	2.17	22.60	1.80	20.27	5.87	61.13	5.17	58.22	1.56	16.25	1.91	21.51	
1964	0.70	--	1.3	8.12	6.21	100	1.84	22.66	1.26	20.39	4.92	60.59	4.02	64.73	1.38	16.75	0.93	14.98	
1965	0.67	--	0.9	6.81	4.74	100	1.56	23.20	0.88	18.57	4.14	60.79	2.98	62.86	1.09	16.01	0.88	18.57	
1966	0.91	--	1.2	6.88	6.47	100	1.79	28.01	1.24	19.17	4.03	58.58	4.2	68.32	1.06	15.41	0.81	12.51	
1967	0.93	--	1.1	6.80	5.51	100	1.97	29.85	1.26	22.87	3.80	57.57	3.63	62.50	0.83	12.58	0.75	13.61	
1968	0.90	--	1.2	8.38	8.45	100	2.03	24.22	1.64	19.41	4.96	59.19	5.82	68.88	1.39	16.59	0.99	11.71	
1969	0.60	--	0.6	7.55	7.37	100	1.84	24.37	1.58	21.44	4.45	58.94	4.90	66.49	1.26	16.69	0.89	12.07	
1970	0.96	--	1.0	9.44	5.29	100	2.5	26.48	0.88	18.53	5.46	67.84	3.68	69.57	1.48	15.68	0.63	11.90	
371	0.64	--	0.6	8.55	4.11	100	2.12	24.80	0.48	11.92	5.22	61.05	3.17	77.13	1.21	14.15	0.45	10.95	
1972	0.60	--	0.6	8.04	4.04	100	1.98	24.63	0.45	11.14	4.84	60.20	3.16	78.71	1.22	15.17	0.41	10.15	
1973	0.62	--	0.6	8.07	4.35	100	1.93	23.92	0.59	13.56	4.93	61.09	3.33	76.55	1.21	14.99	0.43	9.89	
1974	--	--	--	6.62	4.03	100	1.78	26.89	0.51	12.66	3.85	58.16	3.10	76.92	0.99	14.95	0.42	10.42	
1975	--	--	--	10.15	6.20	100	3.20	31.53	0.70	11.29	5.2	51.23	4.78	77.10	1.75	17.24	0.72	11.61	

Source: Company records. Tabulation by authors.

VII. MAIN RESULTS OF THIS RESEARCH

Previous chapters in this paper have examined Ducilo Rayon's long-term performance and its relationship with the domestic generation of technology within the plant as well as with the purchase of more modern capital equipment, acquired second-hand from its own corporate headquarters, when the latter closed its rayon-producing plant at Old Hickory.

Also, we have been able to see that technological change affected not only the production costs of the establishment being studied, but also the quality of the manufactured product, the degree of diversification of the marketed output-mix, the expansion rate of installed capacity, etc. Along with the above, we have also seen that technological change in Ducilo Rayon generated significant externalities that were beneficial to equipment and parts suppliers as well as to the firm's customers.

The purpose of this chapter is to sum up the main results obtained in this research, and to point out their importance in some of the theoretical fields mentioned throughout the study.

Definition and 'endogenous' and 'localized' nature of technological change

Throughout this study, 'technological change' has been defined as any modification in the product as well as in the production process, introduced by Ducilo over the years, independent of whether that modification was new or not to the Argentine rayon industry, or to worldwide rayon technology. The only necessary condition for its inclusion was that the modification in the operating routine be new to Ducilo itself.

We have for example, considered technological change the increase in spinning speed as well as the successive improvements in the quality of the manufactured product, the introduction of a new variety, or the development of a more efficient method of recuperating raw materials. Similarly, we have stated that technological change is what is required for lowering the rate of defects and wastes per kilogram of rayon produced as well as for replacing one raw material with another, and so forth. We could make a long list of technological efforts, which, to a greater or lesser degree, are carried out by every sizeable industrial establishment as part of its daily routine trying to increase the operating speed of its equipment, improve the quality of its manufactured product, launch new varieties on the market, reduce costs, etc. The consequence of this flow of technology is the gradual modification of the operating routine followed by the firm in question.

