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TECHNOLOGICAL DIFFUSION AND INVESTMENT BEHAVIOUR : THE CASE OF THE TEXTILE INDUSTRY (*)

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S U M M A R Y

TECHNOLOGICAL DIFFUSION AND INVESTMENT BEHAVIOUR : THE CASE OF THE TEXTILE INDUSTRY

The diffusion of new technology in production depends on both its own characteristics in terms of profit and technical capabilities and the general conditions for investment.

This paper aims to explain how diffusion processes are the combined result of investment behaviours and of learning processes concerning the new equipment.

Simple assumptions about the key factors relevant in the choice of modern equipment, when investing, in a world of bounded rationality, lead to estimations in the case of the Textile industry in a set of 16 countries.

Simulations display endogeneously defined diffusion curves and differences in modernization patterns among countries.

Key-words : Diffusion - technology - learning processes - bounded rationality.

RESUME

DIFFUSION DU PROGRES TECHNIQUE ET COMPORTEMENT D'INVESTISSEMENT : LE CAS DE L'INDUSTRIE TEXTILE

La diffusion d'une nouvelle technique de production dépend non seulement de ses capacités et de sa rentabilité mais aussi des conditions générales d'investissement.

Cet article cherche à expliquer la façon dont les processus de diffusion de nouveaux équipements combinent comportements classiques d'investissement et processus d'apprentissage face à l'innovation.

Des hypothèses simples sur les déterminants des choix d'innovation, dans un univers où la rationalité des agents reste limitée, permettent, à partir de l'expérience de 16 pays dans les années 70-80, d'estimer des fonctions de choix d'équipements nouveaux dans l'industrie textile.

Une série de simulations conduit à distinguer différents modèles nationaux de diffusion.

Mots-clés : diffusion - technologie - processus d'apprentissage - rationalité limitée.

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I - INTRODUCTION

The diffusion of technological innovation incorporated in new capital goods is the result of investment decisions which are influenced by two types of factors : the characteristics of the innovation and the macroeconomic environment in which the adopters operate.

We aim ,in this paper, to explain the role played by these factors in the adoption process at industry level.

The macroeconomic environment, in which firms operate, refers to such factors as demand trends, relative production costs and overall competitivness.

Technological factors refer on the one hand to the capacities of the new machines (or their expected profitability) and ,on the other hand, to the availability of information and of the know-how to which the users must have access. Stickiness of information and rigidity of learning processes generate asymetries between firms, which combine with structural differences to determine adoption and diffusion processes.

The international diffusion of shuttle-less looms in the cotton weaving industry in the late seventies and early eighties seems to provide evidence of the joint effect played in the adoption by the two types of factors, i.e., the technological and macroeconomic context of investment. The cotton weaving industry, in fact, has been faced by dramatic changes in the distribution of market shares, with the major decline of old industrialised countries and the upsurge of newly industrializing ones. At the same time, rates of the adoption of modern capital goods occurred at varying rythms in both new and old industrialized countries.

This paper analyzes such technological diffusion as the result of a sequence of investment decisions by economic agents with limited knowledge and bounded rationality in a given macroeconomic context.

By including a technological and a macro economic dimension, our approach avoids to depend only on learning processes as in the epidemic school or on rational behaviour of investment as in the purely microeconomic approach.

Furthermore it leads to endogeneize the diffusion process on the basis of laws of adoption.

By means of a simple model we shall provide an integrated framework to analyze the adoption of new capital goods in the cotton weaving industry as influenced by market as well as by epidemic factors.

References to the empirical evidence of the international diffusion of shuttle-less looms in the cotton industry are given in section 2 while the theoretical foundation of the model is elaborated in section 3. The econometric analysis presented in section 4, focuses on what determines the probability of introducing modern technology when investment decisions are made. Our conclusions (section 5) include simulations which illustrate our approach.

II - TECHNOLOGICAL CHANGES IN THE TEXTILE INDUSTRY

The cotton industry experienced ,during the seventies, diffusion of major technological innovations in all the different phases of the production process from spinning to finishing through weaving, not to mention changes in inputs such as synthetic fibers mingled with traditional, natural and artificial fibers (in 1985 more than 60 % of the total production of cotton fabrics were synthetic fibers).

In spinning, the open-end technology substituted the ring at least in "low and medium counts" products. In weaving, shuttle-less looms have been introduced. In finishing, a variety of electronic devices made the automatization of bleaching, dyeing and printing possible.

The technological break-throughs on which each of these innovations are based were conceived and first introduced a few decades ago. The most recent is in fact the open-end spinning technology which was introduced in Czechoslovakia in the late fifties.

This study will only consider the case of the shuttle-less loom in its analysis of diffusion because the diffusion process took place mainly in the early eighties while it was just beginning in the case of spinning or finishing innovations.

In itself the case of the shuttle-less loom is quite interesting. Rudolf ROSSMAN, a German textile engineer, patented the basic technology of shuttleless looms in 1928. In 1931 his patents were bought by the Sulzer

Brother Company of Winterthur in SWITZERLAND, a firm traditionally active in steam and diesel engines, with no expertise in textile engineering. The first industrial production of shuttle-less, actually at that time light-shuttle looms, started in the fifties.

Since then, a wave of incremental technical changes have been introduced along a clear technological trajectory in an attempt to reduce the weight of the shuttle and lately to replace the shuttle itself with other tools : such as metal projectiles, grippers, and recently water jets. Recent advances along such a trajectory are summarised in table 1 where the different tools used to carry the thread together with the working speed and the first year of industrial production are shown.

At the end of the seventies, 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.

TABLE 1

TECHNOLOGICAL CHANGE IN WEAVING : THE EVOLUTION OF PRODUCTIVE CAPACITY OF EQUIPMENT (BETWEEN 1970 AND 1980)

TECHNOLOGY	YEAR OF INTRODUCTION	WORKING SPEED
SHUTTLE LOOM	1970	200 KNOTS
SHUTTLE-LESS LOOM PROJECTILE	1970	220 KNOTS
SHUTTLE-LESS LOOM RIGID GRIPPER	1975	250 KNOTS
SHUTTLE-LESS LOOM FLEXIBLE GRIPPER	1976	300 KNOTS
SHUTTLE-LESS LOOM AIR JET	1980	600 KNOTS
SHUTTLE-LESS LOOM WATER JET	1980	600 KNOTS

This price differential has so far been quite stable, due to the nature of the textile machinery industry. Only a few firms, most of them situated in Switzerland, USA, Japan and Germany have been able to produce the most updated versions, due to the technological skills and know-how necessary to produce the modern shuttle-less loom.

