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THE DIFFUSION OF INTERDEPENDENT INNOVATIONS IN THE TEXTILE INDUSTRY

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R E S U M E

LA DIFFUSION D'INNOVATIONS INTERDEPENDANTES DANS L'INDUSTRIE TEXTILE

Cet article se propose d'analyser en combinant les approches des théories de l'investissement et de la diffusion l'interdépendance entre les changements techniques de différents stades de l'industrie textile. Un modèle présente les relations qu'induisent les effets prix et qualité de différentes innovations.

L'analyse empirique s'appuie sur un ensemble de données sur la diffusion de trois innovations majeures : l'introduction des fibres synthétiques et deux innovations radicales de process dans le filage et dans le tissage. Le modèle est estimé sur les données concernant 16 pays sur 8 ans.

MOTS CLEFS : Changement technologique, Diffusions interdépendantes, Industries textiles, Externalités.

JEL : 621 211 611.

S U M M A R Y

THE DIFFUSION OF INTERDEPENDENT INNOVATIONS IN THE TEXTILE INDUSTRY

The present paper focuses on the interdependence among technical changes in different stages of production in the textile industry. A model tries to present the different linkages induced by price and quality effects of technical change and technological complementarities. The empirical analysis is based on data on the diffusion of three major innovations. One is the product innovation of synthetic fibres, the other two are process innovations in spinning (open-end rotors) and in weaving (shuttle-less looms), respectively. A model is estimated pooling information of 16 countries over 8 years, where the propensities to modernize are dependent variables.

KEY WORDS : Technological Changes, Interdependent Diffusions, Textile industries, externalities.

I - INTRODUCTION

In the literature on technological change, decisions of firms to modernize their production process depend on expected gains in terms of profitability as well as on market prospects for their products. The available information about supply and demand (profitability of the new process, prospective future demand) is however limited as is the ability of entrepreneurs to use it. In a previous paper [ANTONELLI, PETIT, TAHAR, 1989] we tried to analyze how the information about both sides of the market is combined when choices to modernize are made. That paper was specifically concerned with the process of diffusion of a specific new piece of equipment in an industry, namely shuttle-less looms in the weaving industry. The present paper shifts the focus to another aspect of technological change, the interdependence between changes in various stages of an overall production process.

Technological change at one stage of production often induces new requirements in the quality of inputs and results in a changed quality of outputs. In this way technological changes tend to be linked along the production profile even of a single product. The bundling or networking of technological changes is neglected in most studies of diffusion, although their importance is acknowledged [DAVID 1985]. The reason for this is twofold. This type of interdependence is difficult to model. Even on the conceptual level the system of interdependence of technical changes is little explored. For an empirical analysis, systematic data of the diffusion of new machines are often not available, even for a single stage of production. To address this issue of interdependent technological changes, we had the advantage that data on the diffusion of three major technological innovations in the textile industry were available. This gave us the opportunity to study the interdependence between successive stages of production of a single product by using the relevant data. The study considers two modern machines, open-end rotors and shuttle-less looms, belonging to two adjacent stages of production ,spinning and weaving, in the textile industry. We study the interdependence of the diffusion of these new machines with the diffusion of new synthetic fibres.

Section 2 describes the processess of these technical change in the textile industry and explains their interrelatedness.

Section 3 presents a model for this pattern of technical change.

Section 4 tests the hypothesis about the interdependence of the diffusion of new technologies by estimating the parameters of a reduced form equation system of the model. That model was estimated for sixteen countries over a period from 1977-1984.

2 - TECHNOLOGICAL CHANGES IN THE COTTON INDUSTRY

2.1. The introduction of product and process innovations

In the 1970s and 80s the cotton industry experienced a process of radical changes in all the main stages of production. These changes were driven by the introduction and subsequent diffusion of major technological innovations generated by upstream industries :

- synthetic fibres as new inputs produced by the chemical industry ;
- open-end rotors in spinning produced by the engineering industry ;
- shuttle-less looms in weaving produced by the engineering and electronic industries.

The diffusion of new synthetic fibres brought major changes such as:

i) the partial substitution of natural fibres by more resistant and cheaper fibres ;

ii) the substitution of old cellulosic artificial fibres ;

iii) the introduction of an array of mixed fibres made of different combinations of natural and synthetic fibres especially conceived for diversified uses from garment to furnishing ;

iv) extended physical properties of new fibres which can be worked at higher speed both in spinning and weaving ;

v) the integration of up to five preliminary stages, loosening, carding, drawing, winding and roving plus spinning. Fibres being directly extruded into yarn, with enormous reductions in manufacturing costs.

The introduction of open-end spinning rotors in the late sixties in the production of yarn is the second most important innovation. Technological change in the production of yarn has been steady over the last forty years. Increased machine speed has developed separately in each of the five stages of the spinning process ; however, spinning technology by itself (i.e. the winding of yarn into spools or bobbins) had experienced the most dramatic progress. Incremental innovations in the ring technology doubled working speed during the period 1950-1975 as well as bringing additional advantages in terms of the quality of output and reliability of operation.

As these incremental improvements seemed to have reached some limits, open-end spinning technology began to develop in the mid 1970s following its first introduction in Czechoslovakia in the late 1950s. Open-end machines make it possible to form a strand of independently moving fibres which is then formed into yarn by means of a rotor similar to a high speed centrifuge system. The first open-end machines were able to operate at two or three times the speed of ring spindles. However, the first open-end machines had the disadvantages of high energy consumption and of producing only short-staple fibres. Moreover, the capital intensity of open-end rotors, with respect to labor inputs, is four to five time higher than in the ring technology.

