"How persistently do firms innovate?" An Evolutionary View. An empirical application of duration models*

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second draft

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1. Opening an other black box: the determinants of the continuity of firms innovating behaviour.

Many contributions to the Economics of Technological Innovation explain why firms in a specific context innovate and why others do not. These contributions are concerned with analysing the determinants of innovating behaviour (see for instance W. Cohen 1995, P. Geroski 1994, F. Malerba, L. Orsenigo 1995, R. Nelson, S. Winter 1982, P. Patel, K. Pavitt 1995, J. Tirole 1988). There is a closely related question but which has different theoretical implications: once it is acknowledged that some firms innovate over a long time period and others fail to do so persistently, what keeps a firm innovative over time? Economic theory has not paid much attention to the question of the duration of innovation, which has nevertheless a lot of industrial policy implications. For instance, if we could identify why firms fail to innovate for other than short periods of time we would be able to imagine new institutional arrangements for strengthening incentive structures. Findings from two theoretical frameworks cast relevant light on innovation duration at the firm level: a standard framework, based on a resource approach and patent race, and an evolutionary framework, based on a capability/competence approach. In the patent-race literature we find that technological dynamics are explained by a "replacement effect" (firms are reluctant to innovate in period t because they are afraid of cannibalising rents arising from innovations created in t-1) or by a "pre-emption effect" (firms receive incentives to innovate in t for exploiting more effectively innovations done in t-1, see for instance R. Gilbert, D. Newberry 1982). These two effects have very opposite consequences. The second body of knowledge is based on "evolutionary competence based approach". The evolutionary theory of the firm and innovation focuses on learning capabilities and (imperfect) adaptative behaviour and the interactions between behaviours and economic selection mechanisms (S. Metcalfe 1995). The fact that some firms innovate over a short period of time and others over a long period of time is normal in an industrial environment characterized by diversity and variety. S. Winter (1984) has defined two technological regimes: entrepreneurial and routinized. The first favours entry into the industry, for this reason innovation largely occurs whithin small firms, but mortality is high. In the second, innovation occurs in the R&D department of large oligopolistic firms which have a longer economic life than small firms in the entrepreneurial regime. We can easily predict, roughly speaking, that a small firm innovate over a shorter period of time than a large firm. The theory of "dynamic capabilities of firms" (see D.J. Teece, G. Pisano 1994) argues that the winners in the global market have been firms that can demonstrate timely responsiveness and rapid product innovation, coupled with the management capability to coordinate and redeploy internal and external competences. Their competitive advantage has its roots in their "dynamic capabilities".This term emphasizes the role of stategic management in adapting, integrating, and re-configuring internal and external organizational skills and competences in a shifting environment. Thus competitive success arises from the continuous development and exploitation of firm-specific assets. This approach analyses how firms accumulate knowledge and use it productively. These evolutionary references will be useful in our study.

2. Data and empirical analysis.

We conducted an empirical analysis of French industrial firms during the 1969-1985 period. This type of study is strongly influenced by the seminal paper from P. Geroski and alii (1997) entitled "How persistently do firms innovate?". Using two data bases concerning UK firms (the SPRU data base of innovation in UK from 1945 to 1982, and a patent data base that contains firms which registered patents in the US from 1969 to 1988) it is shown that the two samples yield the same result: few innovative firms are persistently innovative. The main conclusions are that: demand growth has a negative (but not significant) effect, spillovers have a positive effect on the duration of firms' innovating behaviour, and that size does not greatly determine this duration. In this paper our aim is twofold: 1. we wish to confirm or refute the conclusions found by P. Geroski and alii (1997), particularly concerning the hazard function, 2. we want to suggest the relevance of the evolutionary competences/capabilities approach.

We use a sample of French firm**s** which made patent applications to the US Patent office from 1969 to 1985. We have 22 000 patents granted and 3347 firms. We intend to estimate the coefficients of the main variables which explain the duration of innovation (the length of the innovation period) by using an econometric model of duration (for more about these models see N. Kieffer 1988, C. Gourieroux 1989).

2.1. The patent as an indicator of innovative activity.

Following the seminal work of Schmookler (1966), patent statistics are now widely used as an indicator of innovative activity and a proxy for innovation in econometrical estimations (see in particular Crepon, Duguet 1994, Griliches 1990, Pakes 1985, Scherer 1986, Soete 1981). However the use of patents has been critized because this indicator has limits as a measure of technical change (Le Bas, Pavitt 1999): patents are only one means of protecting innovation and their importance as protection against imitation varies amongst sectors. Patents are not a good measure of radical innovation associated with new paradigms such as software and bio-technology. Moreover, raw patent counts may fluctuate over time because of constraints on the number of patent officers and budgetary allocations of the patent office (Griliches 1989) rather than fluctuations in the technology levels. Since they play a significant role at every stage of the innovation process (Basberg 1982), patents are also an indicator of technological competences. Here we define technological competence as the ability to transform technological and market opportunities into an activity or knowledge that leads to industrial production (Carlsson and

Eliasson 1994). As the codified and publicly available outcome of cognitive and tacit problem-solving processes, a patent is the result of a process of accumulation and the production of technological knowledge.

