Technology Relatedness and Corporate Diversification 1890 – 1995*

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Abstract

Received wisdom suggests that seemingly unrelated technologies become more related during the second half of the twentieth century. In this paper, quantitative measures of the relationship between technologies are used to document this received wisdom. Our measures suggest that certain technologies may be identified as *pervasive* – that developments in one technology have a pervasive impact upon developments in other technologies. We also identify the changing role of *associated* and *non-associated* firms. The early parts of the twentieth century were characterised by firms that developed pervasive technologies and were responsible for their diffusion. Conversely, in the latter part of the twentieth century, *non-associated* firms appear to have been increasingly responsible for the diffusion of these technologies.

Technology Relatedness and Corporate Diversification 1890 – 1995

The pace at which the scientific and technological complexity of products and processes is increasing has escalated substantially in recent time. This is a result of the growing science base of industrial technology together with the spread of new technological paradigms (or regimes) that pervade an increasing number of industries through time (Dosi, 1982; Freeman and Perez 1988; Cantwell and Fai, 1997; Von Tunzelmann and Wang, 1999; Cantwell and Santangelo, 2000). Operating within such environments of converging or increasingly inter-related technologies, large firms are seen to accumulate and maintain a much broader technological base thereby becoming *Multi Technology Corporation* (MTC) (Granstrand and Sjölander, 1990; Granstrand et al. 1998). By broadening their technological competencies in a coherent manner, firms widen the scope of their absorptive capacity (Cohen and Levinthal 1989; Kogut 1983, 1989; Patel and Vega, 1999), and create corporate environments that are conducive to a type of multi directional *technological osmosis.*

Although corporate diversification has long been considered an integral part of growth and sustained competitive advantage, the underlying motivation is believed to have changed in recent times. In the latter part of the nineteenth and for most of the twentieth century, firms grew by capturing the joint economies of scale and scope through diversifying across products and geographical markets (Chandler, 1990). Latterly, corporate diversification is more intimately connected with the pressure to broaden the technological activities of the firm. Above all, firms must now seek to ensure a high degree of overall technological coherence across the operations. This often necessitates product restructuring in large firms in order to take advantage of increasing levels of corporate technological coherence (Cantwell and Fai, 1999, Cantwell and Santangelo, 2000).

The technological opportunities facing firms change through time. As technological paradigms shift and different technologies become increasingly relevant (or *pervasive*) to a growing number of industries, the nature of corporate activity changes. Through time, we suggest that firms have been steadily adapting their research profiles to embrace such changes and secure Schumpeterian-type (innovative) profits. As firms change the co-development of specific technology combinations through time, technologies that were formerly classified as *unrelated* become increasingly *related* to one another.

This study seeks to decipher the evolution of such technological relationships. The remainder of this paper is organised as follows. The first section elaborates upon changing technological opportunity and discusses the role of *pervasive* technologies. In section two, we briefly discuss the data used for this study and outline an empirical metric that captures technological relatedness. Section three reports our results and identifies the key technology combinations that drove (i) the chemicals paradigm in the earlier years of the last century and (ii) the electronics paradigm in more recent times. In section four, we identify the industries that have been driving these technology combinations and discuss the relative role of *associated* and *non-associated* industries. We conclude by summarising our key findings and suggest directions for future research.

1. Innovation and the Business Cycle

Using international data on prices, wages, interest rates and industrial production and consumption, Russian economist, Nikolai Kondratieff (1925) drew attention to the fact that economic activity tends to occur in long waves. Schumpeter (1939, 1942) advanced this idea by suggesting that each wave or business cycle is unique and underpinned by different groups of innovations, which take place within different industrial clusters. These innovations are the *modus operandi* of competition because they affect profits in a very fundamental way. Rather than the traditional preoccupation with price competition, Schumpeter (1942, p. 84) argues:

> '(But) in capitalist reality as distinguished from its textbook picture, it is not that kind of competition which counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization (…….) (*This*) strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives. This kind of competition is as much more effective than the other as a bombardment is in comparison with forcing a door ….”

