ACCUMULATING TECHNOLOGICAL COMPETENCE - ITS CHANGING IMPACT ON CORPORATE DIVERSIFICATION AND INTERNATIONALISATION

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ABSTRACT
Recent studies have suggested that firm-specific technological competence may be diversified and internationalised. We show that increases in competence increased corporate technological diversification until the early 1970s, and then again more recently. However, a new interrelationship has now emerged between the accumulation, diversification and internationalisation of technological competence, due to the formation of internationally integrated networks within firms. The empirical analysis consists of a dynamic cross-section model applied to the corporate patenting in the US, of 166 of the largest European and US industrial firms from 1901-1995.

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1. Introduction

The dispersion or spread of productive activity within the firm has been the subject of systematic research by economists and strategic management researchers for over 30 years, but there is a great deal of variation in the way it is conceptualised, defined and measured. At a general level, a firm's operations may be dispersed across different types of productive activity (the diversification of technologies or products), or over geographical space (the internationalisation of the same). However, diversification and internationalisation have often been considered and analysed separately as two distinct phenomena or alternative routes to growth, in the analytical framework that originated from Penrose (1959). The traditional perspective concerned essentially the firm's expansion into new markets, whether this be new product markets or new markets outside the firm's home country. From this standpoint, the focus of attention was the way in which a firm exploited its existing potential for growth, a potential that takes the form of the firm's given competence or inherited managerial resources (although Penrose herself had recognised the cumulative process by which expansion into new areas will influence the firm's future potential for growth).

More recently, Penrose's resource-based view of the firm as a collection of productive assets has given rise to a competence-based theory of the firm (Richardson, 1972; Winter, 1988; Nelson 1991, 1992; Loasby, 1991, 1998; Cantwell, 1991, 1994; Foss, 1993; Teece, Rumelt, Dosi and Winter, 1994; Teece, Pisano and Shuen, 1997; Hodgson, 1998; Chandler, Hagström and Sölvell, 1998), in which the firm is seen as an institution that constructs capabilities through internal learning processes in the form of evolutionary experimentation. In this event the major issue is not so much how the firm exploits a given competence, but rather how it establishes a (spatially and sectorally) diffuse system for the creation of new competence. In order not just to exploit effectively but also to consolidate an existing capability, it is generally necessary for a firm to extend that capability into new related fields of production and technology, and across a variety of geographical sites. The firm evolves typically along paths in which its own past history plays a critical role, rather than through a series of discrete and unrelated steps, so that it is thereby able to benefit from the dynamic economies of scope (increasing the firm's rate of innovation rather than its static efficiency) that derive from the technological complementarities between related fields of activity, and the complementarities between related paths of innovation or corporate learning in spatially distinct institutional settings or environments.

The central point here is the distinction (suggested in Cantwell and Fai, 1999a) between the ever-changing composition of product markets in which the competence of firms is exploited, and the more stable character of underlying competence itself due to its being created through systematic learning in production (by way of a process of cumulative and incremental problem-solving activity). Hence, we should emphasise that in examining the diversification and internationalisation of corporate technology we are not looking at a simple reflection or another aspect of product diversification and the internationalisation of markets, nor do we need to concern ourselves with the dialectical relationship between the expansion of the firm's competence base and the extension of its markets (which is the subject of a separate literature, see Piscitello, 1998). The trajectories that firms follow in accumulating competence are of interest in their own right, and the rationale of incorporating a diversity of sources of learning is to raise the firm's potential rate of innovation, whereas the objective of serving diverse product markets is (at least in the first instance) to exploit the firm's established competence to better effect.

In the new perspective, the corporate internationalisation and diversification of technological activity are both ways of spreading the competence base of the firm, and of acquiring new technological assets, or sources of competitive advantage. This has led to a new focus on the internationalisation and diversification of corporate technology, as a reflection of the development of the underlying capability of firms. In the internationalisation field, new theoretical and empirical models have been devised of the process by which multinational companies access locationally dispersed technological assets, through their own international operations and through alliances with other firms (Cantwell, 1989; Kogut and Chang, 1991; Dunning, 1995; Pugel, Kragas and Kimura, 1996; Almeida, 1996; Frost, 1996; Kuemmerle, 1996; Cantwell and Barrera, 1997). In the diversification field, the notion of technological diversification has been conceptualised, as a means by which firms extend their technological base and capabilities. Various authors have shown that technological diversification at the firm level, defined as the process by which the breadth of corporate technology is increased over time across a wider range, was an increasing and prevailing phenomenon in Japan (Kodama, 1986), in the UK (Pavitt *et al.*, 1989), and in Sweden (Granstrand and Sjölander, 1990; Oskarsson, 1993).

In this study, we develop a dynamic cross-section econometric analysis to examine the interrelationship between the diversification, internationalisation and accumulation of technological competence in large industrial firms, over a long historical period. We pay particular attention to the changing significance over time of the impact of competence accumulation upon the diversification and internationalisation of technology, but discuss too the role of feedbacks in the other direction. However, since we consider the cross-section dynamics of competence accumulation across firms over time, in which the characteristics of the distribution of inter-firm variety tend to be quite persistent over time (Cantwell and Andersen, 1996; Patel and Pavitt, 1998; Cantwell and Fai, 1999a) we do not need to take separate account of industry- and country-specificities (which do indeed influence the nature of the distribution at any point in time but much less the way in which it changes over time). The sample considered is a large cross-firm panel of technological activity over time, proxied by the corporate patenting in the US of 166 of the largest European and US industrial firms over the period 1901-1995.

Therefore, the paper provides three main contributions: (i) a conceptual one, related to further working through the inferences for large multinational companies of the idea that the firm is the principal source and not just a beneficiary of innovation and growth, a device for the establishment of technological competence, and for its continued development over time; (ii) an empirical one, since the availability of a large, complex and consistent data set allows us to explore in a coherent way (that is for a consistent set of firms) the existence of distinct historical phases in the patterns of competence accumulation in the world's largest firms; and (iii) a methodological one, since while other previous research relating to diversification and internationalisation has been purely cross-sectional, we take into account dynamic processes over time.