In the period following 1975 further innovations were introduced within the framework of open-end spinning technology. The introduction of the self-twist device led to substantial increases in working speed and, most importantly, made it possible to process long-staple fibres. The spinning process was further improved when opening and cap forming, which used to be performed manually, were automated. Subsequent innovations, patented in the late 70s and early 80s, were designed mostly to enable the yarn spun by open-end rotors to be used in the manufacture of top quality fabrics as well as to reduce energy consumption. Improvements have also been introduced in the field of air-jet spinning and friction spinning. New and automated piecing -up and cleaning devices as well as improved stop-motion devices, which control tension in the case of yarn breakage on supply failure, have been developed. The production technology improvements finally brought about major reductions in the price and operation costs of new machines (ANTONELLI, 1989).

Since the 1950s, the weaving technology has made important progress after continued efforts to reduce the weight of the shuttle. More recently the shuttle has been replaced by other tools, such as metal projectiles, grippers, and recently water jets. The advances are summarized in Table 1 where the different tools used to carry the thread, the working speed, and the first year of industrial production are shown.

By the end of the 1970s, the modern shuttle-less loom was able to work at a speed of 600 knots per minute with much lower levels of noise and labor input. Shuttle-less looms, however, cost almost as twice as shuttle looms.

In 1985, the advantages of shuttle-less looms in terms of technical-productivity, operating costs, quality of fabric and maintenance costs reduced current production costs by between 30 and 50 percent compared with traditional automatic shuttle looms. This corresponds to an average reduction in labour costs of US 50 000 dollars.

The introduction of all these product and process innovations occurred in a 20 year span and their diffusion was influenced by their technical interdependence.

TABLE 1

TECHNOLOGICAL CHANGE IN WEAVING : THE EVOLUTION OF PRODUCTIVE CAPACITY OF EQUIPMENT (between 1970 and 1980)

TECHNOLOGY	YEAR OF INTRODUCTION	WORKING SPEED (KNOTS)
Shuttle loom	1970	200
Shuttle-less loom projectile	1970	220
SHuttle-less loom rigide gripper	1975	250
Shuttle-less loom flexible gripper	1976	300
Shuttle-less loom air jet	1980	600
Shuttle-less loom water jet	1980	600

2. The interdependence of innovations in the textile industry

The technical requirements for the open-end rotors and the shuttle-less looms are the availability of elastic, resistant, low-cost fibres. The introduction in the spinning process of new synthetic "cotton flock" with higher properties of elasticity, malleability and resistance to heat, both with respect to natural "flock" and to artificial "cotton flock" makes it possible to take full advantage of new high speed spinning capacities brought in by the open-end-technology.

While open-end rotors can spin only low-quality cotton from natural flock with yarn of low levels of counts, the yarn spun from synthetic and mixed flock reaches high quality standards. As a result the unit value of yarn spun with open-end rotors increases in conjunction with the levels of diffusion of synthetic fibres. Additionally, the working speed of open-end rotors is higher with synthetic flock than with natural cotton flock. Higher levels of diffusion of new synthetic fibres therefore lead to lower operating costs.

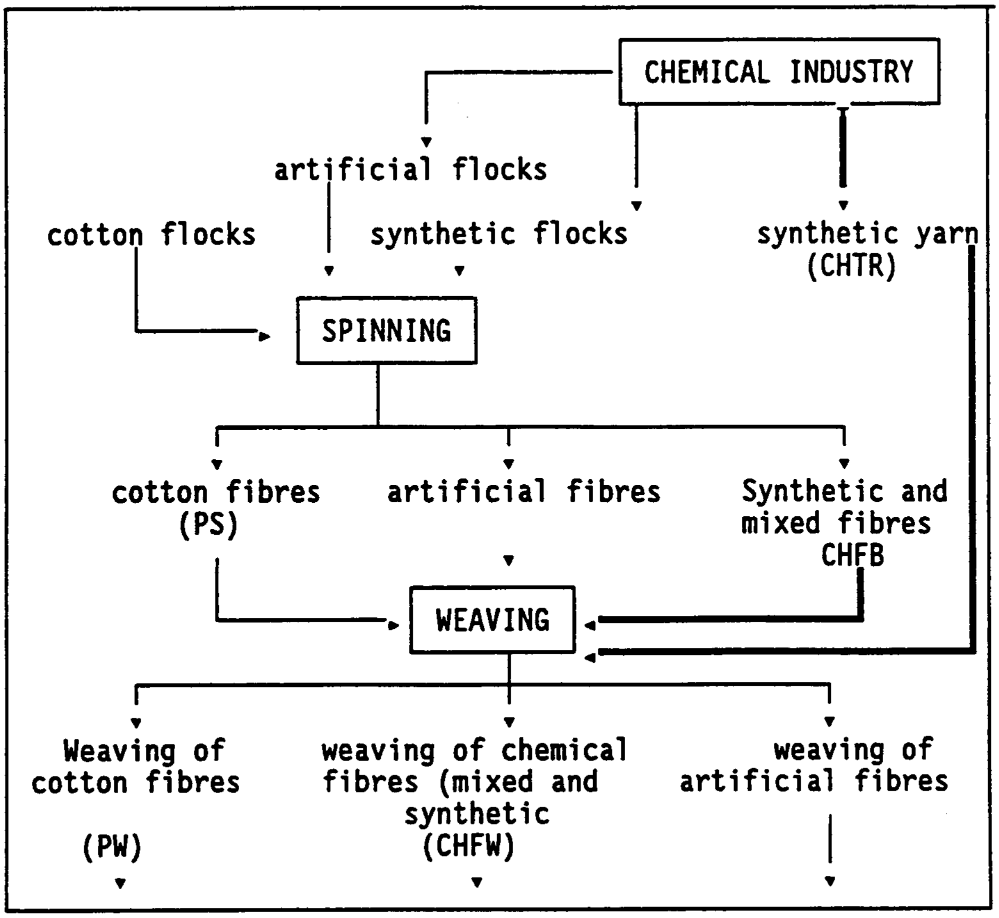
The adoption of open-end rotors in spinning depends to a great extent on the diffusion of new synthetic fibres.