The advantages of shuttle-less looms in terms of technical productivity, operating costs, quality of fabric and maintenance costs in 1985, brought about a reduction in current production costs of between 30 % to 50 % with respect to traditional automatic shuttle looms, corresponding to a cost of 50 000 US dollars per machine with average OECD labour costs (*).

Since the mid seventies, in every country, from a technical and economic point of view, the strategy of adopting shuttle-less looms seems to have been fully dominant, with the exception of certain specialist production.

In such a context the evolution in the seventies and early eighties of the choice by cotton weaving firms between modern shuttleless looms and traditional shuttle looms offers an important opportunity to analyze the adoption of modernized capital goods and to study technological resistance, i.e. the obstacles to the instantaneous diffusion of superior process innovations.

Table 2 shows the evolution of the share of shuttle-less looms in total looms installed each year in sixteen countries, over a period of eight years (1977-1984). This ratio concerning equipment flows will be noted m(t). It should be distinguished from the similar ratio applying to stocks of equipment, D(t), that we shall use afterwards as our diffusion variable. Table 3 shows the evolution of D(t).

For the purpose of measurement the data of installed machines has been weighted by their respective average technical productivities (**).

(*) Non-automatic shuttle looms are still part of the stock of weaving machines in many countries. We shall not consider them for a variety of reasons : i) they are most used in the weaving of silk rather than cotton ; ii) their utilization levels in the weaving of cotton are extremely low ; iii) they are often used in the weaving of speciality products by craftmen.

(**) According to technical information, productivity of shuttle looms is set equal to 180 knots/min and that of shuttle-less looms to 300 Knots/min.

T A B L E 2

SHARE OF MODERN CAPACITIES IN ANNUAL FLOWS OF NEW CAPACITIES

m_t	1977	1978	1979	1980	1981	1982	1983	1984
ASIE								
HONG KONG	.3472	.5683	.8633	.9434	1.0000	1.0000	1.0000	1.0000
INDIA	.2137	.1967	.0560	.0737	.0519	.1446	.1228	.2537
JAPON	.2506	.5475	.4237	.5787	.6970	.6062	.8260	.8433
KOREA	.0128	.1062	.2166	.5507	.0201	.1595	.1940	.3789
TAIWAN	.4583	.6886	.8782	.5273	.4633	.9991	.8379	.9752
EUROPE								
AUSTRIA	.8243	.8837	.9763	.9672	.9549	.9770	.9470	1.0000
BELGIUM	.9407	.9115	.9870	.9632	.9950	.9978	.9971	1.0000
FRANCE	.8300	.9753	.9501	.9692	.9760	.9888	.9957	.9895
GERMANY	.8173	.9081	.9552	.9488	.9936	.9773	.9932	.9992
ITALY	.8557	.9463	.9538	.9653	.9443	.9869	.9979	.9976
NETHERLANDS	.9263	.9036	.9664	.1923	1.0000	.7042	1.0000	1.0000
SPAIN	.6673	.4762	.7633	.8950	.9785	.9959	1.0000	.9991
SWEDEN	.9416	.8571	.9898	.7692	1.0000	0.8824	1.0000	.9659
SWITZERLAND	.6857	.9304	.9499	.9113	.8457	.9444	.9524	1.0000
U.K.	.9687	.6831	.9238	.7944	.7600	.8993	.9980	.9874
U.S.A.	.8358	.9153	.8366	.9520	.9948	.9927	.9998	.9840

Data on the evolution of technological choice show (see m(t) in table 2) a clear international variance with countries such as Japan, India, Taiwan, Korea and Spain, where the ratio of purchases of shuttleless looms to shuttle looms in 1977 was well below average.

Data of table 2 were used to test the following simple regressions :

$m = a + b \quad TREND$

TREND (1 for 1977 ... 8 for 1984) is a continuous time variable.

No exogeneous variable have been introduced due to the small size of the time series (8 years).

TABLE 3

SHARE OF MODERN CAPACITIES IN CURRENT STOCKS OF CAPACITIES

D_t	1976	1977	1978	1979	1980	1981	1982	1983	1984
ASIE									
HONG KONG	.0158	.0221	.0228	.0462	.1416	.2350	.2375	.2692	.3474
INDIA	.0059	.0059	.0093	.0139	.0168	.0195	.0167	.0226	.0452
JAPON	.1269	.1418	.1497	.1576	.1885	.1840	.2167	.2571	.2902
KOREA	.0120	.0121	.0128	.0329	.0271	.0280	.0314	.0350	.0822
TAIWAN	.0000	.0564	.0954	.2021	.2671	.2626	.2624	.2503	.3057
EUROPE									
AUSTRIA	.1404	.1831	.2201	.2293	.2821	.3091	.3866	.4799	.6054
BELGIUM	.0404	.0550	.0730	.0943	.1331	.1848	.2571	.5220	.5146
FRANCE	.1340	.1554	.2094	.2609	.3306	.4575	.5405	.5735	.6386
GERMANY	.0466	.0693	.1103	.1495	.2080	.2964	.4492	.5006	.5478
ITALY	.1137	.1297	.1549	.1930	.2465	.2847	.3155	.4899	.5780
NETHERLANDS	.2189	.2792	.3476	.4156	.5181	.6590	.6697	.6964	.7032
SPAIN	.2004	.2090	.1679	.2418	.2107	.2215	.2597	.3110	.3398
SWEDEN	.2952	.4094	.5919	.7454	.7454	.8174	.7955	.7921	1.0000
SWITZERLAND	.0960	.1032	.1124	.1632	.2047	.2424	.2589	.2755	.3199
U.K.	.2995	.3211	.3607	.3916	.4053	.4129	.4224	.4584	.4994
U.S.A.	.1121	.1328	.1891	.2008	.2290	.3331	.3724	.3716	.4354

Results, listed in table 4, exhibit significant differences among countries. The values of the estimated intercept (a) show that in most countries in the period 1977-1984 the probability of adopting shuttleless looms was already close to 80 % with the relevant exceptions of Korea (0.054), India (0.115), Taiwan (0.120), Japan (0.197) where the majority of looms purchased still had shuttles.

Nevertheless the effect of time, as estimated by the parameter b, tends to be small when the intercept a is large. This is confirmed by the negative rank correlation of parameters a and b: r =-731. It suggests that countries with an initially low probability of adopting new equipment are rapidly modifying their attitudes.

