# Innovation direction and persistence within an industry: the refining processes case.

(Draft version- Not to be quoted)

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1st May 1999

Abstract

This paper examines the low persistent innovative behavior results from Geroski et al, in relationship to the direction and intensity of technical change at a sectorial level. Within the refining processes supply industry, incremental and major innovation cases are focused from two full and reduced data files. The specific observed low persistent innovative behavior is referred to some first explaining factors: technical specialization, cooperation and concentration. Results tend to suggest that only a very small number of large technological portfolio firms may be looked as persistent innovators, despite the existence of a constant flow of new refining processes by small innovating firms.

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## Introduction

Geroski et al (1997) paper has been an important contribution, from patent data bases and at an intersectorial level, to the following debate. Among innovative firm subset, what is the relative importance of the persistent ones? If observed share is rather low, what are their explaining factors, and what are the consequences on the validity of the often quoted 'dynamic economies of scale' or 'success breed success' representation?

Our purpose is to assess the eventual existence of persistent innovative behavior within an industry, the refining process supply industry, which has been most often presented in literature as an industry with a preeminence of many incremental innovations, economies of scale, and cumulative learning effects. That is to say with a presumption of possible persistent innovative behavior.

We assume that within a given technological area and over a long period (50 years) the existence of a relationship, which can be documented at a sectorial level, between intensity, direction of technical change on one side, and persistent innovative behavior on the other side.

In first section, innovation taxonomy issues are recalled, and necessary information are provided on our two empirical data files which are related to two kinds (incremental and major) of innovation in refining processes over the 1947-1998 period. We then try to assess in section 2 intensity and direction shifts of innovation. In section 3 persistent innovative behavior is measured with developed methods by Geroski et al., and some first explaining factors are tested.

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## 1-Technical change measurement issues in refining processes technology

### 1.1- Taxonomy of the different technical change categories in refining processes technology

There is a general consensus about the existence of many different forms and intensity of technical change. Unfortunately not one, but several taxonomies of technical change can be found in the literature. This diversity of classifications reflects on one side the broad range of technical progress forms, with for example intersectorial differences, and on the other side the different dimensions of technical improvements. Scholars in majority only focus with the consequences of technical innovations for firm or industry (for example Schumpeter (1939), Schmookler (1966), Mensch (1979), Freeman and Perez (1990)). For a still small community of authors a larger range of criteria should be taken into account, and should include knowledge, industrial capabilities or skills, equipment or processes (for example see Metcalfe and Reeve, 1991).

Looking for a common framework of all innovative energy technologies, Martin J.M (1998, p.227) relies on that last representation to suggest a new taxonomy, which combines two criteria:

- a criterion dealing with the nature of technical innovation, divided into three categories : "radical" innovations would be innovations dealing with new process of energy conversion, while "major" innovations would be innovations implying change in the knowledge base, and finally incremental innovations would be innovations which introduce new capabilities or skills ,

- a criterion of an historical stage of development of the process of innovation with three stages : Emergence, Consolidation or Strengthening stage, Competition stage.

In the refining industry particular case, a correspondence may be found between this taxonomy and the industry experience of technical change. From the life cycle technology side view, refining technology dynamics which will be presented further on, and which concern the 1949-1998 period, may be more likely referred to the third (competition or maturity) than to the second (strengthening stage). Focusing only on the change of refining processes, which may be looked as the "building blocks" of the refining industry technology[1], and with admitted simplification goals in mind, we may find a corresponding classification of innovations.

-Incremental innovations are numerous and gradual innovations[2], such as in other sectors; but in the long term, as it has been highlighted by Enos (1962) and Ayres (1985), the cumulative impact of such innovation is very high in this industry (cf table 1).

Table 1: Measurements of economic improvements from increased experience in refining technology.

| | a = cost reduction with doubled experience | b= learning elasticity |
|---|---|---|
| - Catalytic cracking from 1946 to 1958 (man hours per barrel) | -10% | 0,15 |
| Petroleum refining( 1860 à 1962) | -15% | 0,25 |
| -Hydrocarbon cracking (1942 – 1959) $/barrel | -20% | 0,32 |

Source: from Ayres (op.cit.) p. 379

These innovations for revised existing processes may concern significant or secondary modifications to existing processes, improved design features, slightly broader range of consistent feedstock, slightly improved characteristics of output products, slightly reduced energy consumption, introduction of a new catalyst, new investment or operating costs,….These improvements may be supplied either during the construction stage, or during the maintenance shut-down stage, either by the engineering/construction company, or by the refining firm. This diversity makes difficult an exhaustive compilation of such numerous improvements, as Freeman (1994)[3] and others have already mentioned.

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[1] Other less important but still meaningful sources of technical change may be found in catalyst technology ( new catalyst for existing or new refining processes), auxiliary equipment improvements, new combination of several existing refining processes , new or improved components of equipments in the existing refining processes, and new or improved control/regulation systems. But many of these elementary improvements are often integrated in the new refining processes.

[2] « *The development of processing methods by our industry may seem quite gradual in normal years, but it is steady-and the progress made over the past several year period since the late 1930's is truly remarkable.*
*Also not apparent, but vitally important, is the constant improvement in the operating processes.* »
Source :Petroleum Refiner 1949, p.113.

[3] Incremental innovations « *go unrecorded and unarticulated in the general process of tacit knowledge, accumulation, learning by doing, using and interacting* » (Freeman, 1994, p.476)

-Major innovations correspond to the emergence of new commercially available refining processes, with proprietary original design or devices. They are often protected by one or more patents, and sold by licensors/owners. From the 1950/1960's these new processes include in most cases a new and fitted catalyst; these new processes generally imply development times of six to ten years and very high R&D costs which cannot be financed by small and medium size refining companies (J.B.Sigaud, 1995). At the world level this kind of innovation is rare: from 1 to 15 yearly. [4]

-Radical innovations are still more rare than major innovations. They may be looked as entirely new "family" of processes. In respect to the oldest processes of distilling and fractionating processes, one may account only one (conversion processes) or more (upgrading, finishing and removing undesirable component processes) radical innovations, depending the relative restriction of the criteria of "entirely new" and the resulting technical nomenclature. During the 1947/1998 period one may find according to the adopted definition of radical innovation, one (hydrocracking in 1958) or two (ethers processes in 1980) such kinds of innovation.

We intend to empirically document the first two categories of the innovation taxonomy, namely incremental and major innovations in refining process case.

### 1.2- A full and reduced sample data files on refining processes technology

In the 1932-1998 period, Hydrocarbon Processing and its 'grand-father' (Refiner & Natural Gasoline Manufacturer) and 'father' (Petroleum Refiner, from 1947) have collected basic information about refining processes. They have compiled each year then every two years, *refining processes of importance to the modern refiner*" (1958 Process handbook, Petroleum Refiner September 1958, p.209) in a refining process handbook. This handbook mainly collects technical data: description of the process, application, charge, products, operating conditions, yields, flow diagram; from the 1960's, some elementary economic (investment cost, utilities consumption, number of installed units) information are complemented on the selected processes. Selected processes by the editorial "Process and construction" board[5], include two very different kinds of refining processes.