The complementarity between diffusions of synthetic fibres and open-end spinning is emphasized by its relationship to shuttle-less weaving. The high working speeds achieved by shuttle-less looms are more suitable for yarn with high levels of elasticity and robustness, which lead to low levels of interruption of the weaving process due to breakage of the yarn.

Figure 1 summarizes the flows of production through its different phases. The thick arrows signify the input flows which stimulate the use of the process innovations.

FIGURE 1

THE TEXTILE INDUSTRY PRODUCTS



Note (Our data set includes the variables named in parentheses and these are measured in tons).

The diffusion of open-end rotors and shuttle-less looms is not necessarily related (as is demonstrated by the earlier introduction of the shuttle-less loom), but both are accelerated through the introduction of synthetic fibres. Finally there is an interdependence between the two diffusions. The spread of shuttle-less looms in weaving ensures the spinning industries that the new qualities of thread produced by open-end rotors will have expanding markets. Conversely the new diffusion of open-end rotors reinforces the drive towards shuttle-less looms in the downstream phase of spinning.

This results in a dynamic process of interdependent diffusions at different stages of production. The next section outlines a model accounting for this interdependency through price effects induced by cost reductions, and quality effects which imply specific requirements on the structure of machinery and equipment in both industries.

3 - A MODEL OF MODERNIZATION IN A TWO STAGES PRODUCTION PROCESS.

3.1. A Mix of Investment and Diffusion Analysis.

This section develops a model of modernization in a manufacturing industry composed of two consecutive stages of production which transform materials of two kinds, one of which is new and in increasing demand. The two stages of production can give rise to two sub industries so that the products of each stage of production can be traded and market prices exist. The two sub-industries produce two types of output and the products differ according to the materials they are made of.

Therefore we have four products, i.e. four distinct quantities of output and four prices, which we note, respectively :

Y_{ij} and p_{ij}

with i = 1, 2 for the stage of production (1:= upstream, 2:= downstream)
j = 1, 2 for the kind of material (1:= old, 2:= new).

A process innovation is available for each stage. Equipments thus belong either to a modern capital stock K_i^* or to a traditional capital stock K_i^-. Although both types of capital equipment can treat both kinds of materials, there exists in each case an optimal structure of the capital stock according to the type of material used. This is due to the characteristics of the equipments and to the quality requirements for each product. It implies that there exists one desired capital stock $\hat{K_i} = (K_i^*, K_i^-)$ which minimizes unit costs of production to produce Y_{i1} and Y_{i2}.

We assume simply that the desired capital stock is a linear combination of the two products demanded:

(1) $K_i^{\hat{}*} = h_{i1}\, Y_{i1} + h_{i2}\, Y_{i2}$: desired modern capital

(2) $K_i^{\hat{}-} = (1-h_{i1})\, Y_{i1} + (1-h_{i2})\, Y_{i2}$: desired traditional capital

with $0 \leq h_{ij} \leq 1$

This desired structure of capital equipment [4] cannot be achieved instantaneously because :

- not all firms have the information about the new process,
- for some firms it is not as profitable as for others to invest in new equipment at current prices,
- there are costs in adjusting the existing capital stocks.

The first two reasons are usually recalled in standard analyses of diffusion, the third is common when analyzing investment. There are two possible assumptions concerning the adjustment of the stocks of capital equipment when demand is given :

- the adjustment is instantaneous in capacity terms:

(3) $K_i^{-\hat{}} + K_i^{\hat{}*} = K_i^{*} + K_i^{-} = Y_{i1} + Y_{i2}$

- the adjustment in the structure of modern and traditional equipment is delayed :

(4) $D_i = (1-r_i)\, D_{i,t-1} + r_i \hat{D}_i$

where $D_i = K_i^{*}/(K_i^{*} + K_i^{-})$ defines the effective level of diffusion, $D^\wedge_i = K_i^{\hat{}*}/(K_i^{*} + K_i^{-})$ its desired level and r_i the speed of adjustment [5].

The speeds of adjustment, r_i, depend on :

- the speed with which information on the new techniques diffuses

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[4] A reasoned example of such desired structure is given in TABLE A5 in the appendix.

[5] Time indices will hereafter be omitted when they refer to the current period ; only for lagged variables will time indices be specified.

- the profitability of the move towards the desired capital stock [6].

In accordance with the assumption of the "epidemic" approach of diffusion, as developed after Mansfield (1961), the speed r_i will be assumed to be an increasing function of the existing level of diffusion.

In accordance with the observed effect of cash flow and credit facilities on investment (see Coen 1971), it is assumed that the profitability increases (reductions in unit costs), derived from moving towards the desired structure of capital stock, accelerates adjustment.

The two assumptions are summarized by the following functions :

$$(5)\ r_i = r\left(D_{i,t-1}, \frac{\delta U_{i1}}{\delta(\hat{D_i} - D_i)}, \frac{\delta U_{i2}}{\delta(\hat{D_i} - D_i)}\right)$$

where :

- $D_{i,t-1}$ is the diffusion level in industry i, at time t-1.
- $\delta U_1/\delta(\hat{D}-D)$ is the marginal unit cost effect on producing one unit of product 1 of adjusting the capital stock (same for product 2).

3.2. <u>The Diffusion Rate in Investments.</u>

A key variable accounting for the modernization process is the share of new equipment in total investments. Under certain conditions this variable can be considered as the propensity to opt for modern equipment[7]. It can then serve as an explanatory variable in the diffusion process to qualify the spread of an innovation.

This "propensity" to modernize, m_i, can be expressed as a function of the diffusion levels D_i, $D_{i,t-1}$ and of the growth rate of output y_i ,starting with

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[6] We do not retain the lag tied to the installment of new equipments, as capacity adjusts right away. The specific delays of installment of new equipment are assumed to be constant overtime, but country specific nevertheless.