TABLE 4

MODERNIZATION BEHAVIOURS IN EACH COUNTRY

(Test of linear time trend : m = a+bt)

	a	b	$\bar{R}^2$	SEE	D.W.
U S A	0.822 (23.869)	0.020 (3.884)	0.637	0.040	2.125
HONG KONG	0.434 (3.474)	0.070 (3.688)	0.611	0.148	0.605
JAPAN	0.197 (2.860)	0.072 (6.810)	0.850	0.082	3.172
KOREA	0.054 (0.381)	0.027 (1.247)	0.064	0.169	2.284
INDIA	0.115 (1.760)	0.005 (0.495)	- 0.104	0.077	1.205
TAIWAN	0.120 (1.821)	0.013 (1.623)	0.512	0.081	1.890
BELGIUM	0.921 (52.621)	0.009 (3.395)	0.568	0.020	2.576
GERMANY	0.844 (29.095)	0.018 (4.118)	0.666	0.034	1.102
FRANCE	0.880 (27.035)	0.014 (2.786)	0.458	0.038	1.852
ITALY	0.876 (39.863)	0.014 (4.154)	0.670	0.026	1.742
SPAIN	0.516 (5.565)	0.058 (4.074)	0.661	0.110	1.555
SWEDEN	0.879 (13.070)	0.008 (0.787)	- 0.049	0.079	3.503
SWITZERLAND	0.762 (12.308)	0.025 (2.641)	0.427	0.073	1.781
NETHERLANDS	0.738 (3.143)	0.019 (0.539)	- 0.097	0.278	2.634
AUSTRIA	0.847 (26.391)	0.017 (3.399)	0.568	0.038	1.271
U. K.	0.761 (8.357)	0.021 (1.543)	0.147	0.108	2.315

(t of Student between brackets)

It should also be noted that six countries display high variations in their probability to modernize m(t) which cannot be explained by any time trend ; it is the case for three Asian countries where the average probability to modernize is weak : Korea, India and Taiwan, and three European countries where this probability fluctuates around a high average value : Sweden, Netherlands and U.K.

The strong variance in rates of adoption of shuttle-less looms between countries and over time raises the question of the extent up to which choices of the new technology are influenced by the macroeconomic context and by the international specialisation of each country. The data effectively suggest that:

- investment behaviour and technological choice are influenced by the perspectives of demand for textile products in both domestic and international markets ;
- technological advantages of shuttle-less loom are not sufficient in themselves to induce all potential adopters to adopt them simultaneously;
- rates of diffusion nevertheless increase with time and the diffusion process grows stronger.

To deal with such issues section 3 presents a model of the adoption of new capital goods, which tries to integrate macroeconomic determinants and technological factors.

III - A MODEL OF DIFFUSION WITHIN A MACROECONOMIC ENVIRONMENT

In an industry -the textile industry in subsequent estimations- the introduction of a new technique led to a technological discontinuity between ancient and modern equipment. Both types of investment can coexist although with time the modern machines tend to be preferred.

In the present section we try to formulate a model of this process of modernization, taking into account the behaviours of investors and the general need for investment which support this diffusion process.

Let n_t^* , i_t^* , r_t^*, δ_t^* be respectively at time t for modern machines :

- the stock,
- the number bought in the period,
- the potential output per machine per unit of time,
- the percentage of machines of the previous period scrapped at the begining of the period.

Let $\bar{n}_t$, $\bar{i}_t$, $\bar{r}_t$ $\bar{\delta}_t$ be the similar variables for traditional machines.

r_t^* measures the capacity of the new machines ; this potential output is likely to improve with time in the period of development of the innovation. r_t^* is also an average between the announced capacities of different trade marks. $\bar{r}_t$, which is the corresponding capacity for ancient machines, is less subject to change although the competition of the new machines may stimulate further improvements.

r_t^* and $\bar{r}_t$ are exogeneous parameters fixed on expert advice.

δ_t^* and $\bar{\delta}_t$ are more entitled to be considered as endogeneous variables. As a matter of fact, the scrapping behaviours of entrepreneurs not only depends on the life time of equipment and on the age profile of the capital stock but also on the current needs for production capacity which of course is related to the level of economic activity. Nevertheless empirical evidence shows that when unused equipment is easily stored, equipment still in working-order is scrapped only in case of bankruptcies.

In such a context, we shall be forced to keep the standard hypothesis of constant average depreciation rates ($\delta_t^* = \delta^*$, $\bar{\delta}_t = \bar{\delta}$).

We have the usual relationships between stocks of equipment, current purchases and scrappings :

(1) $n_t^* = (1-\delta^*)\ n_{t-1}^* + i_t^*$

(2) $n_t^- = (1-\bar{\delta}\ )\ \bar{n}_{t-1} + \bar{i}_t$

Our objective is to explain the overall diffusion process of modern machines, using the previous simplifying asumptions about depreciation rates and average capacities of machines, as a combination of an investment function and a modernization choice function. Process of diffusion can be split up in two steps : to begin with, market trends define needs of investment, then choices have to be made between modern or traditionnal equipment. At this second stage decisions by firms concerning the choice between two types of machines depend upon two kinds of factors : those pertaining to the economic environment of firms (mainly expectations regarding market trends) and those referring to the characteristics of the new equipment (productivity, profitability, know-how).

To specify these two aspects we shall consider the conditional probability for any new capacity installed in the industry to be modern ,given that a new capacity had to be installed whether for replacement or enlargement.

Let $m_t = f(g_t, e_t)$ be this probability where g_t stands for an indicator of economic environment and e_t for specific factors favoring the the adoption of the innovation.

Ex post we have a straightforward estimation of m_t :

$$(3)\quad m_t = \frac{i^*_t \cdot r^*_t}{i^* r^*_t + \bar{i}_t \bar{r}_t}$$

As a matter of fact m_t accounts for an average of rather different behaviours between firms receiving a stimulus, e_t, to innovate in an economic environment g_t. Some entrepreneurs are more risk taking than others in evaluating either market trends and/or the costs of innovation. Consequently -according to our hypothesis- the purchases of both ancient equipment and modern equipment will coexist for some time.

It is most likely that the diffusion of new equipment will keep on increasing due to higher unit profits brought about by the new technology. The pace of diffusion however remains determined by economic environment.