- New commercial, and generally proprietary under license, processes are introduced on the market, and identified as such by the editorial board since the previous general compilation (two years on average),

-Older processes, which have been already selected in the previous issue are licensed or unlicensed, and "*are still the backbone of the industry*"(Process Issue-1956, Petroleum Refiner, September 1956, p.199). For these still adopted processes by the refining industry,

[4] The intensity of this category of technical change is however variable according each case, such stated by the Editorial Director of Petroleum Refiner. "*While feed stocks, products, operating conditions, and equipment arrangements are almost endlessly variable, it may be surprising to some to note how uniform are the requirement of processes in regard to equipment components from which they are assembled. The fact is that equipment design for the process industries has reached a high level of development and standardization, and has greatly contributed to the ease with which process designers can assemble their latest process schemes into workable commercial units.*" Source: Petroleum Refiner, 1949 Process Issue, A Foreword, September 1949, p113.

[5] With, then without, the help of industrial advisors of the refining industry: executives, engineers, superintendents of oil and petrochemical companies, engineering and construction companies…

information are updated[6] in the process issue of a given year, due to the incremental innovations or other commercial changes, which are steadily included by process suppliers, and reported in the different Refining Process Handbook.

Focusing on the 1947-1998 period, two distinct files have been constructed from these two subsets of data. The first one, including 262 processes, called "reduced data file" is limited to the compilation of only new refining processes emerging each two years. The second one, called 'full data file', with a cumulated total of 2196 processes, include for each bi-year on one side the new emerging refining processes, and on the other side the other previously existing refining processes which have been selected by the Editorial Board. In other words this full data file may be looked as an bi-yearly inventory of "Best Available Techniques" in refining industry.
In these two files, the main following items define each process:

-"1947 " (first year) code number to identify each commercially new refining process,
-code number of the subfamily of refining process which has been defined from the Heinrich technical nomenclature (see Appendix 1), allowing to document the technical area of the refining process,
-code firm for the company which sells the process[7], including two or more different firm code when there is a cooperation between two or more suppliers, or a new code number when ownership of firm has changed,
-nationality of these firms.

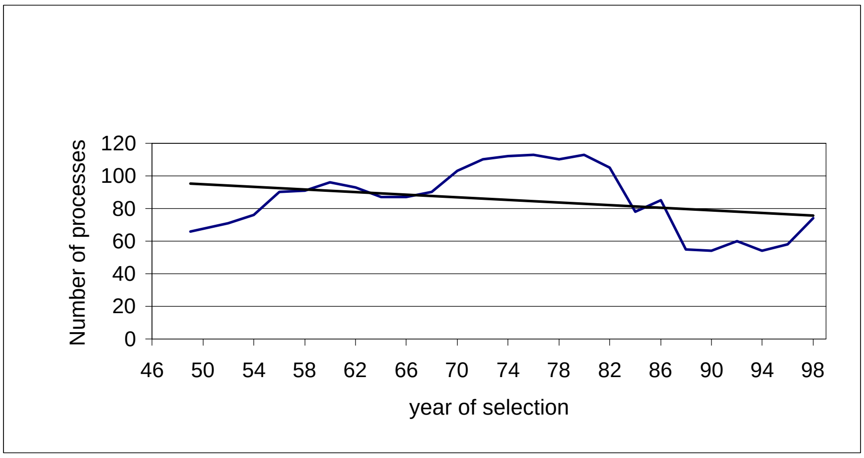
In order to have reliable data on the 1947-1998 period, editorial choices must be understood, and if necessary and when possible, corrected to avoid bias in data processing and interpretation.
Original data have been modified in order to maintain a constant technical area on the 1947-1998 period. Refining processes technology is distinct from petrochemical and gas treatment processes one but close to them in some cases, because the increasing exchanges between refineries and petrochemistry. Focusing only on refining processes, the selected petrochemical and gas treatment processes in the refining handbook have been dropped. This correction has been made until 1952 for petrochemical processes and to 1970 for the gas treatment processes[8].
A different and subtler shift in editorial criteria has occurred between the beginning and the end of period, which has not been corrected in our "full data file". On the 1947-1998 period, one may note an evolution of editorial criteria of selected processes by industrial advisors and the process and construction editor towards stricter ones. In the beginning of period refining handbook editions include a large number of previously existing refining processes in order to give "*a kind of brief process encyclopedia, many of the older processes that are now used less, or not at all, have been included*" (Petroleum Refiner, September 1949, p.67). In the end

[6] In the foreword of the 1982 Refining Process Handbook, the refining editor states than « *of the total refining processes descriptions (84 processes), 88% include updated information-usually investment and utility requirements* ». ( Hoffman H., Handbook to survival, Hydrocarbon processing, September 1982, p.97); updated *Today's process handbook differs from the 1978 version principally in the economics claimed by the licensors*"Source : J.D.Wall, 1980, From the editors: "Tomorrow, and tomorrow, and tomorrow…", Hydrocarbon Processing , September 1980, p.89.
[7] Technical editors precise in each refining process issue that information sources come from two very different kinds of firms i) for the great majority of under license processes the concerned company is the only licensor, ii) for the small minority of unlicensed processes the selected contributor company " *may not the only one qualified to design and construct the process*".
[8] The first dedicated Petrochemical Handbook has been printed since November 1953, and the first Gas Handbook since April 1971.

of period, this objective has evolved to a closed one but not equivalent of a directory of" *typical processes used by modern refineries*"(Hydrocarbon Processing, Nov 1998, vol. 77 p.3). As a consequence selected processes are less numerous than in the beginning. This trend may result either from a smaller number of new processes each bi-year, and or from a smaller number of existing processes which are selected.

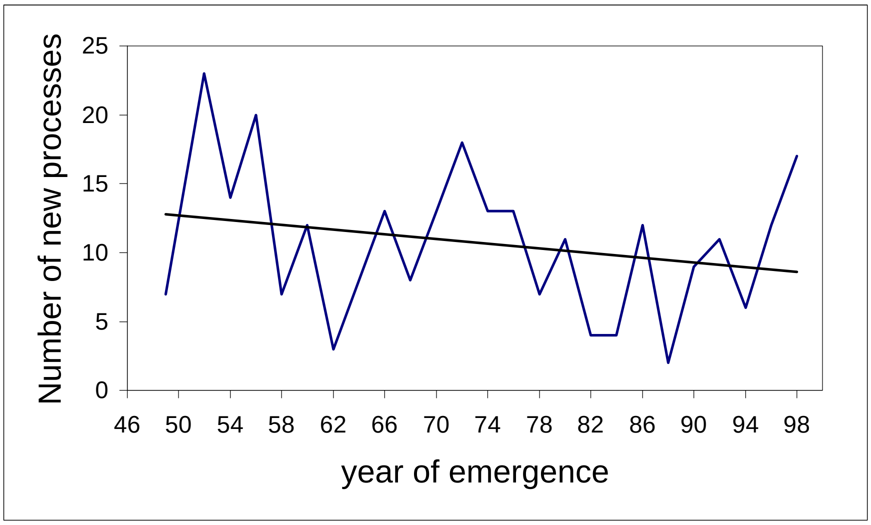
The two following graphs bring some more details on the yearly number of refining processes in the full and reduced data. The evolution appears to be a decrease over time in both full and reduces data files.If the reduced number of selected processes is not mainly resulting from a corresponding change in the new refining processes which are precisely and faithfully documented, then the change is concerning more the older processes which are dropped more often in the end of the period than at the beginning. This bias has not been corrected.