The organisation of the paper is as follows. The next section elaborates upon the interpretative framework for the study, and suggests how the structure of the relationship between the three variables considered (the rates of growth, internationalisation and diversification of corporate technology) may have changed historically. In the third section, the empirical research methodology is set out, and we discuss three improvements over earlier empirical studies that our procedure entails. The data employed are described in the fourth section. In section five we specify the econometric model, the proxies used to measure competence accumulation, technological diversification and internationalisation, and the control variables used; while the results are reported in section six. The last section contains some concluding comments.

2. Historical changes in the roles of diversification and internationalisation in firm growth - an interpretative framework

The literature suggests that one can identify three historical phases in the growth, diversification and internationalisation of the world's largest industrial firms. These three stages of development are associated with three main phenomena: (i) the changes in the international environment for coordinating diverse business operations (Vernon, 1973), (ii) reasons related to the corporate life cycle, particularly the shifts in the maturity of the growth process in large firms (Chandler, 1990), and in the maturity of internationalisation strategies in large multinational companies (Dunning, 1992), and (iii) an historical shift in what has been termed the techno-socio economic paradigm (Freeman and Perez, 1988), from technological diversification linked to economies of scale and increasing size (Chandler, 1990) to technological diversification based on interrelatedness and new combinations (Cantwell and Fai, 1999b).

In the earlier stages of development of large firms in the interwar and early post-war periods, it is reasonable to depict diversification and internationalisation of markets as two alternative strategies for corporate growth, as suggested by Penrose (1959). However, in this phase while large firms were commonly diversifying their technological competence in the normal course of growth (as shown by Chandler, 1990, and in company case studies by those such as Hounshell and Smith, 1988 and Warner, 1978), their internationalisation of research and development (R&D) was aimed at the wider exploitation of the basic competence they had already established at home rather than at extending that competence into new fields or 'sourcing' technology abroad. Affiliate R&D concentrated upon the adaptation of products to local tastes, and the adaptation of processes to local resource availabilities and production conditions (Cantwell, 1995). Thus, in the early stages, although the internationalisation of corporate technology should not be underestimated (a criticism of some recent literature advanced by Cantwell, 1995), it was motivated mainly by the extent of dissimilarity between home and foreign markets rather than by the rationale of the process of further competence accumulation.

In the second phase, by around the mid-1970s, the old technology paradigm ran into difficulties (Freeman and Perez, 1988), as the opportunities for integrating diverse technologies in large scale plants had been gradually exhausted. Thus, it seems reasonable to expect that at around this time the relationship between the accumulation and diversification of competence may have broken down. Technological diversification was now increasingly based instead on the growing interrelatedness between formerly separate technologies (Kodama, 1986), but like with the formation of corporate international networks, the new opportunities for innovative development were still at an early stage in the 1970s.

Even in the second phase, after the early post-war period, there seems to have been a general widening of the internationalisation and diversification of technology across a wider range of firms (Cantwell, 1995). The most common explanation is that lower transport and communication costs contributed to a general expansion across large firms in the internationalisation of technological activity (Vernon, 1973), while an increase in technological interrelatedness prompted a broader cross-section of firms into technological diversification (Pavitt, Robson and Townsend, 1989; Patel and Pavitt, 1997, 1998). Another aspect which has recently entered into the discussion is the changing nature of technological knowledge itself (Nelson and Thomson, 1997), that with the development of scientific and engineering communities became more susceptible to transmission between fields of activity and between countries.

More recently, however, the nature of the competence creation process seems to have entered a third phase in the technologically leading firms (Cantwell, 1995). What previously had been a dispersed set of loosely connected efforts for the consolidation and adaptation of competence within the firm (achieved through some combination of diversification and internationalisation), has been transformed in some companies into a more complex integrated and interactive network for the generation of new competence. This new system for corporate development relies on the interrelatedness between specialised activities conducted in particular locations, each of which takes advantage of spatially-specific resources or capabilities. In this event internationalisation, diversification and competence creation become for the first time necessarily interconnected and thus mutually positively related parts of a common process. The wider picture of which this is part is one which formerly local market oriented affiliates have been increasingly integrated into international networks within their respective multinational companies, such networks coming to resemble 'heterarchies' more than hierarchies (Hedlund, 1986; Doz, 1986; Porter, 1986; Bartlett and Ghoshal, 1989; Dunning, 1992), and affiliates have increasingly pursued 'asset-seeking' motives (Dunning, 1995).

Beyond the emergence of a new interrelationship between the accumulation, diversification and internationalisation of corporate technological competence, the third phase is distinctive in changes in the cross-firm pattern of activity in another respect too. Given that the internationally dispersed development of technology is now a source of competitive advantage, two different types of firm behaviour can be observed, depending upon whether a firm that begins with relatively little international activity needs to 'catch-up' (Cantwell and Sanna-Randaccio, 1990), or an established multinational reorganises its existing international network to better exploit the respective comparative advantages in innovation of the locations in which it operates (Cantwell and Sanna-Randaccio, 1993). Due to the first kind of consideration, we expect that the absolute extension of company networks for technological development has become linked on average to a widening of their international scope. Yet due to the second factor, we have reason to also believe that the firms with the fastest proportional increase in competence will tend in the latest phase to be established multinationals that are restructuring their international networks to better effect, and hence selectively concentrating the development of key fields in the most suitable centres (Cantwell and Piscitello, 1999).