We shall measure the diffusion process as the share of modern equipment in the overall capacity of production.

$$(4)\quad D_t = \frac{\sum_{k=0}^{k=K} C^*_{t-k}\, r^*_{t-k}}{\sum_{k=0}^{k=K} (C^*_{t-k}\, r^*_{t-k} + \bar{C}_{t-k}\, \bar{r}_{t-k})}$$

where :

C_{t-k} stands for the fraction of equipment (accordingly modern or ancient) installed at time t-k and still in potential or effective use at time t, and K represents the maximum life time of both types of equipments.

The level of diffusion D_t can be expressed as :

$$(5)\ D_t = \frac{n_t^* \cdot R_t^*}{n_t^* \cdot R_t^* + \bar{R}_t\ \bar{n}_t}$$

where n_t^* and $\bar{n}_t$ represent the stocks of modern and ancient equipments at t, while R_t^* and $\bar{R}_t$ are average capacity levels of respectively modern and ancient machines still in potential or effective use at time t.

By analogy with the logistic pattern, D_t can be expressed as a function of m_t and D_{t-1}.

Substituting in (5) n_t^* and $\bar{n}_t$ with their expression in (1) and (2), and using (3) one gets the following expression for the diffusion process :

$$(6)\ D_t = \left[m_t \frac{\bar{r}_t}{\bar{R}_t} + \lambda^* D_{t-1} \cdot \frac{K_{t-1}}{K_t} \cdot \frac{r_t^*}{R_{t-1}^*} \cdot (1-m_t) - \bar{\lambda}\ m_t (1-D_{t-1}) \cdot \frac{K_{t-1}}{K_t} \cdot \frac{\bar{r}\ _t}{\bar{R}_{t-1}} \right] / A_t$$

$$\text{where } A_t = \left[(1-m_t)\ \frac{r_t^*}{R_t^*} + m_t\ \frac{\bar{r}_t}{\bar{R}_t} \right]$$

where K_t stands for the overall capacity of production at period t ($K_t = n_t^*\ R_t^* + \bar{n}_t\ \bar{R}_t$) and $\lambda = 1-\delta$ respectively.

Under the very crude assumptions that $\bar{r}_t$ and r_t^* are constant with time, (i.e. technical possibilities of both ancient and modern equipment do not improve with time) then $r_t = R_t = R_{t-1}$ and we have the following expression for the diffusion process :

$$(7)\ D_t = m_t + \frac{K_{t-1}}{K_t} \cdot \left[D_{t-1} \cdot (\bar{\lambda}\ m_t + \lambda^* (1-m_t)) - \bar{\lambda}\ m_t \right]$$

One can reorganize formulation (7) so as to focus on the role of m_t (probability to modernize) on the diffusion variable.

$$(8)\ D_t = m_t\left[1 - \frac{K_{t-1}}{K_t}\left(\left(\lambda^*-\bar{\lambda}\right) D_{t-1} + \bar{\lambda}\right)\right] + \frac{K_{t-1}}{K_t} \cdot \lambda^* \cdot D_{t-1}$$

The diffusion pattern is thus defined by a recurrent process which involves the overall market trend through the growth of capital stock $\frac{K_t}{K_{t-1}}$, the average scrapping behaviours λ^*, $\bar{\lambda}$, and the frequency of adopters m_t.

Equation (8) does not imply the separation of the economic and technological components of the diffusion process, as the probability of choosing a modern unit, m_t, is still subject to the influence of the macroeconomic environment on investment behaviours (i.e. on growth of capital stock K_t/K_{t-1}), through market prospects and relative costs of production factors. The study of this decision-making process has then some similarities with the probit approach (as defined in STONEMAN 1983, p. 97) ; though, the probit approach deals with the overall probability of getting new equipment, while we consider only the probability of getting modern equipment when investing. Therefore the probit approach has to link the diffusion process with an exogeneous evolution which acts as a stimulus to get modern equipment while our analysis relies, above all, on investment flows. Besides, as we shall see in section IV, we don't expect the investment behaviour of the firms to be fully informed and rational.

Let us now characterize our diffusion process compared to the epidemic approach, which looks more similar to ours.

The standard epidemic approach would start with a finite population of adopters, where the probability to modernize m_e would depend linearily, at time t, on the existing level of diffusion D_{t-1}. If the maximum level of diffusion is equal to unity, the previous assumptions lead directly the epidemic approach to determine a logistic pattern of diffusion which can be expressed as follows :

$$(9) \quad D_t - D_{t-1} = m_e\ (1-D_{t-1})$$

with $m_e = a_t\ D_{t-1}$

More precisely, if the probability to meet a new adopter is D_{t-1}, then a_t is the probability for this modernisation behaviour to spread to a new unit. Studies along this epidemic approach tend to explain the factors entering the decision function a_t (to adopt or not once you are in possession of the information), also referred to as the speed of diffusion.

Our approach is distinct from the epidemic one on two grounds :

1°) The "population" of adopters, which is the set of capital units, is not fixed but evolves with time. The share of modernized capital thus is different from standard diffusion variables. Our model therefore gives a rather different formulation to D_t, in equation (8), from the one we get straightforwardly from the epidemic approach in equation (9), without specifying m_e as a function of D.

2°) No assumption is made a priori on the probability m_t, while the epidemic approach ties it directly to the diffusion level. We only consider that bounded rationality and asymetries of information may very well shape the probability of adoption.

It is nevertheless interesting to compare our diffusion process with the general logistic pattern of diffusion, directly reffered to in the epidemic approach.

Equation (8) can be transformed into :

$$(10)\ D - D_{-1} = \left[m\,(1+k-\bar{\lambda}-(\lambda^* - \bar{\lambda})\,D_{-1}) - D_{-1}\,(1+k-\lambda^*)\right] / (1+k)$$

with the following notations $D = D_t$, $D_{-1} = D_{t-1}$, $m = m_t$, $K = (K_t - K_{t-1})/K_{t-1}$.

Diffusions patterns can thus differ widely according to k the rate of growth of capital and λ^* and $\bar{\lambda}$ the depreciation rates.

Let us consider the diffusion patterns corresponding to constant growth rate of capital i. e. k = constant.

If $\lambda^* \neq \bar{\lambda}$, equation [10] has the general form :

$$(11)\ D - D_{-1} = \alpha\ .\ m\,(\beta - D_{-1}) - \gamma . D_{-1}$$

where α, β, γ are constant (*).