Graph 1: Number of processes according to the year of selection 1949-1998




Source : authors from the full data file.

Graph 2: Number of new processes according to the year of emergence 1949/1998




Source : authors from the reduced data file.

Yet this trend can hardly be taken as an evidence of the maturing situation of the refining industry for two reasons:

- First there have been shifts in the criteria of selection of the processes by the experts and editorial board of the Handbook, and this resulted in a more restrictive definition of the eligible processes.
- Second a closer look at the slopes of the trends shows that they do not significantly depart from zero. –0.40 slope in the full data set with t=-1.48 and –0.09 slope in the reduced data with t=-1.17)

The general aspect of the curves backs the idea of successive waves of innovation, these also appear in the next paragraph where the direction of change is examined.

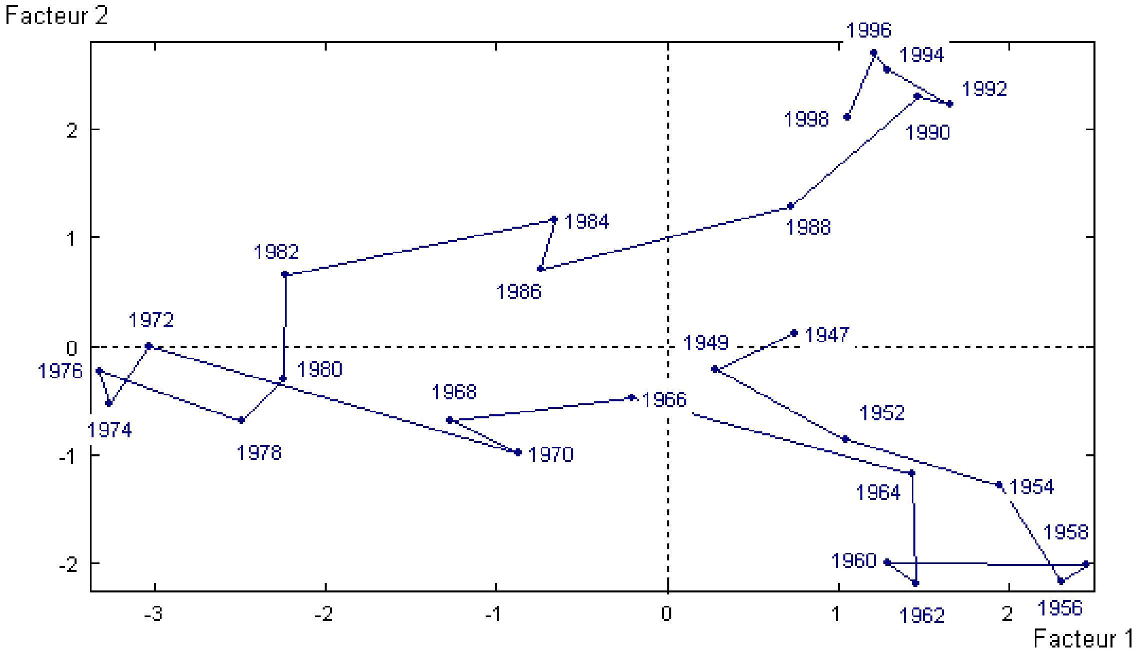
## 2- Direction of technical change in refining processes long term evolution

### 2.1- Assessment of trends

#### 2.1.1- Trends from the full data file

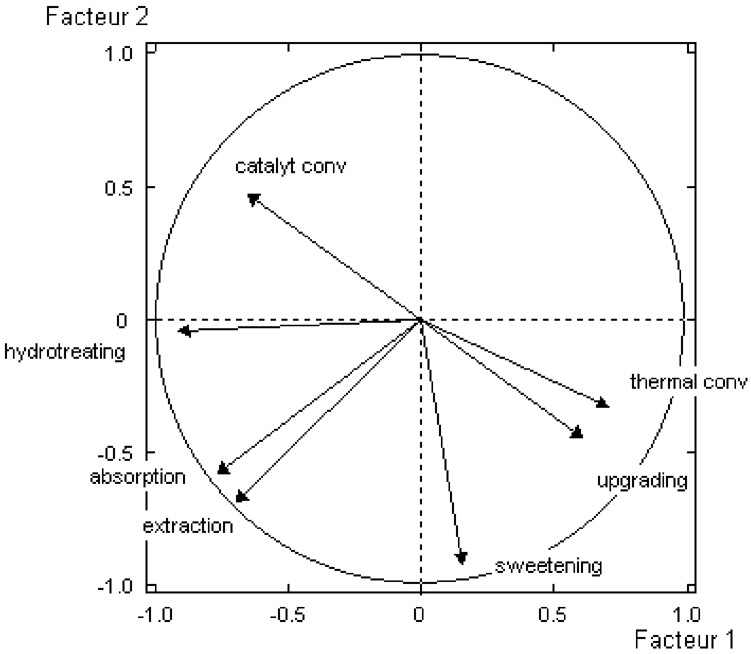
In view to assess the evolution of the technologies provided by innovative firms to the refining industry it is useful to describe the main kinds of techniques proposed over time. The technological path can be depicted in terms of the main families implemented according to the Heinrich classification (given in appendix). As time goes on, used techniques gradually change and these changes provide a good picture of the evolution.

We used the Principal Component Analysis to assess and give an overview of the phenomenon. This data analysis tool was applied to the full data set, but it did not prove useful for the reduced data set, because the too small number of data. The results of this PCA are very robust, since the two first principal component account for 80% of the whole data momentum. This result is reached using normalized as well as non-normalized PCA, and keeping or dropping the year 1947 does not change really the results.
The three groups of "years" which emerge from graph 3 are well represented in the first plane; and so are all the variables in graph 4. The two graphs below give a sketchy presentation of the technological path of innovations and of the main technical families of innovation which influence this path.



Source : authors-Principal component analysis from the full data file.

Graph 4: Heinrich technical “families” in the definition of the two first principal components




Source : authors.

One can derive from them (and from the tables where accurate characteristics justify them) that the evolution follows three main stages, with a fast pace between them.

First stage: 1954 to 1964: is a period with a strong influence of the technical families “thermal conversion” and “upgrading”. After a transition from 1966 to 1970 a second stage appears from 1972 to 1980. In this period the main feature is the development of innovations in the families “absorption” and “hydrotreating”. A new transition happens from 1982 to 1988. And finally a third stage is reached from 1988 to 1998. In this period no particular family seems to influence the landscape of innovation. It should rather be understood like a phase of diversification in various technical families. The influence of the “sweetening” techniques was anticipated but it does not appear in fact. The pieces of information brought by the third principal component do not allow any convincing interpretation.