Economic analysis of technological change has found it difficult until fairly recently: a) to incorporate the idea that "the" technology of an industrial plant should be considered as an "evolutionary" factor of production and b) to devise an endogenous theory of technological change that will throw some new light upon the economic and technical variables which underlie the process of "technological search" followed by any given particular firm, as well as upon the effects of such technological know-how on the long-term performance of the company which "produces" it.

Only recently has the profession shown signs of progress in the understanding of the microeconomic foundations of technological change, leaving behind the conventional "production function" defined as the static representation of the set of production techniques exogenously given to the firm, and the concept, also static, of "frontier of innovative possibilities" (FIP), which indicates the set of capital and labor-saving technological changes available to an enterprise at a given moment of time.

A first important step in a new direction was that taken by Arrow in 1962. ^{60/} From then on, technological change began to be seen as an endogenous phenomenon, like something that comes out of the firm itself and does not miraculously fall down from heaven as "mannas". Although the Arrowian models, where the firm collects the benefits from "learning by doing" as a mere by-product of industrial activity, exhibit an extremely elementary view of the microeconomics of technological change, they do show that the optimum of production under static conditions under-estimates the optimum level of production achievable under dynamic conditions, when the firm learns at the same time as it produces. ^{61/}

Having accepted the endogenous nature of technological change, a second important step has been to go beyond the simple setting of the learning by doing case to consider the existence of an explicit technological strategy on the part of the firm.

The acceptance of an explicit technological strategy of gradual improvement of the available technology assumes picturing technological change as 'localized', that is, specific to a particular technique and not of a general nature that influences each

^{60/} K. Arrow: "The economic implications of learning by doing", Review of Economic Studies, June, 1962.

and every one of the different available techniques. Let us take a closer look at this point.

Somewhat less than a decade ago, A. B. Atkinson and J. E. Stiglitz published their well-known study on "localized technological change." These authors said in their original paper: "There are various differences between technological know-how and basic scientific knowledge... The most important difference is, notwithstanding, the fact that technological know-how is special to a particular production process, (while basic scientific knowledge is not). In other words, the improvement of a given technique leaves the other techniques unchanged." ^{62/}

The importance of this new approach to the technological phenomenon cannot be denied. We are faced here with a setting completely different from the neoclassical one.

The neoclassical production function is no more than a curve representing a series of techniques, or production processes, placed in order according to the relative intensity of capital and labor required by each one to manufacture a given quantity of an homogeneous product. When only a finite number of production processes exist (two, three, for example) the economist resorts to analysis (linear programming might be one of the analytical techniques possible). If, on the other hand, the number of production processes is increased considerably, we can resort to a continuous curve which can be differentiated at any point, typical of the neoclassical production model.

Now then, while in this last approach technological change displaces the entire curve, when technological progress is "localized", the improvement of any one of the production processes does not necessarily affect the other techniques making up the production function.

In the theoretical debate on the concept of 'endogenous' and 'localized' technological change, there are two subjects that are especially important. On the one hand, and provided that the

^{61/} A. B. Atkinson and J.E. Stiglitz: "A new view of technological change," Economic Journal, September, 1969.

^{62/} A. B. Atkinson and J.E. Stiglitz: Op. Cit. Mimeograph, p. 2.

flow of minor innovations following the choice of a specific production technique only affects that particular technique, the historical circumstances which underlie the choice of any given production technique acquires enormous significance. As P. David says 63/ "The historical choice of production techniques governs the future in this way." This is true since it will be this particular production technique, and not all the others, the one that incorporates the benefits of 'adaptive' technological change.

On the other hand, the gradual improvement of any given technology is not costless in the way it is in the conventional neoclassical analysis. It has a price, expressed in terms of research and development expenses. This brings us to a subject that has attracted great interest in recent literature concerning technological change and which we will discuss under the title of "the microeconomic nature of the technological search and induced innovation process". We shall now consider both aspects, beginning with the latter.