Equation (11) has some similarity with a logistic pattern of diffusion if one retains the assumption that m_t is a linear function of D_{-1} : $m_t = a D_1 + b$, which correspond to some generalization of the standard assumption in the epidemic approach (where b=0).

But more generally, our diffusion process will coincide with a logistic pattern if the average probability to modernize m , satisfies the identity

$$(12) \quad \alpha_m (\beta - D_{-1}) - \gamma D_{-1} = a D_{-1} (1-D_{-1})$$

from which, we have :

$$(13) \; m_t = D_{-1} \left[a \, [1- D_{-1}] + \gamma \right] / \left[\alpha \, [\beta - D_{-1}] \right]$$

Condition (13) is rather formal. If, on a constant growth path of capital, our diffusion process is to follow a logistic pattern then it is necessary for m_t to verify relation (13). But we have not so far made any assumption on m_t and there is no reason, a priori, to retain such a complex formulation as given in (13).

The pattern of m_t will be directly analyzed in the following section.

We shall make a step further in the analysis of the diffusion process D_t by investigating the factors at work in the determination of the average probability to modernize m_t in the case of a specific innovation in the textile industry.

(*) Under the very unlikely case $\lambda^* = \bar{\lambda}$, it follows that $D - D_{-1} = \alpha m - b D_{-1}$ which leads to a form rather different from a logistic if we retain the linear hypothesis of the epidemic approach to explicit the probability m.

IV - ESTIMATING THE DETERMINANTS OF THE PROBABILITY TO MODERNIZE

The probability of opting for modern equipment results from the combination of economic market conditions and information and learning processes. In the epidemic approach access to information is a priori tied to the level of diffusion and is a prerequisite to the action of economic variables or to the influence of economic structure (see GRILICHES 1957, MANSFIELD 1968, ROMEO 1977).

In the probit approach, found in DAVID (1969) or DAVIES (1969) (see STONEMAN 1983), the timing of adoption depends on :

a) the structural heterogeneity of potential adopters and their varying economic conditions ;
b) the increasing profitability of adoption due to the increased productivity of innovated capital goods ;
c) the complete rationality and unlimited knowledge of potential adopters.

Our data on the modernization in weaving activities tend to rule out the information model of the epidemic approach. The ratios m(t)/D(t-1) (see Tables 3 and 4) are often greater than one and cannot be considered as conditional probabilities. Reversely, we do not assume full information and perfect foresight. First we believe that potential adopters may face asymetries of information regarding the new technology. Second, we think that the microeconomic behaviour of potential adopters is heavily influenced by the macroeconomic context, as shown by rhythms of investment, rates of utilization of productive capacity, or rates of growth of overall demand. We are therefore led to test the hypothesis that the average probability to modernize depends on the way information is spread and on the role of macroeconomic factors.

As suggested in section III we thus consider two major classes of complementary determinants. One class of factors concerns all the learning processes, which measure the reduction of cognitive and structural heterogeneity, the second class are the macroeconomic conditions which influence, through the level of utilization of productive capacity and market expectations, the choice of adoption of innovated capital goods in the textile industry.

a) Factors measuring the availability of information and the technical capabilities of the new machines. It refers to specific learning processes :

- learning-by-doing by equipment suppliers improving the machines and reducing the cost of machines ;
- collective learning-by-doing in the equipment industry brought on by competition and imitation ;
- learning-by-using by textile firms building up on internal know-how and therefore more inclined to modernize ;
- learning-by-imitating by textile firms as information spills over when the level of diffusion increases.

Limited knowledge, bounded rationality and information asymetries schedule the number of firms which are able at each point of time to choose the new technology when investing. These imperfections decline over time.

Therefore all variables, which may account for these learning processes, will tend to be highly correlated with time. Three indicators will thus be used alternatively : the time trend, the diffusion level or the currently expected profitability of adoption of innovated capital goods. Time trend is, as we have said, a crude proxy for all learning processes. Diffusion level may convey in a better way the real spread of information about the new techniques and the building up of the competitive pressure by modernized competitors. By analogy with the epidemic approach we shall retain the diffusion level at t-1 to specify the stage reached by the various learning processes. The expected current profitability of adoption accounts for the increased productivity of the new looms in relation with their price changes. We have thus used, a measure of knots per minute per money unit of capital, as given by annual experts'estimations (see table 5).

b) The macroeconomic context in which the diffusion process takes place and in which the firms choose their technology is expected to influence the adoption of new capital goods. The choice of adoption seems to depend on :

- expectations regarding market trends,
- actual performances in terms of profit and competitiveness.

The rate of growth of the textile industry or the rate of investment (i.e. . new"investments over total existing capacity) can be considered as proxies for market expectations and are expected to influence the adoption of new techniques.

TABLE 5
EXPECTED PROFITABILITY OF SHUTTLE-LESS LOOMS

	New shuttle looms		New shuttle-less looms		Expected profi-tability
	Prices	Working Sp	Prices	Working Sp	
YEARS	(1)	(2)	(3)	(4)	(5) = $\frac{(4)}{(3)}:\frac{(2)}{(1)}-1$
1977	43 329	210	43 309	275	0.309
1978	50 339	220	50 317	280	0.275
1979	45 985	220	49 992	300	0.254
1980	38 551	230	44 392	350	0.322
1981	27 308	240	32 127	385	0.364
1982	23 450	240	25 352	385	0.484
1983	20 110	240	23 915	440	0.541
1984	17 630	250	20 343	450	0.560

NOTES

(a) Data on working speeds and on prices of modern and traditional looms are based on observations at International Textile Industry Fairs, done by experts of the Assoziazone Cotoniera Italiana.

(b) PRO : levels of expected profitability of choosing shuttle-less looms instead of shuttle-looms are measured by the relative increase of the ratios of physical productivities in knots per minute of new loom (either modern or traditional) to their price.

(c) Prices figures are in constant 1980 U.S. dollars.

(d) Figures in knots per minute are average effective working speed of new machines incorporating incremental innovations in each year. Data for shuttle-less looms differ from the ones in table 1 which refer to maximum potential working speed.

Similarily <u>utilization rates of production capacities</u> should give some insight on the economic performances of the firms and consequently on their ability to choose innovated capital goods timely.

The combination of learning and economic factors is likely to depend upon the national economy considered. But lack of information forced us to pool the data in one inter-country model. The least-squares-with dummy variables (LSDV) method is a commonly used method of pooling, where dummy variables for each country will help to account for the discrepancy between national models.