New innovations or technological discoveries that emerge at various points in time renew business confidence, fuel activity and stimulate an upsurge in investment. Contrary to price based competition, which results in a zero sum game, the alternative Schumpeterian-type competition is centered on these new innovations and is a positive sum game. Rather than profits being captured through the spheres of exchange and distribution, they are associated with more profound or deep-rooted changes at firm level. This reliance on such *innovative* *profits* is believed to be increasingly important within the latest technological paradigm (Cantwell and Santangelo, 2000)[1].

Neo-Schumpeterian scholars, Christopher Freeman and Carlota Perez (1988) identify key technological changes that have underpinned such waves of business activity through the centuries[2]. The authors identify five long waves of economic prosperity. These are (i) The Industrial revolution 1770/80 - 1830/40 (ii) Victorian prosperity 1830/40 – 1880/90 (iii) The 'Belle Epoche' 1880/90 – 1930/40 (iv) The Golden age 1930/40 – 1980/90 and (v) the upswing that has been underway since the 1990s. As is apparent from Figure 1, each successive upswing in business activity has been underpinned by a variety of technological discoveries.

FIGURE 1 HERE

Long waves of activity commence once a new set of technologies have been developed and come into general use. These may be classified as *General Purpose Technologies* (GPT) (Bresnahan and Trajtenberg 1995). Since they are inherently complementary to other technology areas, they quickly become *pervasive* across technological space. As well as giving rise to entirely new sectors, these technologies become increasingly relevant to various branches of the economy through time. When this happens, the prevailing *technological system* (or paradigm) changes (Freeman and Perez. p. 46). For firms, it is insufficient to merely recognise the onset of a new wave of technological innovation, they must also identify ways of integrating the old with the new. By harnessing advances made in other domains and by integrating them into their extant production processes, firms can catapult themselves into the new paradigm thereby ensuring future profitability.

1.1 Wave characteristics

[1] The mechanism through which innovation results in higher overall profit generation has been modeled as a process by which wage increases tend to follow productivity increases but with a lag. Because of this lag, faster innovation rates and productivity increases result in higher shares of profits in income. Even if wages do not track productivity therefore, they still increase faster in innovation rich environments (Cantwell 1989, 1992).

[2] Schumpeter (1942, p. 83) notes that because innovation waves take a considerable amount of time to unfold, it is imperative to analyse such phenomena over long periods of time: 'since we are dealing with a process whose every element takes a considerable amount of time in revealing its true features and ultimate effects, there is no point in appraising the performance of that process *ex visu* of a given point in time, we must judge its performance over time, as it unfolds through decades or centuries'.

It is evident from Figure one that the duration of these waves of innovation appears to be decreasing through time. Although perhaps a rather crude estimation, we see that as we move from the first to the most recent wave, the length has been cut in half. This means that technological change is occurring within increasingly shorter time frames serving to highlight the pressures confronting firms as they try to maintain their technological leads and market positions. In addition, heightened pervasiveness is believed to characterise the contemporary technological realm since the current wave of information and communication technologies (ICT) act as both an agent and a catalyst for increased technology fusion. This has the scope for substantially increasing the rate of innovation through an increase in technological relatedness and a shift in the profile of that relatedness (Kodama, 1986, 1992; Cantwell and Santangelo, 2000).

In addition, science and technology are becoming increasingly intertwined through time. Although there are early examples of scientific discovery fuelling technological advance – for example, the discovery of atmospheric pressure is a good illustration of how an early scientific finding gave rise to a new technology (the steam engine), it is far from typical of the time. After around 1860, gradually at first and then more rapidly, science began to play a bigger role. Chemistry was the first industrial science that steadily gave rise to new industrial techniques and new materials and products. Once physics became an industrial science, electricity and telecommunication technologies were born. With the passage of time, science has become increasingly important to industrial research (cf. Rosenberg, 1992).

1.1.1 *Out with the old in with the new*

The long waves of activity eventually start to slow as the driving technologies mature, opportunities dwindle and returns to investors decline. After a period of much slower expansion, business slowdown and economic recession become inevitable. This is then followed by a new wave of fresh innovations, which destroy the old way of doing things and create the conditions for a new upswing. The entrepreneur's role, as Schumpeter saw it, was to act as a ferment in this process of *creative destruction*, allowing the economy to renew itself and bound onwards and upwards again.