[7] If all units of investments are realised by separate units of production, the rate of diffusion of modern equipment should be seen as a propensity to invest into new machinery. It is only an average since the propensity of each unit clearly depends upon its past experience(whether the unit was or not an adopter).

the standard accounting relations for investments in modern and traditional equipments :

(6) $I^{*} = K^{*} - (1-\delta^{*})\ K^{*}_{-1}$
(7) $I^{-} = K^{-} - (1-\delta^{-})\ K^{-}_{-1}$

(where δ^{*} and δ^{-} are respectively the scrapping rates of the modern K* and traditional K^{-} capital stocks):

$$(8)\quad m_i = I_i^{*}/(I_i^{*} + I_i^{-}) = \frac{(1+y_i)\ D_i - \phi_i^{*}\ .\ D_{i,t-1}}{(1+y_i) - \phi_i^{*}\ .\ D_{i,t-1} - \phi_i^{-}\ .\ (1-D_{i,t-1})}$$

with $\phi_i^{*} = 1 - \delta_i^{*}$, $\phi_i^{-} = 1 - \delta_i^{-}$ and remembering that the growth rate of output y_i is equal to the growth rate of the total capital stock[8].

The diffusion level D_i can be expressed (using equations 1 to 5) as a function of the speed of adjustment r_i, the levels of diffusion at (t-1), $D_{i,t-1}$, and the share F_{ij} of each type of product in production :

$$(9)\ D_i = (1-r_i)\ D_{i,t-1} + r_i\ (h_{i1}\ F_{i1} + h_{i2}\ F_{i2})$$

with $F_{ij} = Y_{ij}\ /\ (Y_{i1} + Y_{i2})$

The substitution of (9) into (8) then leads to:

$$(10)\ m_{it} = \frac{((1+y_i)(1-r_i)-\phi_i^{*})D_{i,t-1}+r_i(1+y_i)(h_{i1}\ F_{i1}+h_{i2}\ F_{i2})}{(1+y_i)-\phi_i^{*}D_{i,t-1} - \phi_i^{-}\ (1-D_{i,t-1})}$$

The "propensity" m_{it} to opt for new machines appears as:

[8] Defined as : $(1+y)=(K_t^{*}+k_t^{-})\ /\ (k_{t-1}^{*} + k_{t-1}^{-})$

- a linear function of the speed of adjustment r_i, increasing as long as the desired level of diffusion at t, $\hat{D_i}$ is above the existing level of diffusion at t-1, $D_{i,t-1}$[9].
- a homographic function of the growth rate of output y_i.

In the above formulation (equation 10) the main unknown parameters are the speed of adjustment r_i and the coefficients determining the desired structure of capital h_{ij}. The scrapping rates, δ^* and δ^-, are assumed constant. This specification will be tested in section 3, assuming that the speed of adjustment is a simple function of the diffusion level at t-1 and of the remaining gap relative to the desired level (as suggested in equation 5).

However, equation (10) only expresses the interdependency between product and process innovations in assessing a desired structure of capital. The interdependency between process innovations in the two stages of production has a supply and a demand dimension. On the supply side one may think that the gaps between desired and actual diffusions can affect the speed of adjustment of each production stage. It could either hamper or boost these speeds if producers anticipate a large catching-up or some persisting mismatch. Conversely, looking on the demand side, adjustments in the structure of the capital stock in both stages will have some effects on the price and quality of the final products which, in turn, will stimulate demand (in both level and structure). These interdependencies will furthermore be conditioned by the ability to buy or to sell on foreign markets.

Accounting for all these linkages between process innovations (on the supply and on the demand side) complicates the analytical expression of the rate of diffusion in investments (equation (10)) leading to the following reduced form (which will be tested in a linear form):

$$(11)\quad m_{i,t} = f\ [D_{i,t-1}, \hat{D_1} - D_1, D\hat{}_2 - D_2, W, c_i, y_i]$$

where c_i stands for the share of each national production Y_i which is exported and W for the wage unit cost. The last two variables recall the specific conditions of competition met by each country.

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[9] The desired level of diffusion $\hat{D_i}$ is defined as the ratio of desired modern capital stock $K\hat{}^*_i$ to the overall capacity $(K_i^* + K_i^-)$.

Let us now see how the above patterns of interdependence can help to explain the diffusion of innovations in the textile industry.

4 - TESTING INTERDEPENDENT SCHEMES OF DIFFUSION

4.1. The data

We start with a set of data on the shipments and stocks of new and old equipments in spinnig and weaving industries for a sample of countries over the period 1977-1984 [10].

In order to transform these numbers of machines into comparable production capacities we have weighted the number of modern machines by their average relative working speeds with regard to traditional ones (for open-end rotors, s=3.22, for shuttle-less looms, s=1.67). The diffusion rates in investments m_i, as well as the diffusion rates in capital stocks D_i represent the shares of modern to total production capacities.

Table 2 shows the evolution of these diffusion rates in investment (m_i) and capital stocks D_i, for selected countries [11]. The data show a significant variance over time and accross countries. In Asian countries both ratios of modern purchases m_1 (spinning machines) and m_2 (weaving machines) are rather low in the 70's, while over 80 % of the weaving equipments bought in Europe and the US are modern (with the exceptions of Spain and Switzerland).

Only in India and in Korea do we still find low shares of modern weaving equipment by the mid 1980's. This variance in modernization behaviour as well

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[10] Our statistics on textile industries consist of annual data from 16 countries between 1977 and 1984 published by the International Textile Manufactures Federation in Zurich (see ITMF(a) and ITMF(b)) The ITMF publishes, data on shipments, i.e. deliveries of equipment, and existing stocks of different types of machines. It should be noticed that data on shipments are collected from the suppliers of equipment. They do not account for casual reselling and second hand transactions. The countries are USA, Japan, UK, Germany, France, Belgium, Netherlands, Switzerland, Sweden, Italy, Spain, Austria, India, South Korea, Hong-Kong, Taiwan. Data on national accounts are taken from the International Financial Statistics Yearbook published by the International Monetary Fund.