Thus pooling the observations of the 16 countries over 8 years, we estimated the following basic equation [2] :

$$[2] \qquad m = m0 + a\begin{cases}PRO\\TREND\\D1\end{cases} + b_1\ UTRAD + b_2\ Q1 + b_3\ IR + c\begin{cases}NATIONAL\\DUMMIES\end{cases}$$

The variables are defined in Table 6. All data for the USA, Hong kong, Japan, Korea, India, Taiwan, Belgium, Germany, France, Italy, Spain, Sweden, Switzerland, Netherland, Austria, UK over the period 1977-1984 comes from the annual statistical surveys of the ITMF (International Textile Manufacturers Federation).

Table 7 shows an array of tests of different versions of the above equations which take into account the different specifications proposed for the basic model (*). All the results appear to be satisfactory in terms of total explained variance (as measured by R2), levels of significance of each variable (as measured by Student's t) and autocorrelation levels (as measured by D.W. values).

The probability of modernization, m(t), thus appears to depend upon :

1°) <u>national factors</u>.

Only four out of the sixteen national dummies were found to be significant. They correspond to the cases of Asian countries : Japan, Korea, Taiwan and India (with the noticeable exception of Hong Kong).

In these Asian countries the chance of modernization is, ceteris paribus, significantly lower than in the other 12 countries (as their coefficients are all negative).

(*) m(t) takes values which are always between [0,1]. A logistic transformation on m to release this constraint does not change the significance levels of the variables much. We present the linear estimates to facilitate further use of the m estimate in simulations of the diffusion process.

TABLE 6 - CONTENT OF YEARLY VARIABLES IN EQUATION [2]

m : the chance of adopting a new capital good instead of a traditional one as measured by the ratio of shuttle-less looms to total looms purchased during year t and weighted by their potential output (cf Table 2).

TREND: the time trend measured as 1 for 1977 ... 8 for 1984.

D1 : diffusion level of shuttle-less looms with one year lag (cf Table 3).

Q1 : rate of growth of textile industry output with one year lag.

UTRAD: utilization level of traditional looms installed, as measured by the ratio of active shuttle looms on total shuttle looms installed.

IR : ratio of new capacities installed, (i.e. total looms purchased in the current year weighted by their potential output (see table 1)) over the total of installed capacities (noted B(t) in section III).

PRO : current ratio of knots per minute per money unit of capital between shuttle-less and shuttle looms.

TABLE 7

A POOLING MODEL OF MODERNIZATION
(16 countries over 8 years)

t of Student in brackets

Dependant variable : modernization probability m	I	II	III	IV	V	VI	VII	VIII
CONSTANT	.5697 (4.23)	.5151 (4.03)	.5166 (3.58)	.4759 (3.35)	.8678 (31.7)	.8541 (31.9)	.8516 (30.8)	.8432 (31.3)
DUMMY Japan	-.3180 (6.75)	-.3305 (7.52)	-.3182 (6.57)	-.3274 (7.07)	-.2980 (5.45)	-.2920 (5.72)	-.3016 (5.62)	-.2942 (5.84)
DUMMY Korea	-.6672 (12.4)	-.6757 (14.01)	-.6629 (12.5)	-.6677 (13.2)	-.6665 (11.5)	-.6539 (12.0)	-.6894 (12.0)	-.6754 (12.4)
DUMMY Taïwan	-.1830 (3.88)	-.1945 (4.43)	-.1822 (3.76)	-.1905 (4.13)	-.1656 (3.03)	-.1594 (3.12)	-.1799 (3.33)	-.1707 (3.37)
DUMMY India (1)	-.7504 (15.4)	-.7572 (16.7)	-.7502 (15.0)	-.7544 (15.8)	-.7307 (12.6)	-.7176 (13.1)	-.7485 (13.0)	-.7350 (13.5)
TREND (1 for 1977,..., 8 for 1984)	.02725 (5.19)	.0301 (3.30)	-	-	-	-	-	-
Level of diffusion D_{t-1}	-	-	-	-	.1511 (1.94)	.1940 (2.36)	.08323 (1.02)	.1170 (1.30)
EXPECTED CURRENT PROFITABILITY OF LOOMS PRO	-	-	.4633 (4.37)	.4727 (3.97)	-	-	-	-
Utilization rate of traditional capacities, UTRAD	.2062 (1.49)	.2704 (2.05)	.1964 (1.33)	.2501 (1.80)	-	-	-	-
Growth rate of textile industry output (2), year (t-1)Q1	-.1474 (1.47)	-.08997 (.92)	-.2030 (2.01)	-.1656 (1.65)	-	-	-	-
(New capacities installed/overall capacity) IR	.4952 (2.16)	.3755 (1.66)	.5750 (2.46)	.4920 (2.10)	-	-	.6418 (2.42)	.5396 (1.98)
n	128	109(3)	128	109(3)	128	109(3)	128	109(3)
σ	.1277	.1176	.1313	.1237	.1465	.1361	.1437	.1342
$\bar{R}^2$	.804	.841	.793	.824	.743	.787	.752	.793
DW	1.83	1.60	1.87	1.69	1.75	1.67	1.77	1.66

(1) The other countries (for which dummy variables are not significative at 10 % level) are : Hong-Kong, USA, UK, Germany, France, Italy, Spain, Sweden, Netherlands, Austria, Belgium and Switzerland.

(2) Using growth rate of GDP at constant prices gives approximately the same résults : negative sign, weak significance, close coefficient value and relative stability of the other explanatory variables.

(3) Observations where m has reached .99 are omitted here.

2°) <u>Factors related to the learning processes</u>. As expected the three indicators, which we considered, are too highly correlated to be used simultaneously (1) although they all display significant and positive effects on the rate of adoption : the time span elapsed from the introduction of shuttle-less looms (variable TREND in equations I and II), the level of diffusion at (t-1) which accounts for the spread of experience (variable D1 in equations V to VIII), the current expected profitability of shuttle-less looms (variable PRO in equations III and IV). Let us mention, here, that the time variable does not stand for a discriminant of a pre and post 1981 recession period as a pre-1981/post 1981 dummy has not been found to be significant.

Effects of macroeconomic variables can be added to these effects of learning processes on the diffusion.

3°) <u>Macroeconomic variables</u>.

Under this heading we have tested simultaneously the effects of utilization levels, of production growth rates and of investment efforts.

Factors linked with the actual situation of firms such as <u>the level of utilization of installed production capacity</u> turn out to be significant, more precisely. Right levels of utilization of installed traditional capacities reinforce the probability of modernization (see UTRAD in equations I, II, III, IV).