Some years ago, Ch. Kennedy 64/ introduced the concept of the "Innovative possibilities frontier" as an analytical device designed to examine the possible existence of trade-offs between labor-saving innovative programs and capital-saving ones. By analogy with the typical transformation curve of the production theory, Kennedy postulated, at that time, the existence of a transformation function between technological changes saving on capital or on labor costs, and from then on, tried to use that analytical instrument to discuss a topic that has proven crucial for the innovation theory as well as for the theory of economic growth since J. Hicks famous conception of induced innovation in his "Theory of Wages". 65/ We are referring to the labor-saving bias which technological change must necessarily have if we are to explain the long-term constancy in the relative spheres of capital and labor in income distribution and make the theory compatible with the observed "stylised" facts. 66/

63/ P. David: Technical Choice, Innovation and Economic Growth, Cambridge University Press, 1975, p. 60

64/ Ch. Kennedy: "Induced Bias in Innovation and the Theory of Distribution", Economic Journal, September, 1964

65/ J. Hicks: The Theory of Wages, Macmillan, 1932. On pages 124 ff., Hicks argues that a relative fall in the cost of capital

Nevertheless, neither the form nor the position of the IPF "Innovative Possibility Frontier" were explicitly studied by Kennedy, or by successive authors who discussed the topic, which were not really trying to construct the analytical structure of a theory of innovation, but were not explicitly concerned with the neo-classical theory of income distribution, and the non-neutral role that technological change should play in the model to make that theory compatible with the "stylized" facts of economic growth. ^{67/}

This is how until relatively recently there has been no innovation theory with solid microeconomic foundations. In 1973, W. D. Nordhaus ^{68/} in an article intended to show that the IPF is based on extremely restrictive assumptions, introduced the concept of the "iso-technology" curve, which is that set of technological innovations which can only be obtained out of a certain expense in research and development activities. In the framework in which certainty is assumed the iso-technology describes a word where certain resources are needed in order to move from one productive technique to another. When the amount of resources is larger the change of the available technique is also greater. From this point of view, the neo-classical production model corresponds to the extreme case in which we assume a zero isotecnology (that is, the acquisition value of the different techniques is nil).

will induce a search for labor-saving inventions and innovations. This is exactly the point where W.E.G. Salter disagrees with Hicks saying that if the search is done "within the fold of existing knowledge", the new labor-saving techniques are only a form of factor substitution. In this case, technical progress and substitution, or movements along and changes in the production function become rather difficult to isolate from each other. If, on the other hand, Hicks implies that new labor-saving know-how is to be sought, Salter is in frank disagreement with the Hicksian view. See W. E. G. Salter: Productivity and Technical Change, Cambridge, 1960, p. 43.

^{66/} We observe on the one hand, an increase in the K/L ratio, and an elasticity of substitution between capital and labor of less than one. In this case, the relative participation of labor in income should have risen. Its stability (or fall) can only be explained by induced technical change of a non-neutral nature; and/or by an autonomous change in the innovation possibility frontier. Since the theory does not discuss the determinants of the form and position of the latter, it is not of much use as a tool of analysis in this field. See P. David: Technical Choice, Innovation and Economic Growth, Cambridge University Press, 1975, p. 52.

Nordhaus's contribution, apart from pointing out the extreme nature of the assumptions underlying the neoclassical case, ^{69/} open up the way to the exploration of possible technological search programs by an individual firm. H. Binswanger, in a study appearing in *The Economic Journal*, in 1974, developed the theory quite considerably, by adopting as an analytical scheme a case where the firm intends to maximize returns on its research and development expenses and not only takes into account the relative prices of factors (as in the original approach of Hicks) and the relative weight of each one of the factors in total production costs (as in the case by Kennedy, Weizsacher, and Samuelson), but also considers the cost of the different research and development programs it is able to carry out at a given point in time (which depended on previous learning and experience), the relative productivity of technological efforts in each one of them (which depends, in turn, on previous achievements in each of the possible lines of improvement of the available technology), and the global scale of operation which regulates the amount of benefits derived from research. In the analytical scheme of Binswanger, investment in research and development must proceed up to the point where marginal costs of research along the different "search paths" equals the marginal benefits of the incorporation of additional technological improvements. ^{70/} Only at this point and not necessarily at the maximum feasible technological level should expenses in technological change be halted, and priority

^{67/} See, for example, P. A. Samuelson: "A Theory of Induced Innovation along Kennedy-Weizsacher lines", *Review of Economics and Statistics*, November, 1965.