In spite of all associated problems, patent statistics provide a rough proxy for innovation.

2.2. Data set: patent granted by US patent office.

An important limitation of the use of patents as technological indicators is related to the differences in international laws on property rights. To solve this problem, and following Pavitt and Soete (1980), it is now common to use American patents rather than national patents in economic studies dealing with technological accumulation. Data on American patents effectively provide a lot of information because of both the efficiency and uniformity of allocation procedures used, and the size of the American market for technology. The American patent is viewed as a better indicator than a domestic patent, since it is assumed that innovations of lower value are eliminated (Archibugi, 1988, Archibugi and Michie 1995, Basberg 1983, Patel 1995). Since the creation of the OST in France, numerous studies have looked at European patents. The European system of patents started in 1978 but became fully effective only in 1985. For this reason the European patent is not yet relevant for assessing the capacity to innovate over a long period of time.

3. A first statistical analysis of patenting spells and an overview of the main variables.

In order to explore the reasons why some industrial firms innovate over a very short period (2 or 3 years) and other over long time period (more 10 years) we begin by exploring our patents data. Table1 give some information concerning the panel of 3347 industrial firms (or their laboratories) observed over the period 1969 to 1985 which have been granted patents by United States Patents and Trademarks Office at some moment during this period. Firstly it is clear that we have only a small part of the 25 000 French firms which have more than 20 workers. Secondly, we have in our panel not only French firms but some subsidiaries of foreign firms which are located in France. Our panel encompasses <u>all</u> the industrial firms which have been granted patents in the US and it is <u>not a balanced panel</u> unlike the work of Geroski and alii (1997). Each firm can patent over one or several spells. Finally we retain the convention that two spells must be separated by a 2 year time period at least. To put it simply one year without being granted a patent is not sufficient to consider that there has been a break in the process of innovation. By convention two years represent a break. There are several reasons for this. Patents are simply an indicator of innovative activity not a precise measure of the timing of the innovation process. In particular they cannot inform us about the time period in which innovation has exactly occured. This is even more the case for the granting of patents than patent applications. This argument is stonger for French firms which are not accustomed to patent abroad (particularly in the 60 and 70s) and which might sometimes decide to cluster their patenting projects over a number of months before making an application.

insert here table1

We are able to conduct a statistical analysis of the total number of spells or of the maximun length of spells (the longest spell for each firm). The time distribution of patenting spells is given in table1. The main feature is that of 3902 spells 71% are very short one year spells. When the length increases from 2 to 15 years the number of spells decrease monotonously. There is a small spike for the longest spell (16 years). We basically found the same features for the distribution of spells studied by Geroski and alii (1997). As regards maximun lenght of spells, the frequency distribution is very similar. Figure1 shows clearly that a large proportion of spells is located on the left for the shortest spells (less than 4 years).

Table2 give information on other features of patenting activity. The distribution of total patents per spell has a mean of 5.649, a median of one patent, and a standard deviation of 35.226. The distribution of spells has a mean of 2.202 years and a standard deviation of 2.570. For each of 3347 firms of the panel we are able to take the longer spell of innovation or the spell maximun (DSPMAX). The distribution of this variable has a mean of 1.83 years and a standard deviation of 2.643. The distribution of total patent per firm has a mean of 6.586 (against 10.8 in the panel of Geroski and alii), a median of one patent (against 2), and a standard deviation of 38.018 (against 79.979). In others words British firms patent more with a greater dispersion. This could be due to two complementary reasons: British firm are more efficient and/or are more accustomed to making patent application in the US. Figure2 shows that the large majority of patents is located on the right that is to say for the longest spells.

insert here table2

Two variables are very important in our model: the number of different technical fields in which a firm patents during one spell (max 34) or technological variety (VT), and the technical field in which a firm patents most during one spell (CTmax). Firstly, let us consider the indicator of technological variety (VT). There is a strong and very significant correlation between VT and the spell length (R^2 = 0,64). A one-year increase of VT entails a 1,138-years increase of the spell length. But correlation is not same as causality. Here, as it is often the case for the phenomenon of duration, we suspect the causality runs in the both directions. The longer the spell the higher the probability of patenting in an other technical field. Conversely the greater a firm's multi-technological knowledge the greater is its dynamic capabilities, and the longer its innovation spell. For this reason we will take into account another variable (VTDP) which measure technological variety at the beginning of the spell. The mean of the VTDP distribution is smaller than the mean of VT. The two distributions are strongly correlated: VTDP explains

50% of VT variance. Because VTDP cannot be determined by the spell length we intend to use it as a variable which explains the persistency of innovation behaviour. In our framework we argue that such a variable (VTDP) is a good measure of the firm's capacity to maintain efficient technological production over several years. We have therefore chosen it as a proxy for the dynamic capabilities of firms.