The positive effect of the rate of utilization of installed capacity confirms our hypothesis regarding the role of actual economic performance in modernization behaviour.

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(1) As can be seen from the correlation matrix :

	M	PRO	TREND	D1	Q1	IR	UTRAD
M	1						
PRO	.20740	1					
TREND	.24166	.91330	1				
DT	.53961	.44237	.48012	1			
Q1	-.23120	-.14294	-.21727	-.22948	1		
IR	.12146	.18624	.21361	.31440	.093297	1	
UTRAD	.35228	-.12100	-.11587	.23746	-.056366	.0088045	1

The growth rate of textile industry output has no significative influence. Only the one year lagged variable Q1 appears to act significantly upon the probability of modernization. This result suggests that a failure inducement model of modernization could have some relevance in the cotton industry (ROSENBERG 1976, ANTONELLI, 1987). According to this failure inducement model, firms are pushed to change their production process and to adopt a new capital good when falls in the production levels of the industry cause economic distress. This is in keeping with the MARCH and SIMON (1958, p. 183) prediction that : "The rate of innovation is likely to increase when changes in the environment make the existing organizational procedures unsatisfactory". The significance of this variable is weak, due to a slight colinearity with the other environment variables. By all means, in our case, the hypothesis of failure inducement effect remains very tentative.

The effect of new capacity installed as a percentage of total capacity is meant to be related with expectations regarding future markets. Though it is a crude indicator of investment effort, this variable significantly displays the expected positive sign, and confirms that the flow of investment plays a major role in influencing the probability of adoption of innovated capital goods.

4°) Finally it should be noted that, if we omit observations, where m(t) the probability of adoption, has reached the value of .99 (supposed to mark the point where there is no difference between modern or traditional machines), the total explained variance R2 has a significant increase, while the effect of investment rate lessens (see equations II, IV, VIII). It indicates that countries with high investment rates tend to retain only modern equipments. The other effects remain approximately unchanged.

V - DIFFUSION PATTERNS AND MODERNIZATION BEHAVIOURS

We can now turn to the diffusion process. Equation (8) shows how to share between various contributing factors to the diffusion process, i.e. how the probability m(t) to opt for a modern equipment when a firm is investing, affects the speed of diffusion, besides the effects of changes in capital stocks.

To assess this relationship between diffusion levels Dt and modernization probability mt under different conditions of investment we have made four simulations using our estimations of modernization laws in the case of the textile industry (see Table 8). In the sample of four countries we have two European countries and two Asian countries displaying a national effect (dummy variables are significative). In both sub groups we find countries with opposite trends in investment. Two countries, France and Italy, start with an high level of diffusion and although they display opposite trends in investment, their diffusion curves are constantly increasing and concave and they close up with their asymptote after 25 years. The two other countries (Japan and Taiwan) display an S-shape curve, which may be due to the low value of the probability to modernize. These simulations underline the differences in the outlook of diffusion processes between countries where the probability to modernize increases in keeping with the levels of diffusion and countries where the probability to modernize is from the start very high.

Our comparative analysis of the probability of opting for modern machines in the case of the textile industry has shown that the process of modernization did not reach the same stage or was not uniform among countries. At the beginning of our survey this probability was already very high (over 80 %) in the U.S.A. and in most European countries. But it remained at a rather low level in most Asian countries, Japan included. Over the eight years of the study the process, whereby choice in favor of new machines became the only rule, was fully completed in Europe and in the U.S.A., as well as in three Asian countries (Hong Kong, Taiwan, Japon). Only Korea and chiefly India lagged behind. This "catching-up" was not only a learning

TABLE 8
DIFFUSION PROCESSES :
ASSUMPTIONS MADE IN THE FOUR SIMULATIONS PRESENTED IN FIGURE 1

A1) Simulations of the diffusion process have been done for four countries, France, Italy, Taiwan, Japan using equation (8) (cf. page 12).

A2) Simulations have been done over 40 periods, starting with the observed initial levels of diffusion D(1). In all runs rather low scrapping rates of 1 % have been taken for modern equipment (i.e. $\lambda^* = 0.99$).

A3) m_t follows the equation V estimated in table 6, except for Japan : for this country, we have taken observations for t = 1,8 and not fitted values because the estimate was not good enough at the beginning of the process.

A4) We have taken a constant (ratio) K_{t-1} / K_t, calculated from the mean of observed annual capacities growth between 1977 and 1984.

A5) We have set $\bar{\lambda}$ in order to reach at t=8 the same level of diffusion D than observed in 1984.