^{68/} W. D. Nordhaus: "Some skeptical Thought on the Theory of Induced Innovation", *Quarterly Journal of Economics*, vol. 87, 1973, p. 208.

^{69/} The most important assumption underlying the IPF is that the rate of technical change saving on a certain factor occurs independently of the level of saving reached previously in relation to that factor. So, as technological progress is accumulated, it does not affect the trade-off between capital-saving and labor-saving technological change. This is an excessively strong assumption indeed. See W. D. Nordhaus: *Op. Cit.*, p.215

^{70/} It is interesting to note that when a R and D budget is set separately from the budget of investment in material equipment,

given to other investment options, as might be the complete renovation of the industrial plant. 71/ 72/

On the basis of the previous discussion, and in order to return to the analysis of the Ducilo case, let us now ask ourselves what does our research teach us about a) the rate, nature etc. of technological change incorporated by this firm over the years, and b) the variables which influence upon the pay off of the different programs of technological change carried out by Ducilo throughout its lifetime.

Let us consider the cost of different alternative research and development programs. It seems clear that in this sense, there are three crucial determining factors to be kept in mind: 1) if corporate headquarters (or some other source of externalities, e.g. universities) was carrying out (or had already carried out) a program to create technological know-how which reduced or simplified the amount and type of technological efforts that the firm had to carry out per se in order to get a certain result, 2) the existence or non-existence (and the alternative cost) of different types of professionals and technicians needed for different programs of R and D. For example, the existence or not (and the cost) of electromechanical engineers and technicians etc., c) the R and D experience accumulated by the engineering team over the years.

These variables undoubtedly affected the technological strategy of Ducilo throughout its lifetime. The main research and development program in the firm's first decade of operation, related to spinning speed - - tube spinning - - was a line of research which the firm started only shortly after its corporate headquarters did, and certainly took advantage of a great amount of information coming from the technical files of Old Hickory. In the same way, we can see that the high solid spinning program, which contained a large relative content of chemical research (compared to the tube

it can very well occur that the firm does not maximize its returns on the total investment. For this to happen the profit rate in both investments should have the same margin, and budget restrictions could hinder this equalization, while a certain bias in the type of research projects could be introduced.

71/ A similar situation has been examined by this author in Importation of Technology, Learning and Dependent Industrialization, Fondo de Cultura Económica, Mexico, 1976, ch. 3.

72/ See the study of A. Canitrot with respect to the dilemma between modernizing and renovating a certain industrial plant: "A guide to evaluating the importance of macroeconomic variables in

spinning program which was predominantly mechanical, for example), was first carried out in the second half of the 1950s, and even more intensely in the first half of the 1960, when the firm had a sizeable number of chemical engineers graduated from the Santa Fe Chemical Engineering School, which at that time was the best educational institution for chemists in the country. Finally, the experience gained in R and D also played an important part in determining the selected research lines, which not necessarily have to be related to the same production line, as mechanical knowledge has a high degree of transferability, as evidenced in the examples of transfers of professionals from Rayon Mechanical and Chemical Experiments to the manufacturing plants of Cellophane, Nylon and Freon gas.

In summary then; From the point of view of the cost of carrying out the various optional R and D programs that the firm could potentially tackle at a given moment in time we see that it depends greatly on the type of potentially available program and the qualitative level of the professionals and technicians involved in them, on the R and D experience accumulated by them over the years, on the amount of externalities that the professional team can eventually pick up from technological know-how previously achieved by another research entity (corporate headquarters, university, etc), on the complexity and degree of novelty of the subject studied, etc.

Let us now look at the other side of the picture, that is, the benefits of different optional research and development programs.