[11] The whole series of diffusion levels and shares of new machines in investment are given in the statistical appendix

as differences in the investment patterns lead to a wide range of diffusion levels in Asia as well as in Europe. We can therefore characterize the period under study as one of catching up in modernization behaviour, reaching its maximum in weaving and still fully developing in spinning by the mid 80's. The large differences in the rates of investment among countries is another strong characteristic.

TABLE 2

THE DIFFUSION RATES OF OPEN-END ROTORS IN SPINNING

AND OF SHUTTLE-LESS LOOMS IN WEAVING INDUSTRIES

		WEAVING		SPINNING	
		Diffusion rates in :			
		invest.	capital	invest.	capital
USA	1977	.8358	.1328	.3986	.0335
	1984	.9840	.4354	.9778	.0632
FRANCE	1977	.8300	.1554	.6601	.0766
	1984	.9895	.6386	.6332	.2312
ITALY	1977	.8557	.1297	.0768	.0464
	1984	.9976	.5780	.4410	.0792
INDIA	1977	.2137	.0059	0	0
	1984	.2537	.0452	.0059	.0006
KOREA	1977	.0128	.0121	.0537	.0140
	1984	.3789	.0822	.4625	.0275
JAPAN	1977	.2506	.1418	.0207	.0581
	1984	.8433	.2902	.2416	.0856

Note : Annual time series data for 16 countries are included in the appendix; for the definition of the diffusion rates (see text).

In this set of diversified experiences it is interesting to test the interdependence between the diffusion processes in using the two formulations of the diffusion rates in investment (as given in equations 10 and 11).

4.2. Estimating and testing the diffusion process

Firstly we will estimate some characteristics of the adjustment process and of the desired structure of capital directly from equation (10), assuming that demand is independent from the levels of diffusion. The second step considers that the composition of demand will be affected by the levels of diffusion. This will be estimated as a reduced form, integrating determinants of demand (as in equation 11).

To estimate the diffusion rates m_i we pooled cross-section (16 countries) and time-series (8 years) data.

4.2.1 Direct estimates of diffusion rates in investments.

Assuming that scrapping rates are equal in modern and traditional equipment ($\delta_i^- = \delta_i^*$ and therefore $\phi_i^- = \phi_i^*$) the diffusion rate m_{it} (given in equation (10)) has the following form :

(12) $m_{it} = (1-r_i e_i)\, D_{i,-1} + r_i e_i\, (h_{i1}\, F_{i1} + h_{i2}\, F_{i2})$

where $e_i = (1+y_i) \,/\, (y_i + \delta_i)$

Equation (12) is estimated after adding a simple assumption on the speed of adjustment r_i. In accordance with equation (5) it is assumed that r_i is proportionnal to the difference between the past and the present desired level of diffusion : $(\hat{D}_i - D_{i,t-1})$ times the previous level of diffusion $D_{i,t-1}$ [12]

(13) $r_i = v_i\, D_{i,t-1}\, (\hat{D}_i - D_{i,t-1})$

[12] This formulation rules out all form of interdependence between the two diffusion processes through learning processes or unit costs changes.

Solving, equation (4) for $\hat{D_i}$ and substituting the result in equation (13), one obtains :

$$(14)\ ro_i = v_i D_{i,t-1}\ (D_i - D_{i,t-1})^{0,5}$$

Taking into account that the shares of the different products in each phase i, F_{i1} and F_{i2}, add up to one : $F_{1i} + F_{i2} = 1$, and that the e_i are constant over time, we get the following form.

$$\begin{aligned}(15)\ m_{it} = {} & D_{i,t-1} - a_i\ D_{i,t-1}\ [D_{i,t-1}(D_i - D_{i,t-1})]^{0,5} \\ & + a_i\ (h_{i1} - h_{i2})\ F_{i1}\ [D_{i,t-1}\ (D_i - D_{i,t-1})]^{0,5} \\ & + a_i\ h_{i2}\ [D_{i,t-1}\ (D_i - D_{i,t-1})]^{0,5}\end{aligned}$$

with $a_i = e_i(v_i)^{0,5}$

Table 3 presents the results of the estimation of equation (15) for both phases of production spinning and weaving. The estimates were obtained by OLS without an intercept term.

T A B L E 3

THE DIFFUSION RATES IN INVESTMENTS

COEFFICIENTS	SPINNING i=1	WEAVING i=2
ai	43.396 *** (7.168)	11.859 *** (1.315)
ai (hi1 - hi2)	1.904 (2.283)	1.323 (2.251)
ai hi2	13.002 *** (1.798)	7.624 *** (1.620)
hi1 desired share of modern equipment for natural	0.344 ** (.151)	0.755 * (.410)
hi2 desired share of modern equipment for synthetic	0.299 *** (.091)	0.643 ** (.208)
number of observations	112	112
SSR square sum of residuals	13.074	9.503
SER standard error of regression	0.346	0.295

Notes: - (standard errors in parenthesis)
* significance at the 10% level
** significance at the 5% level
*** significance at the 1% level
- Proxies of the SER on the h_{ij} have been calculated under the assumption that the estimated SER (given in the upper part of table III) were measurement errors which induced some errors on the calculus of h_{ij}.

As the results reported in table 3 show, we obtain significant parameters for the h_{ij} which define the desired percentage of modern equipment to produce each type of product j. However the values of these estimates are not as expected: there is no significant difference between the requirements for modern equipment in the production of natural products and of synthetic products, whereas we expected these latter to be larger (see the illustration given in Tables A5 and A6). This could be partly the result of some spurious correlation, if for instance the structure of demand (as given by the F_{ij}) is affected by the rates of diffusion), but it could come as well from the fact that the desired percentage of modern equipment to produce a given type of product may not be uniform across countries. Differences in labour costs may well lead to different desired structures of capital stocks. In order to take such a possibility into account we have reestimated equation (15) allowing for the possibility that the h_{ij} were not constant across countries but proportional to the wage indicator W (see table 4[13]). With that additional assumption, the estimate of the percentage of modern equipment, in the weaving industries, desired to make synthetic product is significantly higher than in the one to make natural product. However, in the spinning industry such interdependency between process and product cannot be confirmed. The fact that in this industry the diffusion of open-end rotors was still in its infancy over the period 1977-1984 may help to explain this negative result.