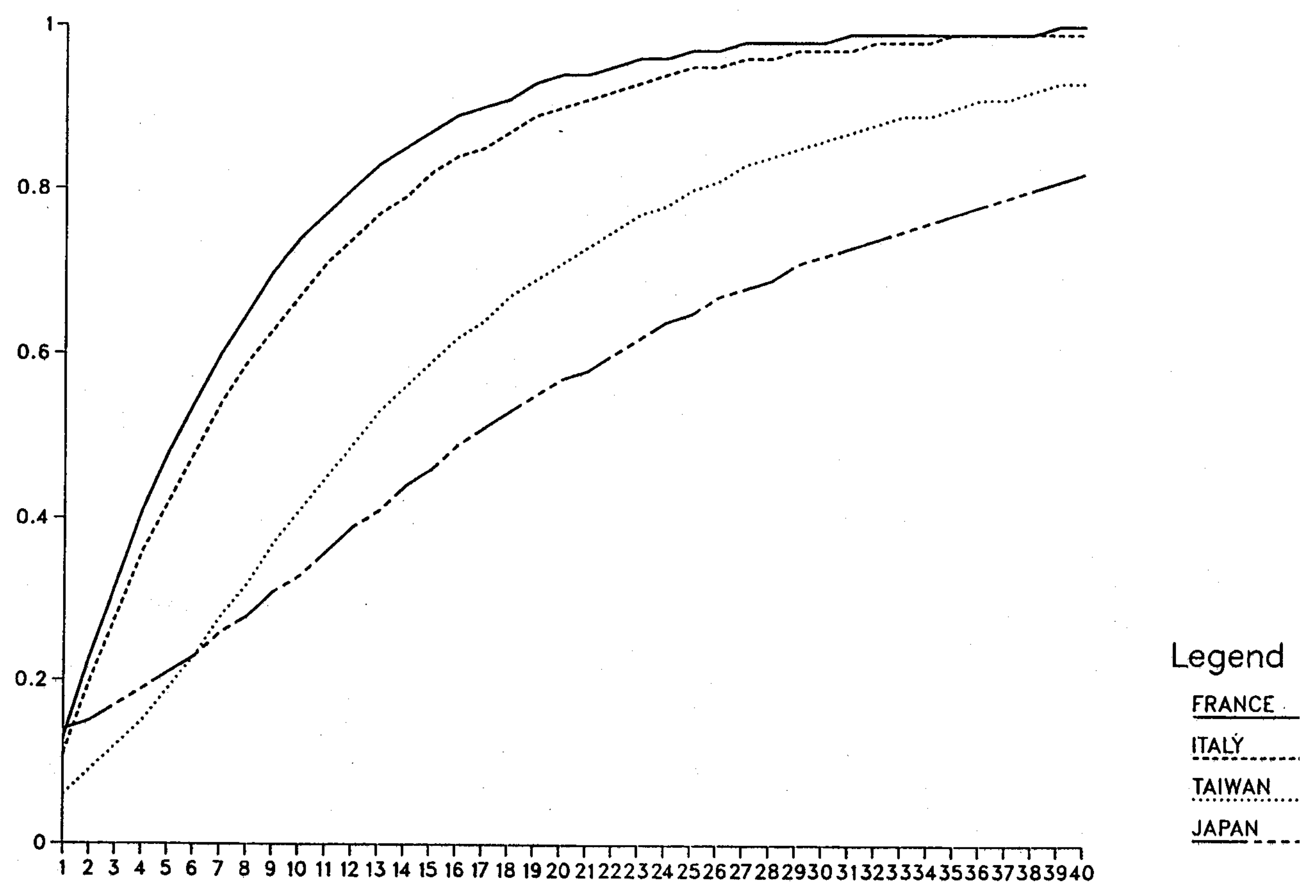
COUNTRY	D(1)	$\frac{K_{t-1}}{K_t}$	λ^*	$\bar{\lambda}$
FRANCE	.13	1.02	.99	.85
ITALY	.11	.96	.99	.92
TAIWAN	.06	.95	.99	.98
JAPAN	.14	1.03	.99	.93

process dependant on time but involved what we have called environmental variables, i.e. the economic conditions of the firms. Our estimates suggest that both the booming phases of the business cycles (as measured through capacity utilisation rates) and expectations about future markets (as revealed through current efforts of investment) spurred the frequency of adoption of new machines. The hypothesis of possible failure inducement, i.e. the fact that noticeably bad economic performances could stimulate and not hinder modernization, remains open to further investigations.

Before drawing some general conclusions one should, as a warning, mention some of the initial limits of our analysis of modernization of the textile industry. First of all we have considered only one stage of the production process namely weaving. The strategies may widely differ from one stage to the other according to the country factor, costs and access to the markets. So only further investigations on the other stages of production could really lead to an analysis of the modernization of the textile industry. Secondly our approach was strictly concerned with incorporated technical change, as expressed by investment which assumes that forms of non incorporated technical change were uniformily widespread and had negligible effect on the firm's modernisation behaviour.

The model proposed and the econometric estimates confirm that modernization behaviour must be considered as the combined outcome of both learning processes and macroeconomic factors. More specifically it showed that the macroeconomic determinants of the diffusion of new techniques relate both to the rhythm of investment and to the level of utilization of installed production capacity. Only a combination of these two dimensions i.e. the "traditional" microeconomic determinants and the macroeconomic factors can help us to understand the dynamic of productivity gains.

FIG. 1
DIFFUSION PATTERNS UNDER VARIOUS ASSUMPTIONS
ON MODERNIZATION BEHAVIOURS



Diffusion of new techniques lead directly to higher levels of productivity. In turn these gains in productivity have two types of effect. On the one hand they can have a demonstrating effect on the investment behaviours of firms, on the other hand they can contribute to stimulate overall demand in a general way as is assumed in a cumulative growth model (see PETIT, TAHAR, 1985) which tends to press in favor of more investment. Both factors lead to a boost in the diffusion of new techniques. Policy makers are more acquainted with the effect of investment on production and employment than with the impact of their action on modernization behaviours themselves. This paper has tried to show that both factors channelling modernization -i.e. macroeconomic investment rhythm and microeconomic behaviours of firms- can be helpfully disentangled and monitored. Further research and measures could help to balance the advantages of these respective ways of speeding up or of slowing down modernization.

BIBLIOGRAPHY

ANTONELLI C. (1986)
The international diffusion of process innovations and the neotechnology theory of international trade.
Economic Notes, Vol. 15, N°1.

ANTONELLI C. (1987)
A failure inducement model of research and development expenditures, the Italian evidence in the early eighties.
Working document, Politecnico di Milano.

DAVID P.A., OLSEN T.E. (1986)
Equilibrium dynamics of diffusion when incremental technological innovations are foreseen.
Stanford University, Center for Economic Policy Research, Working Paper N° 9.

DAVIES S. (1979)
The diffusion process innovations.
Cambridge University Press.

GRILICHES Z. (1957)
Hybrid case : an exploration in the economics of technological change.
Econometrica, October.

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

MARCH P., SIMON R. (1958)
Organization.
Wiley & Sons, New York.

NELSON R., WINTER S. (1982)
An Evolutionary Approach of Economic Change.
Cambridge, Belknapp Press.

PETIT P., TAHAR G. (1985)
La relation automatisation-emploi, effet productivité et effet-qualité.
Working Paper, CEPREMAP N° 8520.

PETIT P., TAHAR G. (1986)
Dynamics of technological change and schemes of diffusion.
Working Paper CEPREMAP N° 8713.

ROMEO A.A. (1975)
Interindustry and interfirm differences in the rate of diffusion of an innovation.
Review of Economics and Statistics, August.

ROMEO A.A. (1977)
The rate of imitation of a capital embodied process innovation
Economica, February.

ROSENBERG N. (1969)
The Direction of Technological Change : Inducement Mecanisms and Focusing Devices.
Economic Development and Cultural Change, reprinted in ROSENBERG (1976).

ROSENBERG N. (1976)
Perspectives on Technology.
Cambridge University Press.

SCHMOOKLER J. (1966)
Invention and Economic Growth.
Harvard University Press.

STONEMAN P. (1983)
The Economic Analysis of Technological Change.
Oxford University Press.