**212- Trends from the reduced data file**

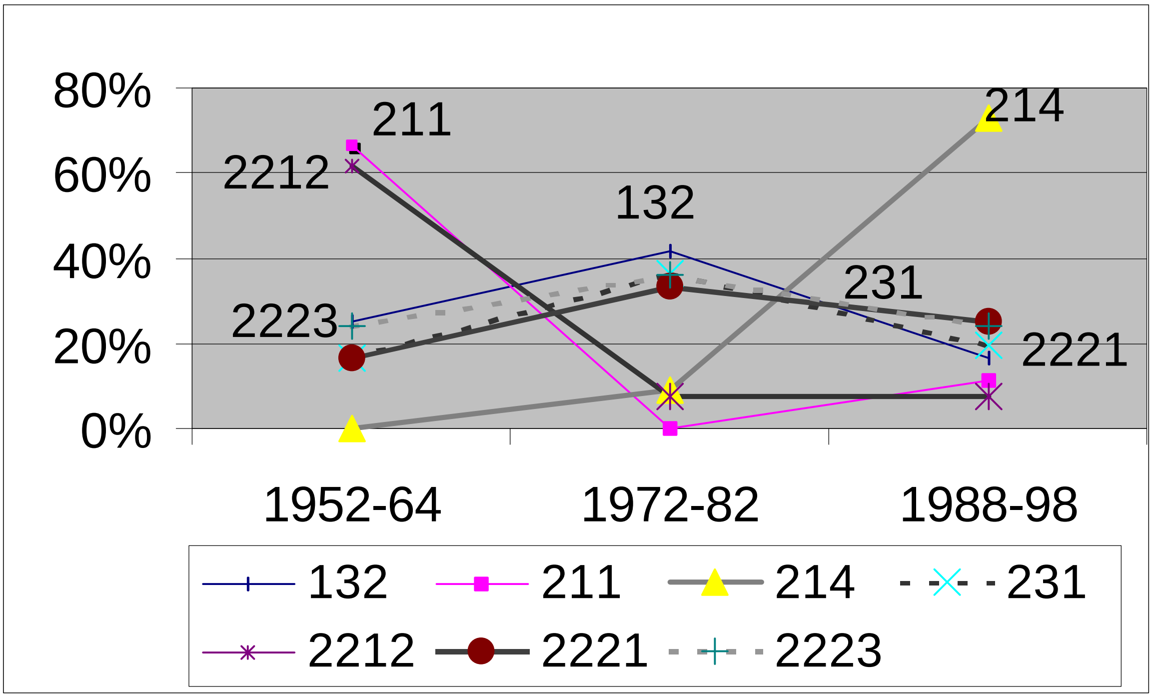
From the reduced data file, one may try to assess the historical breakdown of these new refining processes according to their technical area (Heinrich nomenclature, appendix 1).

Firstly we observe than on the 37 theoretically possible Heinrich classes, there are 0 innovation in the 9 following ones: 2110 (Thermal reforming), 2213 (Steam reforming, by construction because their classification in petrochemical processes), 2215 (Thermal reforming & thermal cracking), 2224 (Catalytic conversion with fixed bed process), 233 (

Molding-packaging, storing), 234 (Chlorine refining without hydrogen), 2411 (Acid gas treating- H2S recovery) and 2412 ( Acid gas treating-sulfur recovery), by construction because their classification in gas treatment process, or environmental processes. If one excludes these classification artifacts, remaining classes are from the end of 1940's mainly obsolete processes (thermal conversion, or fixed bed catalytic conversion process).

More precisely on the 269 innovations of the 1949/1998 period, we focus only on the most important 7 subclasses, which represent a total of 169 (63%). Using the three sub periods (1952-1964, 1972-1982, 1988-1998) of relative stability which have been found in the previous PCA analysis, we assess their relative share in the total of innovations by Heinrich class on the full period (1949/1998).

Graph5: Breakdown of different classes of new refining processes by sub-periods in relation to the total number of innovation per class on the 1949/1998 period.




Legend: 132:solvent refining, 211: catalytic reforming, 214: ethers (MTBE, ETBE,TAME), 231: hydrotreating, 2212: thermal coking, 2221: fluid catalytic cracking, 2223: hydrocracking.
Source : authors from reduced data file.

This graph shows very contrasted development paths of each of these 7 classes.

-Two classes 211 (catalytic reforming accounting for 14 innovations during the 3 sub periods out of a total of 18 over the 1949/1998 period) and 2212 ( thermal coking accounting for 10 innovations during the three sub periods out of a total of 13 on the 1949/1998 period) display a sharp decreasing trend.

-One class 214 (ethers (MTBE, ETBE, TAME) accounting for 9 innovations during the 3 sub periods out of a total of 11 on the 1949/1998 period) is almost exclusively concentrated in the third sub-period.

- The four remaining classes (132 (solvent refining), 231(hydrotreating), 2221(fluid catalytic cracking), and 2223 (hydrocracking) account for a cumulated 98 innovations during the three sub periods out of a cumulated total of 127 over 1949/1998) display a much more stable historical path, despite the relative peak of 1972-1982.

## 2.2. Some likely explaining factors of these direction trends

Although the technical change direction results from full and reduced data files are not identical, their proximity invites to look for some common explaining factors of their shifts. We intend to only present here speculative arguments of which some later on could be quantified and tested.
The selected refining processes on one side (full data), and the new refining processes on the other side (reduced data file) may be linked to a specific development path of refining industry, and to the shifts of this path introduced by the modifications of the selection environment.
Regarding the specific development path of oil refineries, one may in a first attempt refer to industry expert's assessments. "*It is interesting to observe how in the course of its history, refining has been built up in successive strata in order to provide the appropriate answer to changes in demand or in specifications. The refining structure is expanded at each stage by new complementary units, which do not fundamentally affect earlier investment. These successive strata are still present and still make substantial contributions to meeting requirements* " (J.P. Gaessler, 1994, p.60). Therefore refinery units evolve more by addition of new equipment than by substitution of older processes by more recent ones, without excluding that possibility[9]. One important example of this last effect, which clearly appears in the PCA analysis of the full data file and in the reduced data file with the steep decline of thermal conversion processes (2212 class), is represented for example by substitution in the 1940/1960's of thermal cracking processes by catalytic cracking ones.

Shifts in the selection environment of industry are larger and more complex than the only market ones. They are not independent from science and technology push, such as the new opportunities for process designers stemming from new zeolithe catalysts, new chemical compound (MTBE), which contribute to explain the dramatic increase of Heinrich class 214: ethers (MTBE, ETBE, TAME). This last example is a good illustration of the combined play of science push and market pull factors, as we show later on the influence of environment selection shifts.
By which national refining industry, selection environment changes in refining processes are mostly influenced? US seems to be one of the most prominent one's, because it's recognized double leadership:

- leadership on refining technological supply side, which begins to be challenged by European competitors only from the 1960/1970's,
- leadership or "advances" in the demand/market side, which is mainly revealed by the relative share of motor fuels consumption, and their specifications in respect to the others world regions.