The empirical model here aims at investigating changes in the nature of competence accumulation over a long period from company data covering most of the twentielth century. In particular, we have two objectives. First, to establish whether we observe three distinct phases in the relationship, as suggested above; and second, if so, to indicate the approximate dates at which the switch between these stages occurred. These objectives are pursued by investigating through an econometric model the statistical relationship between firms' competence accumulation (GWT), the change in their degree of technological diversification (DIV) and internationalisation (INT) over time. To distinguish between effects associated with the scale of competence accumulation or its rate of change (which we have just argued we believe need to be treated separately when examining the latest stage of development), we use alternatively the absolute increase in corporate patenting or its proportional rate of change to represent GWT.

3. The empirical research methodology

In order to model the historical relationship between the three aspects of large firm growth and to study changes in the structure of the relationship itself, we employed a set of three equations related to DIV, INT and GWT, across firms and over time. In particular, it is worth noting that, according to the results of an earlier paper (Cantwell and Piscitello, 1997), the variables INT and DIV should be jointly modelled since causation between them runs in both directions and neither of them can be treated as strongly exogenous in the estimation of the parameters of the other. Our approach here has three advantages over similar kinds of previous empirical investigations. First, we consider explicitly the relationship between competence accumulation and DIV and INT. Other studies (of the diversification and internationalisation of production) have examined just the direct relationship between DIV and INT, treating the overall level and growth of competence of firms at best only implicitly, and often not properly considering it at all. Therefore, unlike other previous research which has been purely cross-sectional, we allow for changes over time and thus are also able to include a third variable (GWT).

Second, we control for the established or inherited level of competence in each firm through the use of a lagged dependent variable in each of the equations for DIV and INT. At any point in time, firms that are more capable than others will tend to have both a more diversified and internationalised competence, or in other words they have more widely dispersed learning or search activities (achieved in large industrial firms mainly through a greater spread of research and development activity). This problem has confronted cross-firm statistical studies such as those of Pearce (1983, 1993), which found a positive relationship between the extent of sectoral and geographical diversification across firms in a given period. It may be that the complementarity between DIV and INT across companies at a given point in time reflects their mutual positive dependence upon an omitted variable, namely the existing level of firm-specific competence. For this purpose a dynamic approach is required, and in our method this effect is allowed for through the introduction of lagged dependent variables, which proxy the previously established level of competence and enable us to model changes in the dependent variable rather than its level at each point in time.

Third, to consider separately the effects of increases in competence as opposed to established levels, we examine the impact of cross-company variations in rates of competence accumulation (GWT) upon shifts in the cross-firm structure of DIV and INT over time. Indeed, as explained already, with a lagged dependent variable in the DIV and INT equations, the other independent variables capture the pattern of changes in DIV and INT. If DIV and INT were virtually unchanged over time, then only the lagged dependent variable would be significant. If instead the GWT variable is significant as well, this implies that those firms with the highest rates of competence accumulation have achieved on average a greater change in DIV or INT in the period in question.

Hence, our model separately identifies the mutual effect of new competence creation on DIV and INT, having allowed for the association across firms between the existing level of competence and the current levels of DIV and INT. As argued earlier, we expect to find that the impact of competence accumulation on DIV and INT passed through three distinct historical phases. Over and above these effects, we examine whether there is a separate direct relationship between DIV and INT themselves. It may be that having allowed for the complementarity between DIV and INT which is attributable to variations across firms in competence and in competence accumulation, that no further direct association remains. However, with reference to our earlier argument about the third phase of large firm development involving the creation of internationally integrated corporate networks in which DIV and INT become more closely bound up with one another, we might expect that any additional direct positive association between these two variables would be a recent phenomenon. From somewhat different perspectives, Cantwell (1992, 1995), Granstrand (1998) and Zander (1997) have all suggested the emergence of a positive relationship in recent years between the diversification and the internationalisation of corporate technology.

Additionally, following an argument suggested by Andersen and Cantwell (1999), the degree of technological leadership of a firm (the extent to which it is specialised in the development of leading edge technologies for which opportunities are greater) is likely to influence both the form and direction of the structure of its technological competence as well as its capability to innovate. Therefore, since when examining the association between corporate technological leadership and competitiveness (growth) existing historical evidence suggests that sometimes leaders have an advantage, and sometimes followers have the competitive edge (Teece, 1992), it can be expected that the presence or absence of an effect of leadership upon competence accumulation varies over time.

4. The data

The study was based upon a database on the patenting activity in the US of the largest US and European companies over the period 1901-1995,[1] developed at the University of Reading (see Cantwell 1995). The firms included in the database were identified in one of three ways. The first group consisted of those firms which have accounted for the highest level of US patenting after 1969; the second group comprised other US, German or British firms which were historically among the largest 200 industrial corporations in each of these countries (Chandler, 1990); and the third group was made up of other companies which featured prominently in the US patent records of earlier years. In each case, patents were counted as belonging to a common corporate group where they were assigned to affiliates of a parent company.[2] The location of the original research facility that gave rise to each patent (the country of residence of the original inventor) is recorded in the data. The location of the parent company is another important dimension of the analysis, as this is treated as the home country or the country of origin of the corporate group. By consolidating patents attributable to international corporate groups, it is then feasible to examine the geographical distribution of the technological activity of these firms (Cantwell, 1995). In addition, the primary field of technological activity of each patent can be derived from the US patent class system, which provides a measure of corporate technological diversification. We have grouped these fields into 56 technological sectors (see Cantwell and Andersen, 1996).

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[1]The advantages and disadvantages of using US patents as an indicator of technological activity are well known and quite widely discussed in the literature (e.g. Schmookler, 1950, 1966, Pavitt, 1985, 1988). Concerning our analysis, the major problems are controlled for by the methodology adopted - *e.g.* by the use of ratio measures such as RTA or INT (see below) which normalise for differences in the propensity to patent across sectors or firms, or the elimination of sectors with small numbers of patents in the calculation of DIV - and by the fact that we consider only the largest firms, which have a high propensity to patent their commercially useful inventions.

[2]Affiliate names were normally taken from individual company histories.