[13]GDP per capita in US dollar has been used as wage indicator.

TABLE 4

THE DIFFUSION RATES IN INVESTMENTS

(estimates of equation 15 when the desired percentage of modern equipment is proportional to a wage indicator)

COEFFICIENTS	SPINNING $i=1$	WEAVING $i=2$
a_i	34.198 ***	10.129***
	(7.168)	(2.07)
$a_i\ (h_{i1} - h_{i2})$	15.1 e ***	-56.58 e**
	(3.27 e)	(22.9 e)
$a_i\ h_{i2}$	50.65 e***	109.1 e***
	(12.6 e)	(18.0 e)
hi1 desired share of modern equipment for natural product	2.935 e	5.184 e
	(2.52 e)	(7.40 e)
hi2 desired share of modern equipment for synthetic product	1.481 e	10.771 e
	(.668 e)	(3.99 e)
number of observations	112	112
SSR	14.297	17.135
SEE	0.3622	0.3965

(standard errors in parenthes s)

notes:
- $e=10^{-5}$
- * significance at the 10% level
- ** significance at the 5% level
- *** significance at the 1% level
- GDP per capita, in US dollars, was used as wage indicator.

As shown by the a_i[14] the speed of adjustment appears to be greater in spinning than in weaving. This might be explained by the early stage of diffusion in the spinning industry in 1977-1984.

Thus the direct estimates of our model equation supports our hypothesis on the interdependence between the desired structure of capital and the

[14] Equation (15) shows that, for a given growth rate of demand, ai is a monotoneously increasing function of the adjustment parameter vi.

structure of demand for the weaving industry but should be rejected for the spinning industry.

As an alternative we estimated a reduced form which takes the links between the structure of demand and the levels of diffusion of new processes into account.

4.2.2 Estimates of a reduced form of the diffusion model

The previous specification of our model (equation 15) did not account for all interdependencies. On the one hand, the speeds of adjustments could be linked between the two industries and , on the other, the cumulative costs reductions might affect the evolution of demand by changing the structure and level of final demand. Any of these interdependencies might have contributed to the discrepancy between our econometric results obtained so far and the views of industry experts who emphasize the links between process innovations and product demands. Hence a log-linear specification of the general form of equation (11) is used to take these interdependencies between process innovations and the effect of cost reduction on demand into account.

Table 5 summarizes the results of this estimation for the two industries. Export ratios c_i are defined as net exports over domestic uses. The desired levels of diffusion $\hat{D_i}$ are approximated by using current values of diffusion levels[15].

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[15] The previous estimation showed that substituting observed diffusion rates in place of desired values introduce non-linearities. This is the reason why a log linear form has been introduced.

TABLE 5

A REDUCED FORM OF THE OVERALL DETERMINANTS OF THE DIFFUSION RATES

(estimation of equation 11 in a log-linear form)

VARIABLES	SPINNING i=1	WEAVING i=2
Diffusion levels Log Di,t-1	0.4523** (0.210)	0.1790*** (0.0660)
Diffusion gaps .in spinning Log(D^1-D1)	0.2192 (.154)	0.01819 (0.0291)
.in weaving Log(D^2-D2)	0.1556 (0.155)	0.08492*** (0.0315)
Log wage indicator W	0.2136 (0.299)	0.3425*** (0.0649)
Log Share of export Ci	1.752** (0.730)	0.1086 (0.140)
Constant	-.3392 (3.30)	-2.6538 (0.713)
R2	0.206	.654
SER	2.106	.4277
DW	2.52	2.14
number of observations	112	112

notes: (standard errors in parenthesis)
* significance at the 10% level
** significance at the 5% level
*** significance at the 1% level

The results, we obtain in estimating this reduced form, are rather supportive of the model. The significant parameters have the expected sign. However the parameter accounting for the cross effect between the two diffusions is insignificant. However, if one includes only the increases in diffusion rates as explanatory variables (see table 6) the regressions display significant effects of cross influences, confirming the estimates in table 5.

TABLE 6

CROSS INFLUENCE OF DIFFUSION INCREASES ON THE DETERMINATION OF THE DIFFUSION RATES

VARIABLES		SPINNING i=1	WEAVING i=2
Diffusion increases	.in spinning Log(D^1-D1)	0.4081*** (.125)	0.1508*** (0.0334)
	.in weaving Log(D^2-D2)	0.2531* (0.153)	0.1923*** (0.0407)
Constant		1.195 (0.759)	1.135 (0.203)
R2		0.126	.344
SEE		2.209	.5891
DW		1.77	1.37
number of observations		112	112

notes: (standard errors in parenthesis)
* significance at the 10% level
** significance at the 5% level
*** significance at the 1% level.

The coefficient of determination is in all regressions lower for the spinning industries. This may be caused by the early stage of the diffusion of open-end rotors or by the fact that spinning process is open to large economies of scale.

5 - CONCLUSION

The paper studied the diffusion of technological change in two consecutive production stages in the textile industry. Over the last decades technological change in the spinning and weaving industries involved three major innovations : the surge of synthetic fibres, the development of shuttle-less looms and the development of open-end rotors. These radical innovations were introduced at quite different dates: synthetic fibres in the 1940's, shuttle-less looms in the 1960's, open-end rotors in the 1970's. They were all preceded and followed by incremental innovations which constantly improved techniques and products.

These technological changes were accompanied by specialisation processes among firms and countries. During the 1950's different processes of textile production tended to be integrated within one firm. During the 1960's, development in weaving techniques was accompanied by a growing division between weaving and spinning activities. Spinning industries, which benefitted from large economies of scale, tended to concentrate further and to relocate production, eventually outside old industrialized countries. The diffusion of open-end rotors occurred in the middle of this latter period.