These US advances result in a much higher complexity index[10] of US refining industry to the rest of the world, and therefore in a much higher capital cost of capacity increase [11]. These last

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[9] This trend could be precisely checked, with a Saviotti's method of technology variety analysis, by using an appropriate statistical measure of the technical characteristics of each refining process.
[10] Index of refinery complexity can be measured by the rate of equivalent conversion capacity to the distillation capacity, both expressed in barrel/day of installed capacity. The higher relative share of gasoline in petroleum products, the higher the share of conversion units in refinery, and the higher the complexity index.
[11] « *The capital expenditure related to the increase in refining capacity for the United States is two or three times as much as for capacity outside the United States. Using data from 1969, a capacity increase in the United States costs about 2000$ per daily barrel as compared to an average cost outside the United States of less than 800$.* « Hydrocarbon Processing, September 1970, p.164.

shifts in market side are at the origin of continually improved (ex hydrotreatments) or" radically " new processes such as hydrocracking (2223 Heinrich class) or ethers processes (214 Heinrich class). Among the major shifts in refining environment selection industry have faced higher crude oil prices, lighter barrel, gasoline with an higher octane number, and a reduced petroleum products demand in US and Europe from the beginning of eighties. One of the most important shift occurs at the beginning of the 1970's in US with tougher regulation standards on environment. New specifications on gasoline[12], from a complex compromise between motor car industry and public authorities, result in a big push given to new or revamped processes such as alkylation, etherification (MTBE), hydrotreating.

So to conclude, this first analysis tends to suggest on one side idea of "wave innovations" which are pulled in three sub periods by high development in some very precised technical areas, and on the other side a closed link between these temporary focuses and market issues and needs of the refining industry.

## 3- Firms persistence in the supply of innovating refining processes

Persistence includes two components grasped in the idea of a flow of processes over time. A persistent innovative firm will produce "new" processes continuously, year after year. But these processes may be new because they are major innovations or because they bring incremental innovations. The existence of technical reviews in the field of refining industries makes it possible if not easy to document both types of innovation. In this framework we used the Handbook of refining processes that was presented above (section 12). Thus we had access to a list of processes over time; experts set up this list so that the selection of a process ascertains its importance among the implemented technologies by user firms. Indeed this list is only established every other year, but this is not a serious hindrance and we shall call "year" every other year. The definition of the processes concerned in the research is thus sometimes wider in terms of novelty (full data set), and sometimes narrower (reduced data set). The type of definition used is always made clear in the text below.

In this framework we made an attempt to test the following assumption relating to the innovative firms dynamics and their behaviour in terms of evolution. This assumption, often put forward in the literature and especially by Geroski (1997) is that firms who produce technical processes will be more persistent (as innovative firms year after year) as they will have produced more new processes in the first year of a continuous set of years. It is the assumption that "success breeds success". This assumption includes the idea that innovation within firms being a cumulative process over time. It is justified by the quality of research teams, the good anticipation of the directions of successful technological development for the user firms, the dynamic of organisation and the snow ball effect in know-how.

Our results are given first for the full data set, and second for the reduced data set. In both cases the period of time expands from 1949 and 1998. In fact the first year of observation was 1947, but since it is the first year all processes appear to be new, it was considered this

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[12] « *Refiners are forced to find substitutes for the decreased use of lead antiknock additives. The first step has been to increase processing severity with its consequent reduction in gasoline yield. Now specific hydrocarbons are being made and diverted into motor fuel blends. These include alcohols and ethers.*» Hydrocrabon Processing, September 1980, p.94

novelty had little meaning, we only took in consideration the flow of processes selected during the following years.

**311. Firms persistence according to the "wide " definition of innovative firms**

* Distribution of spells
Over the period, 82 firms produced altogether 2074 processes that were selected in the handbook. They give birth to 96 sets of continuous selections, that is 96 spells. Each spell includes from one to 246 processes over the period, with a maximum of 15 processes for a spell in one year.

Table 2: Distribution of the spells according to their duration

| Spells duration (years) | Number of spells | % | Spells duration (years) | Number of spells | % |
|---|---|---|---|---|---|
| 1 | 21 | 22% | 13 | 2 | 2% |
| 2 | 17 | 18% | 14 | 1 | 1% |
| 3 | 7 | 7% | 15 | 3 | 3% |
| 4 | 3 | 3% | 16 | 2 | 2% |
| 5 | 6 | 6% | 17 | 1 | 1% |
| 6 | 3 | 3% | 18 | 1 | 1% |
| 7 | 4 | 4% | 19 | 2 | 2% |
| 8 | 3 | 3% | 20 | 2 | 2% |
| 9 | 5 | 5% | 23 | 1 | 1% |
| 10 | 4 | 4% | 24 | 3 | 3% |
| 12 | 1 | 1% | 26 | 4 | 4% |
| | | | | 96 | 100% |

Source: authors from the full data set

The distribution of spells according to their duration is skewed (coefficient 2.6) but the tail of the distribution is rather thick because of 7 spells lasting over almost the whole time span (24 and 26 "years"). These spells refer to "major" innovative firms with processes in various technological families of refining processes, these firms manage real portfolios of processes.
At the other end of the distribution shorter spells refer mainly to firms coming up only for one year and eventually two or three, but who are not selected most of the time. It can be noticed that the firms with the shortest spells especially come up in the eighties and nineties.

*Survival rates of the spells and the cumulative assumption

We reckoned the survival rates of the selected firms as innovators combining the spell duration with the number of processes in the first year of the spell.
The number of processes selected in the first year ranges from 1 to 9. Yet the relatively small number of spells recorded compels us to collapse dramatically the classes in order to produce significantly different rates of survival, as shown in the table below. Indeed 23 spells start with 2 or 3 processes in the first year, and 12 spells start with 4 processes or more.

Table 3: Survival rates of spells according to their duration in years

| | Number of selected processes in the first year | | |
|---|---|---|---|
| Spell duration | 1 | 2 or more | all |
| 2 | 0.72 | 0.89 | 0.78 |
| 4 | 0.43 | 0.71 | 0.53 |
| 7 | 0.28 | 0.63 | 0.41 |
| 10 | 0.20 | 0.43 | 0.28 |
| 15 | 0.11 | 0.34 | 0.20 |
| 20 | 0.03 | 0.23 | 0.10 |
| | | | |
| Total count | 61 | 35 | 96 |

Source: authors from the full data set

The result is a clear difference between survival rates of the spells in the first column (1 process in the first year) and those in the second column (2 processes or more). Yet the assumption we started from is more demanding than that, it states an increase in the rate of survival (for a given duration of the spells) as the number of processes in the first year increases. The small size of the data does not allow testing it accurately.