In all, the historical path was traced of the US patenting activity from the beginning of the century of 857 companies or affiliates that together comprise 283 corporate groups.[3] In particular, we considered data on cumulated stocks of patents for individual years spaced at five year intervals. Starting with the 1930 cumulated stock we have 14 (1930, 1935, .., 1995) observations for each firm. The stocks for each year were accumulated from patenting over the previous 30 years, incorporating a straight line depreciation function as in vintage capital models, based on the assumptions that new technological knowledge is partially embodied in new capital equipment which has an average life of 30 years, but that the value of this knowledge (like the devices in which it is partly embodied) depreciates over time (see Cantwell and Andersen, 1996). The justification for this procedure is that in our case patents are used as a proxy for advances in underlying technological knowledge, rather than as a direct measure of the legal instrument of the patent itself, the life time of which is shorter. So, for example, the stock in 1930 represents a weighted sum of patenting between 1901 and 1930.

The group of companies used in the econometric analysis consists of 166 firms, which are the ones for which complete time series relating to the period under examination were available, plus the most significant cases in which firms present throughout the period undergo a change in identity owing to mergers, acquisitions or break-ups (as in the case of IG Farben and its successors). The choice of this set of firms allows us to infer from our study evidence of the 'life cycle' or stage of development of large companies (since they all came into existence at around the same time), as well as on the effect of changes in the international environment in which they operate[4]. The group obtained (see Tables 1 and 2) can be regarded

[3]Births, deaths, mergers and acquisitions as well as the occasional movement of firms between industries (sometimes associated with historical change in ownership) have been taken into account.

[4] It is worth noting that firms considered in the econometric analysis are those which satisfy a dimensional constraint which is necessary in order to avoid small number computational problems. The constraint requires that the stock of patents granted to a firm is at least 10 in each period considered. We conducted a sensitivity analysis to changes in the size of this constraint, and found that with a cut-off point anywhere between 10 and 30 the results of our estimates below were largely unaffected.

as quite representative of the world's largest firms in terms of technological development as measured by patenting, and it shows many of the same statistical characteristics as the overall database.[5]

5. Specification of the model

5.1. The measures of technological diversification, internationalisation and competence accumulation

The proxy for the degree of technological diversification of firm i is based on the consideration that technological diversification is inversely related to the extent of the concentration of the firm's technological specialisation in favoured sectors. The firm's specialisation can be measured by an index of its revealed technological advantage (RTA) which for each particular sector of technological activity is defined by the firm's share in that sector of US patents granted to companies in the same industry, relative to the firm's overall share of all US patents assigned to firms in the industry in question. Specifically, denoting as P_{ij} the number of US patents granted in sector or activity j to firm i in a particular industry, then the RTA index is defined as follows:

$$RTA_{ij} = \left(P_{ij} / \sum_{i} P_{ij} \right) / \left(\sum_{j} P_{ij} / \sum_{ij} P_{ij} \right)$$

The index varies around unity, such that values greater than one suggest that a firm is comparatively advantaged in the sector of activity in question relative to other firms in the same industry, while values less than one are indicative of a position of comparative

[5]The differences are mainly attributable to the fact that US firms were rather under-represented in the original data (since we included all US firms granted at least 30 patents per year historically, but all European companies granted at least 5 patents per annum), while Swedish firms were over-represented (owing to a particular search conducted on behalf of some Swedish colleagues, see Zander, 1997).

disadvantage. Importantly, the use of RTA index allows us to control for inter-sectoral and inter-firm differences in the propensity to patent (Cantwell, 1993, 1995) .

The degree of technological diversification of the firm is measured by the inverse of the coefficient of variation of the RTA index, CV_i, across all the relevant sectors for the firm.[6] Therefore, for firm i in each period considered, the proxy DIV_i for technological diversification will be the reciprocal of the CV_i. In particular:[7]

$$DIV_i = 1/CV_i = \mu_{RTA_i} / \sigma_{RTA_i}$$

where s_{RTA_i} is the standard deviation and m_{RTA_i} is the mean value of the RTA distribution for the firm i.

The firm's degree of internationalisation, INT_i, has been proxied by the foreign share, which is defined as the share of corporate patenting that is attributable to research located outside its home country in each period considered.[8]

Competence accumulation is defined both as the absolute and the proportional growth of the firm’s technological base in any period ($GWTA_{it}$ and $GWTP_{it}$), measured by the absolute and the proportional difference between the overall size of patenting at time t and t-1, respectively (that is, P_{it} - P_{it-1} and ln P_{it} -ln P_{it-1})[9].

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[6]The choice of the relevant sectors (from an initial 56) defines the range over which the RTA distribution is to be considered. We analysed two alternative measures. The first one is the coefficient of variation of the RTA distribution across all sectors in which firms in the relevant industry had a stock of at least 100 patents at some point during the period 1930-1990. In this case the number of sectors considered is the same for all firms in an industry, and it is fixed over time. The other one is the coefficient of variation of the RTA distribution across a variable number of sectors, according to the constraint that firms in an industry group collectively have an accumulated stock of at least 100 patents in each year considered separately. Although the two measures are strongly correlated, the latter one performs better in the following models and therefore has been preferred.

[7] The CV measure has often been used as well in the analysis of business concentration across firms within an industry, as opposed to concentration or dispersion across sectors within a firm (see Hart and Prais, 1956). It is worth noticing that alternative measures could be used (*e.g.* the Herfindhal index) but that for a given number of firms or sectors (N), there is a strict relationship between the Herfindahl index (H) and the coefficient of variation (CV) (Hart, 1971). The relationship is: $H=(CV^2+1)/N$.

[8]Using the same procedure applied to build the proxy DIV, we considered a second proxy defined as the coefficient of variation across national shares of patenting for the firm. Nevertheless, this is strongly correlated with the foreign share measure and therefore we preferred the latter which is also the proxy more commonly used in the literature. Results of the correlation analysis are available on request.