In our analysis we started with the hypothesis that the wider use of synthetical fibres was likely to favor the diffusion of new equipments in spinning and weaving, given certain levels of demand for these products. We modified this hypothesis by adding that demand itself could be affected by the cost advantages brought about by the diffusion of new equipments. Two simple models of diffusion were used to explain the rates of diffusion of modern equipments among industries. These models used two explanatory variables : one to account for market conditions and expectations by the firm, the other to assess the specific learning processes of firms faced with a choice of techniques.

From the empirical analysis one gets the result that the estimated desired structure of capital depends upon the relative labour costs in different countries. From this specification a bias favouring the use of synthetic fibres with a more intensive use of shuttle less looms could be confirmed. However, the same could not be shown with respect to the diffusion of open-end rotors in spinning.

Generalizing the model by taking into account the effects of diffusion on the demand side we estimated a reduced form of the determination of diffusion rates in investments. The significant parameters had the expected signs and magnitudes. The parameters revealing the interactions of diffusion processes were shown to be influenced by the national conditions of competition.

The previous analysis brought some first support for the hypothesis of links between the diffusions of product and process innovations in national textile industries. However, the empirical results and the models fall short to give a complete answer to the question of interdependency. The poor results in the case of diffusion in spinning might be attributable to the early stage of diffusion. These interpretations have to be checked by using additional data on diffusion in spinning and by reformulating accordingly the determinants of diffusion rates in weaving.

Furthermore, the support of the hypothesis of interdependencies in diffusion processes would make it reasonable to extend our analysis for the final stages of production in the textile industry (including clothing and distribution). This would give a more comprehensive view of the diffusion of new technologies in a whole branch.

BIBLIOGRAPHY

ANTONELLI C. (1989)
"The Role of Technological Expectations in a Mixed Model of International Diffusion of Process Innovations. The Case of Open-End Rotors".
Research Policy, 18, October .

ANTONELLI C., PETIT P., TAHAR G. (1989)
"Technological diffusion and investment behaviour : the case of textile industry".
Weltwirshaft Archiv. Band 125 Heft 4

COEN R.M. (1971)
"The effect of cash flow on the speed of adjustment".
in Tax Incentives and Capital Spending ed. G. FROMM,
Washington D.C., Brookings.

DAVID P.A. (1985)
Clio and the economics of Qwerty
A.E.R. Papers and Proceedings, 75, May.

ITMF(a) (International Textile Manufactures Federation)
International Cotton Industry Statistics, Zurich, 1977 and following years

ITMF(b) (International Textile Manufactures Federation)
International Shipments Statistics, Zurich, 1977 and following years

MANSFIELD E. (1961)
"Technical change and the rate of imitation".
Econometrica, October.

PETIT P., TAHAR G. (1989)
"Dynamics of Technological Change and Schemes of Diffusion".
The Manchester School Review, vol LVII n°4, December.

STATISTICAL APPENDIX

DIFFUSION OF OPEN-END ROTORS IN SPINNING.

Table A1 Share of modern machines (measured in terms of output capacity) in annual shipments (m1,t)[16]

	1977	1978	1979	1980	1981	1982	1983	1984
Asia								
Hong Kong	0.9984	0.9225	0.2156	0.5417	0.9511	1	0.4798	0.4758
India	0.0	0.0012	0.0002	0.0012	0.0123	0.0160	0.0026	0.0059
Japan	0.0207	0.1626	0.2216	0.0222	0.1765	0.0748	0.4055	0.2416
Korea	0.0537	0.0234	0.0711	0.0304	0.1149	0.0192	0.0231	0.4626
Taiwan	0.3933	0.4713	0.2416	0.2049	0.1557	0.7571	0.1623	0.0597
Europe								
Austria	0.1066	0.3530	0.0604	0.0187	0.0817	0.8778	0.1623	0.4146
Belgium	1	0.6162	1	1	1	1	1	1
France	0.6601	0.7374	0.7630	0.4419	0.6995	0.6558	0.6588	0.6332
Germany	0.1540	0.1628	0.3291	0.4633	0.5357	0.7481	0.7749	0.5655
Italy	0.0768	0.1389	0.0903	0.1382	0.2903	0.2412	0.5115	0.4410
Netherlands	1	0.7630	1	1	0	1	0	0
Spain	0.2783	0.3263	0.2579	0.1789	0.1619	0.5587	0.5907	0.3840
Sweden	0	0.9530	0	1	1	1	0	1
Switzerland	0.1420	0	0.1403	0.1411	0.0412	0.0683	0.0244	0.3195
UK	0.2800	0.6148	0.9300	0.0820	1	0.5702	0.1142	1
USA	0.3986	0.3409	0.6548	0.4202	0.5472	0.5295	0.7260	0.9778

Table A2 Share of modern capacities in current capital stocks (D1,t)[17].

	1977	1978	1979	1980	1981	1982	1983	1984
Asia								
Hong Kong	0.1866	0.2369	0.2423	0.2422	0.2498	0.2374	0.3189	0.3469
India	0	0	0	0.0001	0.0004	0.0007	0.0008	0.0006
Japan	0.0581	0.0629	0.0696	0.0708	0.0958	0.0672	0.0667	0.0856
Korea	0.0140	0.0135	0.0186	0.0179	0.0218	0.0218	0.0228	0.0275
Taiwan	0.0311	0.0422	0.0493	0.0615	0.0613	0.0813	0.0899	0.0843
Europe								
Austria	0.0040	0.0044	0.0044	0.0053	0.0076	0.0160	0.0341	0.0500
Belgium	0.0866	0.0773	0.0837	0.1015	0.1177	0.1459	0.1848	0.2208
France	0.0766	0.0911	0.1046	0.1223	0.1519	0.1784	0.2071	0.2312
Germany	0.0522	0.0523	0.0614	0.0804	0.0840	0.1051	C.1254	0.1444
Italy	0.0464	0.0583	0.0724	0.0753	0.0871	0.0877	0.0821	0.0792
Netherlands	0.1538	0.1597	0.1952	0.1996	0.1944	0.2198	0.5299	0.5124
Spain	0.1088	0.0592	0.0632	0.0650	0.0771	0.0896	0.1012	0.1042
Sweden	0.0851	0.0600	0.2098	0.2065	0.2022	0.2553	0.2534	0.4696
Switzerland	0.0264	0.0259	0.0286	0.0292	0.0292	0.0328	0.0359	0.0306
UK	0.0476	0.0538	0.0602	0.0731	0.0926	0.1216	0.1294	0.1240
USA	0.0335	0.0354	0.0386	0.0425	0.0478	0.0547	0.0638	0.0632