**312-. Persistence of innovative firms in the reduced data file**

If one keeps only the processes in the first year of their selection in the handbook that is if working with the reduced data set: only 77 firms are kept. The number of spell (116) is slightly larger than previously. This is counterintuitive but it comes from the fact that fewer processes are accounted for and thus shorter spells can be more numerous. The table below shows this shorter duration of spells.

Table 4: Distribution of the spells according to their duration

| Duration (years) | Number of spells | % |
|---|---|---|
| 1 | 80 | 69% |
| 2 | 12 | 10% |
| 3 | 11 | 9% |
| 4 | 4 | 3% |
| 5 | 5 | 4% |
| 7 | 2 | 2% |
| 11 | 2 | 2% |
| Any duration | 116 | 100% |

Source: authors from the reduced data set

Table 5: Survival rates of spells according to their duration in years

| Rate of survival | Number of new processes first year of the spell | | |
|---|---|---|---|
| Duration (years) | 1 | 2 or more | Total |
| 1 | | | |
| 2 | 0.286 | 0.375 | 0.310 |
| 3 | 0.214 | 0.188 | 0.207 |
| 4 | 0.095 | 0.156 | 0.112 |
| 5 | 0.071 | 0.094 | 0.078 |
| 7 | 0.036 | 0.031 | 0.034 |
| 11 | 0.012 | 0.031 | 0.017 |
| | | | |
| Total count | 84 | 32 | 116 |

Source: authors from the reduced data set

The rates of survival of the spells beyond the first year do not show as large a difference as previously when compared according to the number of processes in the first year. Unfortunately this is due to the small number of observations.

Conclusions

Trying to compare our results with those put forward by Geroski (1997) one should be cautious since the definitions and the nature of the data are quite different. In his work firms qualify as innovators on the basis of patents, the set of observations is much wider in terms of number of industries and especially in terms of number of firms (three thousands against our small hundred). Still it seems that the few conclusions we can derive are along the same lines as his.
A great majority of firms only appear as innovators in a sporadic way or even only once.
The cumulative effect of the production of innovations among firms is not backed by the empirical evidence, but in our case the difference between spells starting with only one process against those starting with two or more processes supports the more accurate observations made by Geroski.

Beyond this attempt we try now to draw some conclusions from our data with respect to the possible factors that could be at the origin of a persistent behavior for the technological processes suppliers to the refining industry.

### 3.2- Test of some explaining factors

Among possible explaining factors of this persistence, we have chosen to focus on the three following ones.

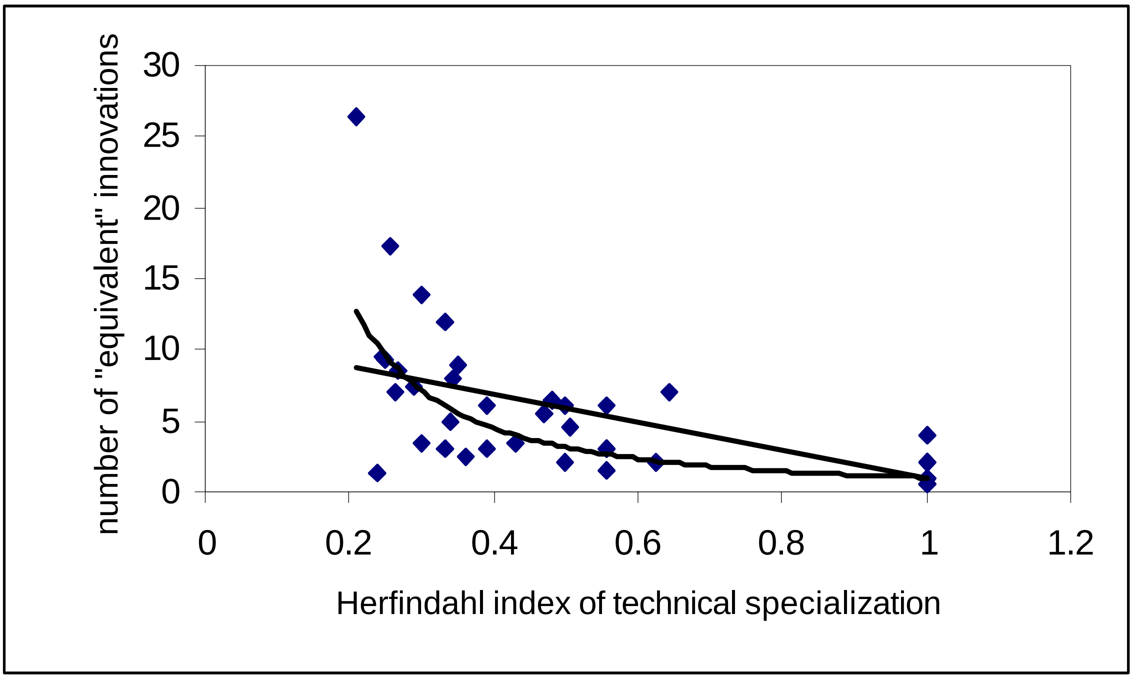
#### 3.2.1- Test of the technical specialization role in innovation persistence

Have the more innovating persistent firms a particular technical specialization profile? Are they persistent in specific niches or do they reach persistence through a large portfolio of refining processes in a broad range of different technical fields?

To answer this question, we try to measure for each firm of the reduced data file the strength of the link between an index of propensity to innovate on the period 1949/1998, and an index of technical specialization. Due to scale and indivisibility effects in the refining processes technology, we assume that a highly technological diversified firm has a greater probability to be persistently innovative than a niche specialized one. Index of number of "equivalent innovations" by firm is used as a proxy of the first explained variable. An Herfindahl index of technical specialization is used as a proxy of this assumed explaining variable. This index measures the extent to which the number of "equivalent innovations"[13] is concentrated in the different Heinrich classes.

The result displays a positive and increasing relationship between broader portfolio of new refining processes (decreasing Herfindahl index of specialization) and a proxy of innovation persistence (number of "equivalent" innovations). This relationship appears to be statistically significant, (the statistical parameters of this linear regression are significant: absolute value of t greater than 8).

Graph 6: relationship between the number of equivalent innovations and the technical specialization of each firm (1949/1998) (reduced data file)




Source : authors

### 3.2.2- Test of the cooperation intensity role in innovation persistence

Literature on industrial organization of technical innovation very often focus on the closed relationship between cooperation and technical innovation, highlighting the numerous configurations of innovation creation and diffusion in which cooperation between suppliers and users, or between suppliers is increasing. In that direction, Teece (1992) states that, in front of the respective drawbacks of coordination or/and incentives in the price-system and fully integrated companies: "*Strategic alliances constitute viable alternatives in many*

[13] « Equivalent innovations » are the addition of i) entire innovation supplied by one firm (multiplied by n in a given year if there are n different innovations), and, ii) of fractional number of innovations: 0,5 when two firms are cooperating for a new process, 0,333 when three firms. (multiplied by m if there are m such cooperated innovations).