[9] It worth noting that for proportional growth we also tried the proxy given by $(P_{it} - P_{it-1})/P_{it-1}$.

The statistical properties of the four proxies considered for technological diversification, internationalisation, and competence accumulation (DIV, INT, GWTA and GWTP), are illustrated in Table 3.

5.2. The model

The model considered in order to represent the relationship between the three aspects of firm growth and to detect any general historical shift between them, starts from the results achieved in a previous study conducted on the same data set, where the null hypotheses of absence of mutual (Granger) casuality between internationalisation and technological diversification had been rejected (see Cantwell and Piscitello, 1997, and Holtz-Eakin *et al*, 1988, for details of the methodology employed). Therefore, these two variables are jointly modelled through simultaneous equations. Specifically, since INT and DIV cannot be considered as strongly exogenous in their estimation, INT_{it} and DIV_{it} have each been introduced as explanatory variables in the DIV_{it} and the INT_{it} equation respectively, in addition to competence accumulation ($GWTA_{it-1}$ and $GWTP_{it-1}$), and the previous level of diversification and internationalisation (INT_{it-1} and DIV_{it-1}). Moreover, the size of the firm's technological base ($SIZE_{it-1}$) has been introduced as a control factor.

Similarly, a third equation representing firms' growth of technological capabilities has been modelled as a function of the earlier technological diversification and internationalisation strategies pursued by the firm, in order to capture feedbacks from these strategies to an enhanced accumulation of competence; additionally, the size of the firm's technological base ($SIZE_{it-1}$) and the firm's technological leadership ($LEAD_{it-1}$) have been considered in the model.

The model is a dynamic cross-section analysis in accordance with our central aim of examining shifts over time in the distribution of competence accumulation across large firms.

Indeed, for the purpose of our analysis, which aims to investigate the changing nature of the interrelationship between technological competence accumulation, diversification and internationalisation, a dynamic cross section estimator is more appropriate than a panel estimator (of the kind that derives essentially from the extension of the methods of time series econometrics to panel data analysis as developed *e.g.* by Pesaran and Smith, 1995, 1997; Ahn and Schmidt, 1995; Lee, Pesaran and Smith, 1997; Pesaran and Zhao, 1998; Pesaran, Shin and Smith, 1999) since competitiveness and performance are by their nature relative concepts[10]. Therefore, we run a series of levels cross section regressions at different points in time to examine influences on changes in the structure over time, as well as first difference cross section regressions in order to allow for the possibility of coefficient heterogeneity[11].

The inclusion of a lagged dependent variable on the right hand side of a levels regression (or expressing the dependent variable in first difference form) allows us to take into account the temporal dimension of the relationship between the different aspects of corporate growth, and so while previous studies have focused essentially on the static cross-section association between DIV and INT, it becomes possible here to analyse the dynamic nature of the relationship too. In particular, having controlled for the established level of competence, we want to test whether (period by period, over time) the firms that e.g. increased their competence the most were also those that geographically and sectorally dispersed it the most,

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[10] In fact, in a panel estimator, cross sectional observations would be pooled in order to run a single time series regression and individual heterogeneity is then controlled for by cross-sectional *fixed effects*. In examining a multi-country empirical analysis of the Solow growth model, Pesaran and Smith (1995) and Lee *et al* (1996) suggest estimating the coefficient of individual time series regressions for each country (or group of countries) and examining the distribution over groups of these estimates. In our case, the heterogeneity of individual firms is allowed for by introducing variables that represent their individual characteristics (namely firm- and industry-specific factors), instead of calculating a mean-group estimator. On the contrary, in studies like ours the latter procedure seems to be inappropriate since the interest lies precisely in the cross sectional structure or the pattern of individual heterogeneity, and in how it evolves over time.

[11] Indeed, if there is individual firm heterogeneity captured by the intercept α_i in the equation $y_{it} = \alpha_i + \beta x_{it} + \lambda y_{i,t-1} + \varepsilon_{it}$, then since we estimate $y_{it} = \alpha + \beta x_{it} + \lambda y_{i,t-1} + ((\alpha_i - \alpha) + \varepsilon_{it})$, the heterogeneity term in the disturbance $(\alpha_i - \alpha)$ could be correlated with the lagged dependent variable which is determined by $(\alpha_i - \alpha)$. In the context of our model, this would occur if the value of one of our dependent variables increased (or decreased) persistently in certain firms but not in others. The problem can be shown not to arise when first difference cross-section regressions and the traditional levels cross-section regressions yield similar results (the authors are particularly grateful to Ron Smith for this suggestion).

relative to other firms in the distribution. Thus, a significantly positive slope coefficient implies an association with a change rather than in the level of the dependent variable (because of the inclusion of the lagged dependent variable on the right hand side) - *i.e.* the firms with the highest values of the independent variable also tend to be those which most increase the dependent variable. Indeed, since we expect the cross-sectional structure to be fairly stable over time (*i.e.* the structure shifts only gradually over time partly due to our use of patent stocks), we expect that the coefficient of the lagged dependent variable will not be too far from unity. Besides the fact that we are using patent stocks that change completely only over periods of 30 years (not at 5-year intervals), we have economic reasons to believe that individual firm heterogeneity follows a fairly persistent pattern. Among large firms distributions of competence (and its various dimensions) do not change very rapidly over time. So-called 'competence-destroying' innovations are unusual rather than frequent occurrences (Patel and Pavitt, 1998). The test of our belief that the coefficient on the lagged dependent variable should be genuinely close to one is that our regressions in first difference form should yield very similar results to levels regression (see footnote 11 above).