[16] These capacities are estimated from datas on deliveries of machines of both types, weighted by their average capacity per unit of time.source: ITMF(b).

[17] source: ITMF(a)

DIFFUSION OF SHUTTLE-LESS LOOMS IN WEAVING.

Table A3 Share of modern machines (measured in terms of output capacity) in annual shipments (m2,t)[18].

	1977	1978	1979	1980	1981	1982	1983	1984
Asia								
Hong Kong	0.3472	0.5683	0.8633	0.9434	1	1	1	1
India	0.2137	0.1967	0.0560	0.0737	0.0519	0.1446	0.1228	0.2537
Japan	0.2506	0.5475	0.4237	0.5787	0.6970	0.6062	0.8260	0.8433
Korea	0.0128	0.1062	0.2166	0.5507	0.0201	0.1595	0.1940	0.3789
Taiwan	0.4583	0.6886	0.8782	0.5273	0.4633	0.9991	0.8379	0.9752
Europe								
Austria	0.8243	0.8837	0.9763	0.9672	0.9549	0.9770	0.9470	1
Belgium	0.9470	0.9115	0.9870	0.9632	0.9950	0.9978	0.9971	1
France	0.8300	0.9753	0.9501	0.9692	0.9760	0.9888	0.9957	0.9895
Germany	0.8173	0.9081	0.9552	0.9488	0.9936	0.9773	0.9932	0.9992
Italy	0.8557	0.9463	0.9538	0.9653	0.9443	0.9869	0.9979	0.9976
Netherlands	0.9263	0.9036	0.9664	0.1923	1	0.7042	1	1
Spain	0.6673	0.4762	0.7633	0.8950	0.9785	0.9959	1	0.9991
Sweden	0.9416	0.8671	0.9898	0.7692	1	0.8824	1	0.9659
Switzerland	0.6857	0.9305	0.9499	0.9113	0.8457	0.9444	0.9525	1
UK	0.9687	0.6831	0.9238	0.7944	0.7600	0.8993	0.9980	0.9874
USA	0.8356	0.9153	0.8366	0.9520	0.9948	0.9927	0.9998	0.9840

Table A4 Share of modern capacities in current capital stocks (D2,t)[19].

	1977	1978	1979	1980	1981	1982	1983	1984
Asia								
Hong Kong	0.0221	0.0228	0.462	0.1416	0.2350	0.2375	0.2692	0.3474
India	0.0059	0.0093	0.0139	0.0168	0.0195	0.0167	0.0226	0.0452
Japan	0.1418	0.1497	0.1576	0.1885	0.1840	0.2167	0.2571	0.2902
Korea	0.0121	0.0128	0.0329	0.0271	0.0280	0.0314	0.0350	0.0822
Taiwan	0.0564	0.0954	0.2021	0.2671	0.2626	0.2624	0.2503	0.3057
Europe								
Austria	0.1831	0.2201	0.2293	0.2821	0.3091	0.3866	0.4799	0.6054
Belgium	0.0550	0.0730	0.0943	0.1331	0.1848	0.2571	0.5220	0.5146
France	0.1554	0.2094	0.2609	0.3306	0.4575	0.5405	0.5735	0.6386
Germany	0.0693	0.1103	0.1495	0.2080	0.2964	0.4492	0.5006	0.5478
Italy	0.1297	0.1549	0.1930	0.2465	0.2847	0.3155	0.4899	0.5780
Netherlands	0.2792	0.3476	0.4156	0.5181	0.6590	0.6697	0.6964	0.7032
Spain	0.2090	0.1679	0.2418	0.2107	0.2215	0.2597	0.3110	0.3398
Sweden	0.4090	0.5919	0.7454	0.7454	0.8174	0.7955	0.7921	1
Switzerland	0.1032	0.1124	0.1632	0.2047	0.2424	0.2589	0.2755	0.3199
U.K.	0.3211	0.3607	0.3916	0.4053	0.4129	0.4224	0.4584	0.4994
USA	0.1328	0.1891	0.2008	0.2290	0.3331	0.3724	0.3716	0.4354

[18] These capacities are estimated from datas on deliveries of machines of both types, weighted by their average capacity per unit of time. source : ITMF(b).

[19] source ITMF(a)

TABLE A5

DESIRED STRUCTURE OF EQUIPMENT BY TYPE OF PRODUCT SPUN

(rough expectation, from expert advice)

	NATURAL Fibres	SYNTHETIC	SYNTHETIC YARN
(Spindle) . traditional	h11 = .7	h12 = .2	0
(open-end) . modern	1-h11 = .3	1-h12 = .8	0

(Figures show the share of production done by each kind of equipment).

TABLE A6

DESIRED STRUCTURE OF EQUIPMENT BY TYPE OF PRODUCT WEAVED

	NATURAL YARN	MIXED YARN	SYNTHETIC YARN
(automatic) . traditional	h21 = .8	h22 = .3	h22 = .3
(shuttle-less) modern	1-h21 = .2	1-h22 = .7	1-h22 = .7

(Figures show the share of production done by each kind of equipment).