*instances. Alliance structures can facilitate innovation, and are increasingly necessary as the sources of innovation and the capacities necessary to effectuate commercialization become increasingly dispersed.*" (p.23). But the theoretical relationship between cooperation and persistent innovative behavior is not so clearly tackled. Can a such trend be observed in refining process technology over the period? In that case, are the more cooperating firms the more persistent innovative ones?

Dealing first with full data file, we have defined the at least ten times selected processes over the full period. That sample of 75 processes, which most likely have been improved several times during that selection, constitutes the evolving technological "basis" of the refining industry. From that sample we look for the number of these processes which have been associated[14] between two or three firms. Table 6 shows that 1960 is a turning point. Given that there is not a single refining process after 1976 year which has been selected ten times, the two sub periods are: 1947-1958 and 1960-1976.

Table 6: Rate of association for the ten times selected processes over the 1947-1976 period (full data sample)

| Number of presence of a second firm | Emerging processes in the 1947-1958 period | | Emerging processes in the 1960-1976 period | |
|---|---|---|---|---|
| | Number of process | In % | Number of process | In % |
| 7 | 1 | 2% | 1 | 4% |
| 6 | 1 | 2% | 2 | 8% |
| 5 | 0 | 0% | 2 | 8% |
| 4 | 3 | 6% | 0 | 0% |
| 3 | 2 | 4% | 2 | 8% |
| 2 | 6 | 12% | 4 | 17% |
| 1 | 15 | 29% | 6 | 25% |
| 0 | 23 | 45% | 7 | 29% |
| Total | 51 | 100% | 24 | 100% |

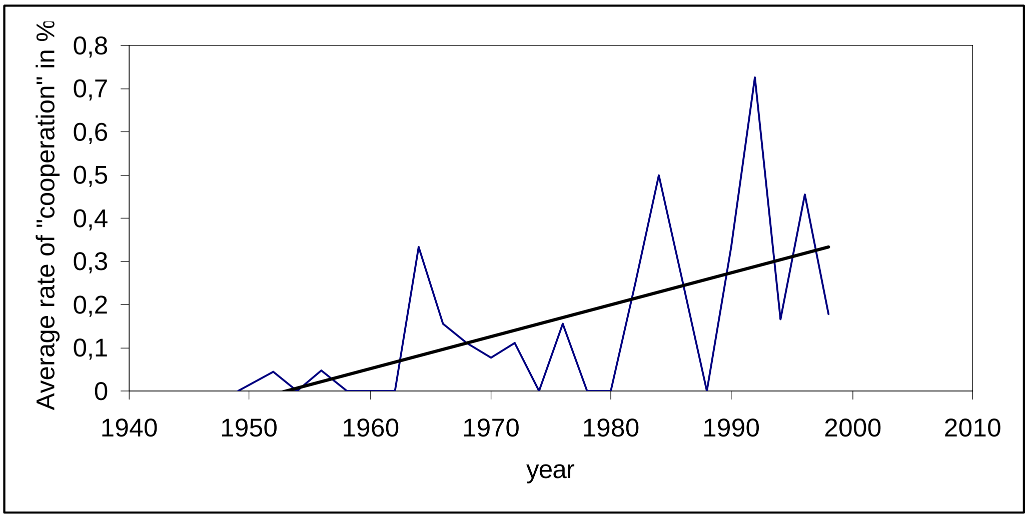
Source: authors

After 1960 an increase of presumed associations is observed (1-0,29=0,71) in respect to before 1960 (1-0,45=0,55), i.e. 71% to 54% of association rate. Among these associations, there is also an increasing proportions of multiple or successive associations, as far as the proportion of association with three firms increases from 14% before 1960 to 28% in the following sub-period.

Then we assess the existence of this eventual relationship in the reduced data file. From this file we define an index of cooperation not directly between firms, but on the relative number of new refining processes in cooperation. For each "year", an average rate of cooperation is defined by the division of the number of new refining processes in cooperation between 2 or 3 firms to the total number of new refining processes (Graph7).

[14] Association is presumed as soon as for a process an another firm than licensor is mentioned, or when there are two cooperating licensors.

Graph 7: average rate of cooperation of new refining process/innovation for each “year” from 1949 to 1998 (reduced data file)




Source: authors.

The trend of cooperation shows a slight increase over time (both the slope and the intercept significantly depart from zero, with an absolute common t value of 3.3). Yet the variance also increases over time and the small number of records on which the percentages are built compels to a cautious interpretation. But when we look for a relationship between persistent innovative firms and cooperation, no clear linkages are displayed.
Although further tests should be defined, the two sets of results (full data and reduced data) tend to suggest that association rate is higher for basic and successful refining processes than for the new emerging ones. Or in other words if one new refining process has relative success, and even if it is provided by only one innovator, then after the likelihood of association increases. According these results, persistent incremental innovations would have a higher rate of association than the major ones.

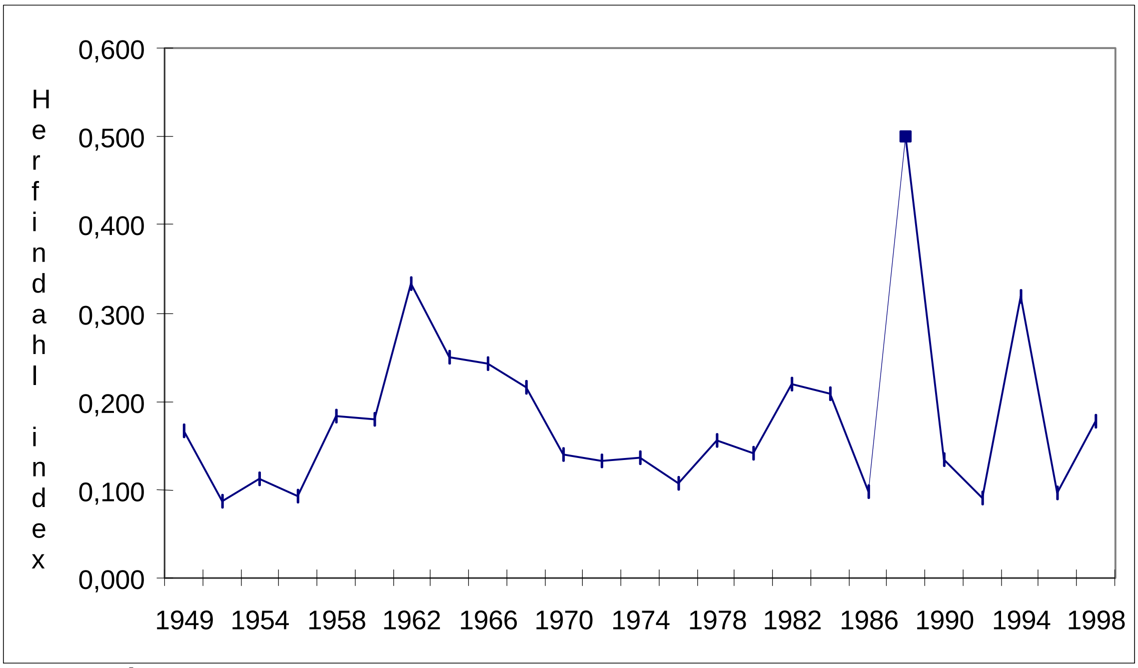
### 3.2.3- Test of the concentration of refining process supplier in innovation persistence

Do the process refining suppliers tend to be more and more concentrated during the 1949/1998 period? Is this presumed concentration positively linked with innovation persistence? Scholars on one side, professionals on the other side seem to converge in respect to refining technology to claim that technological development in this industry goes along with economic concentration, economies of scale, high capital intensity, high barriers to entry.