The models considered consist then of the two following sets of equations:

$$DIV_{it}=\lambda_{0t}+\lambda_{1t}DIV_{i,t-1}+\lambda_{2t}INT_{it}+\lambda_{3t}SIZE_{i,t-1}+\lambda_{4t}GWT_{i,t-1}+\varepsilon_{it}$$

$$INT_{it}=\pi_{0t}+\pi_{1t}INT_{i,t-1}+\pi_{2t}DIV_{it}+\pi_{3t}SIZE_{i,t-1}+\pi_{4t}GWT_{i,t-1}+\nu_{it}$$

$$GWT_{it}=\mu_{0t}+\mu_{1t}GWT_{i,t-1}+\mu_{2t}SIZE_{i,t-1}+\mu_{3t}INT_{i,t-1}+\mu_{4t}DIV_{i,t-1}++\mu_{5t}LEAD_{it-1}+\sigma_{it}$$

where:

$i = 1,...., 166$; $t = 1935,...., 1995$;

$SIZE_{it}$, is the overall size of the technological activity of the firm i, measured by the logarithm of the total patent stock of the firm at time t;

GWT_{it}, is a measure of competence accumulation (both in proportional and absolute terms);

$LEAD_{it}$, is the technological leadership measure measured by the weighted averages of the RTA index for each firm across the fastest growing sectors for each industry/period combination[12].

While the second set of equations is:

$dDIV_{it,t-1}=\lambda_{0t}+\lambda_{1t}INT_{it} +\lambda_{2t}SIZE_{i,t-1}+\lambda_{3t}GWT_{i,t-1} +\varepsilon_{it}$

$dINT_{it,t-1}=\pi_{0t}+\pi_{1t}DIV_{it}+\pi_{2t}SIZE_{i,t-1} +\pi_{3t}GWT_{i,t-1}+\nu_{it}$

$dGWT_{it,t-1}=\mu_{0t}+\mu_{1tt}SIZE_{i,t-1}+\mu_{2t}INT_{i,t-1}+\mu_{3t}DIV_{i,t-1}++\mu_{4t}LEAD_{it-1} +\sigma_{it}$

6. The results of the econometric analysis

The results of the analysis for the general model are shown in Tables 4a, 4b and 4c, in which we report the estimated value of the coefficients and the values of t-statistics for each period considered, from t=1935 to t=1995, for the DIV, the INT and the GWT equations (in both absolute and proportional terms), respectively[13]. The results of the standard tests all suggest that the model has been estimated reliably - the residuals are approximately normal, there is little autocorrelation, and the test for the absence of heteroscedasticity fails to reach the standard significance levels only occasionally in the DIV equations. Likewise, Tables 5a, 5b and 5c (which are in the Appendix) report results of the first difference models.

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[12] In particular, we selected the 6 fastest growing sectors (from among the 56 technological fields considered) for each 5-year period, and within each of the 4 principal industrial groupings of firms (industries dependent mainly on chemical, electrical, mechanical or transport technologies respectively). Then, we calculated both the weighted and the unweighted averages of the RTA index across the relevant 6 sectors for each firm at the beginning of each period. The sectors chosen reflect growth in the subsequent period - thus the 'leadership index' for 1930 is based on choice of the fastest growing sectors in the following period 1930-35 (defined by the proportional increase in patent stock). The weighted average treats the sectors as a common aggregate entity, and so the average RTA is weighted towards the values of whatever happen to be the largest sectors. The unweighted average simply takes the mean of the 6 RTA values of the individual sectors, calculated at the 56-sector level of disaggregation. In the weighted case $LEAD_{it} = (\Sigma_j P_{ijt} RTA_{ijt})/(\Sigma_j P_{ijt})$, and in the unweighted case $LEAD_{it} = \Sigma_j RTA_{ijt} / 6$, where the j's (j=1, .. , 6) are the six fastest growing technological sectors between t and t+1 in the relevant industry group for firm i. Both versions of the index were tried in the models but the weighted variant seems to behave better.

[13] Similarly, Tables 5a, 5b and 5c report results from the first difference models (in the Appendix). Nonetheless, since the results are - as expected - very similar to those in the traditional levels regressions, we preferred to put them in an Appendix.

Tables 4a and 4b show the results obtained for the DIV and INT equations run simultaneously through a 2SLS technique based on instrumental variables. It is worth observing that the autoregressive part, that is the earlier levels of diversification or internationalisation respectively, is positive and highly significant ($p<.01$) throughout the period considered. As was expected, this implies that the cross-company structure of DIV and INT does not shift that markedly over time, at least not in the short term. Meanwhile, the role of GWT changes over time, as hypothesised above, and bearing in mind that as outlined earlier, with a lagged dependent variable the other independent variables explain mainly variations in the pattern of changes in DIV and INT, rather than in the pattern of their levels. We can identify a first phase in large firm growth, from the interwar period through to the early 1970s, in which faster competence accumulation led to increases in technological diversification. In this first phase, the largest firms accumulated competence by diversifying their technological base but while they exploited their competence through internationalising their markets, at this stage they internationalised R&D as a means of adapting products to local tastes and processes to local resource and production conditions, rather than in an attempt to internationalise the process of competence creation itself (Cantwell, 1995).

The second phase runs from the late 1970s until the early 1980s, in which there was little relationship between GWT and changes either in INT or DIV. By this stage there had been a shift in technological paradigm (Freeman and Perez, 1988), such that the potential for the joint exploitation of economies of scale and scope through technological diversification in large firms (Chandler, 1990) had more or less run its course (Cantwell and Fai, 1999b). Moreover, the development of localised asset-seeking investment (Dunning, 1995) through the creation of corporate international networks had get to properly take effect with the odd exception.

In the third phase, beginning only in the late 1980s, competence accumulation (in absolute terms) began to impact positively upon both DIV and INT. Moreover, this is a joint effect as hypothesised, of a kind that was not observed in the first phase (in which there was at times a positive impact of GWT on DIV but not INT), which began in 1990 and was sustained in 1995. The combined effect of competence accumulation on DIV and INT is consistent with the formation of internationally integrated networks in the largest firms, in which new fields of competence can be sourced from geographically dispersed sites.