Ctmax, defined at the firm, level is an other term for firm core-technological competency. There is an obvious interest in using it as a proxy for technological opportunity. The empirical literature states that technical advance is easier or less costly in some industries than in others (W. Cohen 1995). It is particularly relevant to use this notion for assessing why some firms are able to innovate over a longer period of time than others. Given the difficulty of constructing technological opportunity measures for samples encompassing numerous industries, we treated technological opportunity as dummy variable. For convenience and to facilitate statistical treatment, CTmax is a qualitative variable which can take 6 modalities: A.Electrical-electronic, B.Instruments, C.Chemical-drugs, D.Metallurgical and chemical processes, E.Mechanical/transport, F. Consumer goods/building industry. In order to assess the relative weight of each group of competences we calculated the CTmax associated with each spell. We obtained the following results: A=10.56%, B=8.94%, C=16.76%%, D=17.99%, E=39.80%, F=5.95%. This confirms:

1. the continuing and widespread ("less and less" neglected) importance of improvements in mechanical technologies (Patel, Pavitt 1994)
2. the importance of patenting in drugs and chemicals industries for which the patent is the best mean of protection.

This variable explains 39% of the variance of spell lenghth. When core technological competences are dominated by chemical-drugs technologies the spells have a mean duration of 2.4205 years, 2.4077 years for electrical-electronic technologies, 2.0431 years for mechanical/transport, 1.722 years for metallurgical and chemical processes (that is to say lower than the mean of the panel of 2.0169 years), 1.6963 for instruments, and 1.3836 for consumer goods/building technologies. The results are hightly significant. Firm core technological comptences tend to partly explain innovation spell lengths. These findings are very similar to those in empirical literature (see particularly W. Cohen 1995).

insert here table3

All these remarks can be summarized in a taxonomy of regimes of patenting behaviour (see table3). Four types of behaviour are defined:

1.Single patentors patent over short spells (3 years maximum) producing few patents. This group comprises 71% of the sample (64% in Geroski and alii 1997) and produced 1.146 patents per firm.

2. Heavy patentors patent over long spell (13 years maximum) many patents. This group represents 2.2% of the sample (2 % in Geroski and alii 1997) and produced 136.9 patents per firm.

3. Medium patentors take out between 2 and 10 patents over one spell only. This group represents 12.2% of the sample (this group is not identified by Geroski and alii 1997) and produced 14.1 patents per firm.

4. Sporadic patentors patent over several spells. This group represents 13.9% of the sample (34% of the sample for Geroski and alii 1997, but the two studies do not use the same definition of the spell lengths) and produced 7.02 patents per firm.

insert here fig1,fig2,fig3,fig4

4. Estimations and results.

4.1. Non parametric estimation: Kaplan-Meier estimator.

Table6 shows empirical survival rates and associated standard errors for spells starting with 1, 2, 3, 4, 5 and more patents at the beginning of the spell and for spell linked to each of the 6 large technological fields (CTmax defined as above). The percentage of spells that lasts at least as long as T years is computed using the Kaplan-Meier estimator (see Green 1997). Survival rates for spells with one patent in their year are about 28%, for those with 2 patents 51.5%, for those with 3 patents 78%, for those with 4 patents 88%, and for those with 5 patents or more 90%. These results are very similar to those found by Geroski and alii (1997). A firm which begins a spell

insert here table5a, table5b

with only one patent at time t is less likely to patent in t+1 than a firm that commences a spell with 2 patents and so on. When we consider the survival rates for spells which last 2 years, we find that their chance for surviving a third year is respectively 18.5%, 43%, 69%, 83%, 90%. Figure5a (for the panel as the whole) et 5b (for each group of spells) illustrate graphically these trends. Firms with one patent have only a 13% probability of enjoying a patenting spell of 5 years. This probabilty is increases with the number of patents at the beginning of the spell. When a firm begins to patent 5 or more the probability of surviving as an innovator is 82%. Geroski and his colleagues did not obtain such scores (but the period studied is longer: 20 years). The higher the level in terms of patents at the beginning of the patenting period greater the chance of surviing as a patentor. The degree of relative disadvantage declines as the initial level of patenting increases, but more rapidly than in Geroski and alii (1997). So it seems there is something that resembles "dynamic scale economies" in the patenting activity.

insert here table6

Table6 gives the survival rates for the spells which are associated to each type of technological competence (ctmax). A firm which begins a spell associated to electrical-electronic competences is more likely to patent the second year than a firm that commences a spell associated to chemical-drugs competences which is more likely to patent a second year than a firm that commences a spell associated to metallurgical-chemical processes competences and so on. These results confirm that the effects of technological opportunity are differentiated along each group of competences.