We saw in Chapter V of this study that the various research and development projects carried out by the Department of Mechanical and Chemical Experiments throughout the years could be grouped in the following way: a) projects designed primarily to increase physical volume of production. This category includes those technological changes whose principal objective was to increase the output yield of the available installed capacity.

Obviously the research projects in this sub-group have an immediate impact on the unit cost of production, but the main motivation must be looked for in the goal of producing a greater quantity of rayon and, only secondarily, in the intention of reducing unit costs of production.

b) Projects designed to modify the output mix. In this sub-group we include those technological changes related to 1. the introduction of new varieties of the product, 2. increases in

the analysis of the decision to incorporate technologies," Paper of Research Project No. 12, IDB/CEPAL program.

quality of the varieties already on the market etc.

c Projects directed primarily toward reducing unit costs of production. This sub-group includes very diverse R and D projects such as: i. those directed towards substituting productive factors (capital for labor, for example), ii. projects whose objective was to save, simultaneously, several of the inputs used (capital, labor, energy, etc), iii. projects designed to diminish the amount of waste, to increase the recuperation of raw materials, etc.

d Projects designed to replace imported raw materials, spare parts, etc. by quasi-equivalent domestic ones. This type of R and D projects could actually have been included in item c but since there were many of them and they did not necessarily reduce the cost of production (substitution can meet the need of diminishing the uncertainty of supply even when the cost is marginally greater), we thought they should be grouped in a separate category.

Taking into consideration both the costs and benefits related to different alternative research and development programs, we can understand why the 'technological search' carried out by a firm must change over the years to reflect the alternative profitability from different research strategies. Let us look at several possible cases: I. During a period in which competition was clearly lacking as from 1937 to 1949, and in which corporate headquarters was carrying out research programs in high speed spinning, it is logical to think that the profitability of R and D programs which a) increase the physical output of installed capacity and b) take advantage of externalities from headquarters' technological development would have high potential returns and priority.

II. When competition became more important -- there was never real price competition on the Argentine rayon market -- the direction of the research and development efforts changed and became more important in a) product diversification and b) quality improvements of the items already produced.

While in the 1950s there was a systematic effort in the first direction (introduction of new deniers, flamentint, bright, and dull rayon, etc) the technological progress of the 1960s was directed much more toward improving quality, as a major variable in their oligopolistic confrontation.

III. Just as the 1940s are typically associated with the subject of spinning speed, the 1950s with the diversification of the

output mix and the 1960s with quality, the post war years and even more specifically the 1960s, showed a much greater tendency toward the relative saving of labor than during the first 10 to 15 years of operation.

The programs of textile simplification and substitution of capital for labor in spinning and cake washing and purification, are representative of labor-saving technological efforts which acquired more importance as the years passed.

IV. Also, the lack of raw materials, as well as the scarcity or relative rise in their price (cellulose and caustic soda) gave rise to definite technological efforts designed to replace 'expensive items' by others relatively cheaper (pulp of a lesser cellulose content) or readily available in Argentina (mechanical parts and chemical detergents which were originally imported and later locally acquired.

The above examples reveal that this particular firm had a technological search strategy and that it changed such strategy over the years according to circumstances inherent to the firm itself or to the competitive atmosphere it had to work in on the Argentine rayon market or, finally, as an answer to macroeconomic variables representative of the different "national plans" the country underwent during the four decades covered by the useful lifetime of this plant.

Our results show the strong vitality of some of the traditional hypotheses of firm behavior used by economists, which suggest that the process of technological search is designed to save on those factors which become more expensive over the years, or are in short supply. 73/

At the same time, the results presented here show that competition - - already identified as a major factor inducing technological change by the classic economists - - certainly has a strong influence on the type of 'technological strategy' carried out by a specific firm.

To the extent that our results show that "necessity is the mother of invention", they reaffirm some of the oldest and

most orthodox ideas used by the profession in the area of technological change.

73/ This characteristic is determined mainly by the nature of the technological efforts carried out in the plant under study, which are basically trouble-shooting tasks designed to treat short and mid-term problems more than real long-term research programs designed to greatly change the process as well as the product.

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