Moreover, it is worth observing that in the same period competence accumulation (in proportional terms) impacts negatively and significatively on INT, which implies that simple international extension was not the means by which multinational networks were developed by the fastest growing firms in their process of competence accumulation. Indeed, they tended to be the firms that had the advantage of having already established a base level of international technology creation, and so were able to expand through a restructuring of their international network, which took the form concentrating more specialised lines of development in each major centre in accordance with their respective comparative advantages in innovation (Cantwell and Piscitello, 1999). This might be related to the argument of Porter (1994, 1996) that the firm can build competitive advantage through creating assets in a suitably specialised location, as part of a local cluster of activity of the relevant kind.

The theoretical rationale for the recent international integration of activity within the biggest firms is that the economic benefits attributable to a more refined locational division of labour within the multinational company have often come to outweigh the costs of being less nationally responsive in each market, costs associated with adverse political repercussions and the continued national differentiation of demand (Doz, 1986). In an integrated multinational company network each affiliate specialises in accordance with the specific characteristics of local production conditions, technological capabilities and user requirements. The network benefits from economies of scale through the local concentration of particular lines of activity (increasing returns from local research in a specialised field as opposed to research in general), economies of locational agglomeration through an interchange with others operating in the same vicinity in technologically allied fields, and economies of scope through the international intra-firm coordination of related but geographically separated activities. The experience acquired in a specialised activity in one location creates technological spillovers that can be passed on to other parts of the multinational company network elsewhere. It has been shown that in recent times, in industries in which such net advantages to multinational integration were available, multinationality has been a source of competitive success and faster growth (Cantwell and Sanna-Randaccio, 1993).

Having controlled through the lagged dependent variable for the positive association between the levels of competence, DIV and INT across firms at any point in time, little direct relationship between DIV and INT themselves remain, in contrast to the suggestions made in some purely cross-sectional static studies. However, it is interesting that the only significantly positive coefficient on either DIV or INT in the equation of the other occurs in 1990, showing the positive effect of DIV on increasing INT. This is consistent with the view that we may have entered a new third phase, in which competence accumulation and the diversification and internationalisation of corporate technology have become more closely interrelated with each other than they were in the past.

From Table 4a, larger technological size is occasionally associated with greater rises in technological diversification. This is consistent with a hypothesis of a positive relationship between firm size and technological diversification (see Granstrand and Sjölander, 1990; Oskarsson, 1993). By contrast, from Table 4b, size seems to have had the effect of sometimes reducing changes in INT, in the 1950s and again more recently. This is in line with a so-called 'catching-up' effect, in which the smaller among the set of the world's largest industrial firms have relatively increased the extent of their internationalisation at times in which there are greater potential benefits to be had from the latter (Cantwell and Sanna-Randaccio, 1990).

Turning finally to Table 4c, in the GWT equation - estimated through OLS - the lagged dependent variable is again significantly positive throughout, except for one notable interval in the late 1960s, in which the structure of technological competitiveness across large firms seems to have shifted quite dramatically. Yet in general, competence accumulation has been a path-dependent process (Oskarsson, 1993). Occasionally, we observe significantly positive feedbacks from DIV and INT. We might expect these feedbacks to become stronger and more frequent in the future, if our characterisation of a third phase is accurate, in which competence accumulation is organised through an internationally integrated network. The technological size of the firm is sometimes negatively related to further competence accumulation, which is consistent with explanations of those such as Penrose and Williamson of why large size may impose a constraint upon further growth (for a discussion of this point, see Cantwell and Sanna-Randaccio, 1992). Concerning the leadership variable, it is worth observing that it is always positively related both to the absolute and the proportional growth. However, while it seems only occasionally to significantly influence the competence accumulation process historically, being at the leading edge of development or at the technological frontier seems to assume an important role in the 1990s.

7. Conclusions

Looking back to the first phase of large firm growth in the inter-war and early post-war periods, there was no particular linkage running from either competence accumulation or corporate technological diversification to the internationalisation of a firm's capability. In the past, foreign technological activity exploited domestic strengths abroad, it was located in response to local demand conditions and its role ranged from the adaptation of products to suit local tastes through to the establishment of new local industries. The capacity to develop internationally derived from a position of technological strength in the firm's domestic base and led to similar lines of technological development being established abroad. Today, foreign technological activity increasingly aims to tap into local fields of expertise and to provide a further source of new technology that can be utilised internationally. Multinational companies are increasingly committed to the development of international networks in order to exploit the locationally differentiated potential of foreign centres of excellence. A newly emerging complementarity between competence accumulation and the diversification and internationalisation of corporate technology is thus at work. If our analysis is right that internationally integrated corporate networks create a greater mutual complementarity between these three variables, then the effect should continue into the future, since the third phase of development that we have identified would be at a comparatively early stage.

Although by restricting our analysis to firms in existence in some form throughout the 1930-90 period - akin to the methodology of Hart and Prais (1956) - enables us to make reference to a large firm 'life cycle' effect, it might be objected that firms which have been formed and become large since 1930 may have behaved differently. However, to the extent that they have behaved differently, there are grounds for thinking that their inclusion would have reinforced our results. The leading Japanese firms, and more recently the new multinationals of the newly industrialised countries, moved to both internationalise and diversify their technological base at a much earlier stage of their development than had the largest US and European companies (Ozawa, 1991; Tolentino, 1992). In other words, their life cycles have been similar in direction, but much quicker. Therefore, we would expect the addition of these firms to strengthen the effects that we have observed from the historically longer-established set of companies.