4.2. The determinants of hazard rates: Weibull regression.

We estimated a Weibull model in which the hazard rate is:

$$\text{landa}(t)=p.\ t^{\,p-1} \exp(ß_i x_i)$$

where p is a shape parameter to be estimated from the data (some authors refer to 1/p, see for exemple Geroski and alii 1997), x_i a vector of explanatory variables and $ß_i$ a vector of parameters to be estimated. Table7 summarizes the results of Weibull regressions of patenting spells. For all types of regressions we need data for explanatory variables, in duration models this constraint is stronger. We effectively need information on the determinants of spell length which are not dependent on the spell length. In other words the exogeneous variables must be assumed not to change from the beginning of the spell to the "failure time". For instance the total number of patents granted during the spell is clearly proportional to the spell duration (the longer the spell the greater the number of patent granted). For these reason we are only able to use the estimation variables which describe firms' structural characteristics or initial level of variables (at the beginning of the spell). More generally it is difficult to find information concerning firms' economic characteristics over such a long period of time. We finally decided to insert as explanatory variables technological variety at the beginning of the spell (VTDP), a good predicator of dynamics capabilities of the firms, and the initial level of patenting (nbdp) with 5 modalities: 1,2,3,4, 5 or more. This dummy variable defines the capacity of the firm to maintain innovation activity over a long period of time (in the regression nbdp5 is the dummy omitted). The technical field in which firms patent the most (with the 6 modalities defined above) is a proxy for technological opportunities.

insert here table7

Regression1 in table7 shows clearly that technological variety at the beginning of the spell is a variable which explains spell length. In regression2 we introduce dummy variables (nbdp, ctmax) without any other explanatory variables. Our main findings are:

1. The estimates are very significant (except fot nbdp4).
2. For the 2 regressions we find 0.5   1/p   0.84. This result is very closed to those found by Geroski and alii (1997): 0.5 with patents data, 0.7 with innovation data. They are highly inconsistent with the hypothesis of negative duration dependence.
3. The variable nbdp has clearly a significant impact (except for nbdp4).
4. The effects of dummies concerning the type of technological competencies mastered by the firm, a proxy for technological opportunities, are conform with our expectations based on the preceding statistical analysis. Chemical-drugs technological competences (ctmaxc) and electrical-electronic competences (ctmaxa) have the most important fixed-effect (in the regression ctmaxf is the dummy omitted).
5. When we add the explanatory variable VTDP in regression2 none of the dummies are significant. This confirms that there is a correlation between VTDP and nbdp. The link is obvious: the greater the number of patents at the beginning of the spell, more firms are likely to patent in different technical fields (among the 34). The link between VT and the dummy ctmax is less clear. It is probably due to the fact that large firms are more represented in chemicals, drugs, electronic than in other fields of technological competence. Firm size influences positively the degree of diversity of firms' technological activities (P. Patel, K. Pavitt 1996): large firms are able to patent in several fields. These remarks mean there is probably a firm size effect which is a determinant of spell length through pre-spell patenting and technological variety. This presumption in favour of a size effect is not totally shared by Geroski and alii (1997). They argue that persistent innovation is not strongly linked to firm size, although there does seem to be a positive relationship between the length of innovation spells and firm size, the pre-spell patenting on innovation activity has a much more powerful effect on spell length than firm size. But it seems firm size has necessarily an effect on pre-spell patenting (see Scherer 1965 for an analysis of the relation between firm size and patenting). Finally our opinion is that the relationship between firm size and spell length is complex and should be reexamined more seriously.
6. The main finding is the confirmation of the hypothesis of a positive duration dependence (1/p>1). In other words the likelihood of failure at time t, conditional upon up to time t, is increasing in t. But this general law which governs the hazard function is coupled to an "economic" law which stipulates that there are threshold effects concerning patenting at the beginning of the spell. Technological variety a proxy for dynamic capabilities of the firms plays the same role.

5. Conclusions.

In this paper we have developed an evolutionary competence based approach concerning the persistence of firm innovative behaviour. As regards this very open question, which has not really been dealt with until today (with the exception of S. Lhuillery 1996 and P. Geroski and his colleagues 1997), we largely, confirm using US patents data on 16 years period (1969-1985), the main results from Geroski and alii (1997): positive duration dependence and threshold effects concerning patenting at the beginning of the spell. We find new significant results at the firm level as regards the impact of technological variety, dynamic capabilities of firms or technological opportunities over spell length.

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