In the seminal contribution of Malerba and Orsenigo (1996), an intersectorial patent data based comparison of innovative patterns is defined between 49 technological classes in six countries. Their results tend to suggest that innovative patterns are mainly technology specific, which may be approached by characterization of a specific technological regime defined by conditions of opportunity, appropriability, cumulativeness, and properties of knowledge base. These technological regimes have two broad kinds of behavior. One may be related to a “Schumpeter Mark I” or “Widening pattern”, in which concentration of innovative activities is low, entry of new innovators high, stability in ranking of innovators low, size of innovators low. The other one, “Schumpeter Mark II” or “Deepening pattern”, displays reverse value with higher concentration of innovators, larger economic size of innovators, lower entry rate.

Although oil refining technology is not explicitly quoted in their 49 classes technology classification, class 8 organic chemicals or 9 macromolecular compounds, which are technologically near the oil processes, are clearly belonging to the second pattern, the deepening one.
The analysis and prediction of professional seem to go the same direction. For example Barbier et al. (1995) highlight an increasing concentration in the different categories of refining processes licensors (major oil companies, dedicated specialized licensors (UOP and IFP), big engineering/construction companies). They predict in the near future a trend towards mergers and acquisition and the survival of only two or three general licensors at the world level.
However, if we back to a simple measure of innovator concentration, the herfindahl index of concentration of new refining processes supplier in the 1949/1998 period, empirical evidence (Graph 8) does not fit with these previous representations.

Graph 8: Herfindahl concentration index of innovating suppliers (1949-1998) (reduced data file)




Source: authors

From this graph no clear trend of increased concentration appears. But that does not mean there is not a world trend to concentration at the refining process supply level. Small innovating firms may be frequent innovators. But, because they are not apparently the same ones firms in a medium to long term perspective, they are not persistent innovative.

## Conclusions

Innovation persistence and direction have been mainly documented in this paper by technical indexes, or innovations count number. They should be completed by a combination with patent data, and notably improved in an attempt to document explicitly the small many qualitative changes (incremental innovations) which have concerned some long lasting existing refining processes. But these indexes should mainly be completed by more economical ones on firm size, survival rates, and cooperation patterns between leading suppliers and small innovators.

If these first results are confirmed by further investigation, they may underpin that conclusions on innovative patterns in a broad intersectorial comparison perspective should be checked and eventually re-interpreted in an intrasectorial perspective. Even if there is a large consensus on the preeminence of some specific innovative pattern in refining industry (large size companies, few major innovations but a lot of cumulative incremental ones), the existence of small innovators seem to remain a structural characteristic in this sector. In that perspective, survival rate and cooperation of such innovators becomes a key empirical and theoretical issue. This also might reveal that a global efficient innovative pattern in that industry like in others should try to combine the advantages of both innovative patterns, the widening and deepening ones. Nevertheless from the innovation persistence issues point of view, and taking into account the small number of innovations in our reduced data file, the results tend to highlight a strong relationship between large technical portfolio firms and persistent innovative firms. This is a clear support to the deepening pattern, and to the complementarity of capabilities thesis in the very rare firms (probably 2 or 3 only at the world level) which succeed to implement such technological strategy in a maturing industry. In refining processes sector, persistent innovative firms are only those which succeed to develop innovations in the timely different technical most promising areas on long term, that is to say firms able to master learning efforts to shift their knowledge base, and to increase their initial capabilities. This tends to converge with the conclusions of the numerous contributions of Patel and Pavitt at the intersectorial level: surviving big international companies are the leader ones in their initial specialty field, but simultaneously are able to develop innovative activities in other technical areas.

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Appendix 1

Completed nomenclature of refining processes from Heinrich (1994)

| | | | |
|---|---|---|---|
| 1- Distilling and Fractionating processes | 1.1 Distillation | 1.1.1-Primary distillation | |
| | | 1.1.2-Vacuum distillation | |
| | | 1.1.3-Other distillations (Azeotropic..) | |
| | 1.2-Refinery gases separation | | |
| | 1.3 Extraction | 1.3.1-Deasphalting | |
| | | 1.3.2 -Solvent refining | |
| | | 1.3.3 -Crude oil desalting | |
| | | 1.3.4-Light ends recovery | |
| | | 1.3.5-Other recovery | |
| | 1.4-Crystallizing | | |
| | 1.5-Absorption | 1.5.1-Hydrogen purification | |
| | | 1.5.2-Other purification processes-Centrifuging, filtering,... | |
| | | 1.5.3-Absorption and extraction of lubes feedstocks | |
| | 1.6 Other separating processes | | |
| 2- TRANSFORMATION PROCESSES | 2.1 Upgrading processes | 2.1.1.0-Thermal reforming | |
| | | 2.1.1-Catalytic reforming | |
| | | 2.1.2-Isomerization | |
| | | 2.1.3-Alkylation | |
| | | 2.1.4-Ethers : MTBE , ETBE,TAME | |
| | | 2.1.5-Propylene oligomerization | |
| | | 2.1.6-Lubes feedstocks | |
| | 2.2 Conversion processes | 2.2.1 Thermal conversion processes | 2.2.1 1 Visbreaking, residue reduction<br>2.2.1.2-Thermal coking<br>2.2.1.3- Steam reforming<br>2.2.1.4- Partial oxydation<br>2.2.1.5-Thermal reforming & Thermal cracking |
| | | 2.2.2 Catalytic conversion processes | 2.2.2.1-Fluid catalytic cracking<br>2.2.2.2-Steam reforming-<br>2.2.2.3-Hydrocracking<br>2.2.2.4-Fixed bed processes |
| | 2.3-Finishing and removing undesirable components processes | 2.3.1-Hydrotreating | |
| | | 2.3.2-Sweetening | |
| | | 2.3.3-Molding-packaging, storing | |
| | | 2.3.4 Chlorine refining, without hydrogen | |
| | 2.4-Environment protecting and removing refinery wastes and emissions processes | 2.4.1 Gas treating | 2.4.1.1-Acid gases treating- 1- H2S recovery |
| | | | 2.4.1.2 Acid gases treating- 2-Sulfur recovery- |
| | | 2.4.2 Wasted water processing- | |

Source: From Heinrich G.1994, "Introduction au raffinage", chap.10-p373-453 .- In : Wauquier J.P., dir.- Le raffinage du pétrole-1-Pétrole brut- Produits pétroliers- Schémas de fabrication- Technip, Paris.