Apart from waiting for more data to extend the same type of empirical analysis further into the future, we need to know more about the details of various individual company strategies to better inform and interpret such econometric studies of average trends. It would be useful to be able to say more about how the geographical and sectoral dispersion of new competence accumulation works out at the level of individual firms. For example, even if there is a recent positive association between INT and DIV, we may wish to distinguish between cases in which new international research facilities engage in areas of technological development that are new to the firm, from cases in which an extension of existing lines of innovation abroad releases resources at home to facilitate technological diversification in the parent company. For an initial attempt to support our econometric analysis with a more detailed case study approach see Cantwell and Piscitello (1999).

We need to know more as well about changes in the exact geographical composition of technological activity in each industry. It may be that corporate strategies for international integration are locationally quite specific, both in the macro-regional sense that cross-border interchanges are more easily managed between countries that are themselves closer and more integrated (such as within the European Union), and in the micro-regional sense that innovative activity in some branch of technology may agglomerate in distinct centres of excellence. These issues will be the subject of related future research.

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Table 1 - Data characteristics by industry

		283 firms		166 firms	
		No.	%	No.	%
1	Food, Drink, Tobacco	14	5.0	6	3.6
2	Chemicals	44	15.5	25	15.1
3	Pharmaceuticals	17	6.0	6	3.6
4	Metals, Mechanical engineering	69	24.4	39	23.6
5	Electrical equipment, Office equipment/computing equipment	44	15.5	29	17.4
6	Motor vehicles	22	7.8	17	10.3
7	Aircraft/aerospace, Other transport equipment	18	6.4	15	9.0
8	Textiles	9	3.2	5	3.0
9	Paper products, Publishing	11	3.8	2	1.2
10	Rubber and plastic products	9	3.2	7	4.2
11	Scientific and professional instruments	7	2.5	6	3.6
12	Coal and petroleum/oil	12	4.2	10	6.0
13	Non-metallic mineral products/building materials, Other manufacturing	7	2.5	4	2.4
	TOTAL	283	100.0	166	100.0

Table 2 - Data characteristics by country

	283 firms		166 firms	
	No.	%	No.	%
USA	93	32.8	75	45.2
Germany	40	14.1	24	14.4
UK	65	22.9	28	16.9
Italy	7	2.5	4	2.5
France	29	10.2	16	9.6
Netherlands	2	0.7	1	0.6
Belgium	1	0.4	1	0.6
Switzerland	9	3.2	7	4.2
Sweden	38	13.4	10	6.0
Total	283	100.0	166	100.0

Table 3 - Statistical properties of dependent variables (166 firms)

Variables	Mean	Std Error	Minimum	Maximum
DIV30	0.5405	0.2895	0.2041	1.8109
DIV35	0.5444	0.2953	0.1925	1.9177
DIV40	0.5473	0.2685	0.1890	1.6993
DIV45	0.5539	0.2762	0.1890	1.5731
DIV50	0.5642	0.2789	0.1826	1.5416
DIV55	0.5928	0.2906	0.1796	1.5606
DIV60	0.6041	0.2899	0.1770	1.7968
DIV65	0.6041	0.2910	0.1690	1.6485
DIV70	0.6279	0.2907	0.1690	1.6288
DIV75	0.6368	0.2861	0.1722	1.8897
DIV80	0.6531	0.2895	0.1747	1.9086
DIV85	0.6560	0.3056	0.1686	2.0858
DIV90	0.6544	0.2957	0.1659	1.8401
DIV95	0.6563	0.3026	0.1669	1.7868
FS30	7.4077	18.0688	0.0000	100.0000
FS35	8.6370	19.6412	0.0000	100.0000
FS40	8.9308	20.4407	0.0000	100.0000
FS45	9.1555	20.3777	0.0000	99.3292
FS50	8.6966	19.2997	0.0000	99.5143
FS55	9.4548	19.5836	0.0000	99.6577
FS60	10.1183	20.3417	0.0000	98.8722
FS65	10.8689	20.5671	0.0000	94.3323
FS70	12.7118	21.2033	0.0000	94.1569
FS75	13.5248	20.7207	0.0000	93.4652
FS80	14.0441	20.4352	0.0000	92.2170
FS85	14.5764	20.1419	0.0000	91.8662
FS90	15.9479	20.4250	0.0000	92.4974
FS95	17.7539	22.0489	0.0000	100.0000
GWTA35	127.9468	298.7989	-51.0000	1858.2333
GWTA40	122.8052	295.1533	-119.4667	2046.9667
GWTA45	71.5813	207.1855	-659.3667	1260.7667
GWTA50	34.3454	444.3119	-4193.1000	3147.0000
GWTA55	37.8203	178.0372	-962.0667	956.6000
GWTA60	126.1667	282.6158	-492.7000	2514.8000
GWTA65	133.6267	290.1225	-797.5667	1681.8667
GWTA70	255.8492	623.8669	-2932.4667	4741.6333
GWTA75	261.7315	382.7463	-127.3667	2306.9333
GWTA80	81.1243	314.4801	-1063.8333	1796.5333
GWTA85	33.6189	283.7520	-1294.7333	1464.1333
GWTA90	25.5671	346.1314	-939.5000	1920.1333
GWTA95	6.1253	419.2143	-1585.7333	2512.7000
GWTP35	0.7207	0.7237	-0.2986	4.0307
GWTP40	0.3914	0.5047	-0.3962	2.4636
GWTP45	0.1308	0.3693	-0.4495	1.4905
GWTP50	0.0319	0.3238	-0.6770	1.1017
GWTP55	0.1566	0.4041	-0.6576	1.7999
GWTP60	0.3207	0.5002	-0.9404	2.3467
GWTP65	0.2380	0.4288	-2.3273	1.4872
GWTP70	0.4797	0.6198	-0.4257	4.4006
GWTP75	0.3305	0.3477	-0.4636	2.0287
GWTP80	0.0963	0.1997	-0.5740	0.6517
GWTP85	0.0332	0.1890	-0.8511	0.6791
GWTP90	0.0175	0.3515	-1.6917	2.9347
GWTP95	-0.0832	0.2427	-0.8904	0.8500