Some of the changes inherent in the process of creative destruction can be so far reaching that they stimulate a plethora of fundamental shifts across the economy. This signals the emergence of a *new techno-economic paradigm* (Freeman and Perez, 1988)[3]. Developing initially within the old, the new paradigm demonstrates its true potential during the downswings of the previous cycle. Echoing Schumpeter's notion of *creative destruction* therefore, the authors emphasise that a crisis of structural adjustment involving deep social and institutional changes is a necessary prerequisite to the establishment of the new techno-economic paradigm (Freeman and Perez 1988, p. 45):

> '….major long term fluctuations in economic development (therefore) cannot be explained simply in terms of conventional short- and medium-term business-cycle theory but require an additional dimension of analysis. This involves the rise of new technologies, the rise and decline of entire industries, major infrastructural investments, changes in the international location of industry and technological leadership and other related structural changes, for example in the skills and composition of the labour force and the management structure of enterprises'

Following Schumpeter, this approach points to the inevitability of rising and declining industries through time. This view is similar to the ideas implicit in Vernon's (1966) Product Life Cycle Model.[4] As noted by Sabel et al. (1989, p. 377), if this model is taken to its natural conclusion:

> 'it is an easy step – not required however by the original argument – to the assertion that whole industries or even sectors of the economy rise and fall according to an analogous logic'.

An alternative view rejects this division of the economy into rising and declining sectors and rather views economic development as a sequence of core technologies that are transmitted across sectors through time (Van Tulder and Junne, 1988). The *core technology* concept used by the authors in their discussion of European multinationals is similar to the above discussion of *pervasive* technologies. However rather than technological dispersion resulting in the rise and decline of entire industries (as suggested by Schumpeter 1942/1966, Freeman and Perez, 1988), if used in novel combination, it can result in a revitalisation of extant industrial activities. From a corporate policy perspective therefore, future profitability can be secured by *shifting* and *deepening* the existing resources of the firm. Shifting involves the transfer of

[3] As noted by the authors, the term 'techno-economic' rather than 'technological paradigm' is used because the changes involved in the former go beyond engineering trajectories for specific product or process technologies and affect the input cost structure and conditions of production and distribution throughout the system (*ibid*. p. 47)

[4] Vernon describes how new products originate in the most developed countries and regions of the world and are then diffused to less developed areas once they reach maturity. To maintain their lead, developed countries must therefore invest increasing amounts to create new products and new technologies.

resources from old to new uses, while deepening seeks to increase the productivity of resources in their existing uses (Ergas, 1986 - referenced in Junne, 1989). Both strategies are an inherent part of a broader internationalisation process that requires the firm to adopt an innovative approach to its activity even though it is not operating at some notional 'technological frontier' (Cantwell and Santangelo, 2000, p. 134).

An example of these two strategies is that of German industrial activity in the last number of years. A *shifting* process was very clearly evident in the case of industrial revival within the Ruhr area. Whereas producers within area were traditionally the key international players within the coal and steel sector, this changed in the 1970s as the industry came under increased pressure on a number of fronts[5]. By the 1980s, factory closures and a shift of economic activity to the more prosperous south of Germany became characteristic of the re-organisation process that resulted[6]. In addition however, the leading firms (e.g., Thyssen, Krupp and Mannesmann) began to reduce activities within their central steel divisions in favour of new fields of production (Grabher, 1991, p. 68). Plant engineering, environmental technology, mechanical engineering and electronics emerged as the sectors at the center of this industrial reorientation[7]. Cumulated skills from the historically strong industries were combined with alternative technologies to develop new areas of strength.

On the other hand, a deepening process is evident in the traditional industries (machine tools, automotive parts etc) of Baden Württemberg. By applying the latest electronic components to traditional products and production processes, they have become high-tech industries. By engaging in this process of *deepening*, they have managing to survive and maintain leading positions in the midst of growing international competition (Sabel et al. 1989).

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[5] Having been strongly fuelled by the post war period of reconstruction, the strength of this region's industries started to weaken as early as the 1960s and was under increasing pressure throughout the 1970s. This was attributed to a number of demand and supply side factors. In addition to the fact that the enormous spurt in the demand for basic materials and capital goods weaned as the process of reconstruction reached completion, the coal and steel industries were also faced with internationally declining income elasticities of demand. Increased competition from the newly industrialised countries further fuelled the decline (Grabher, 1991).

[6] For example, the oldest firm in the iron and steel industry, the Gutehoffnungshütte (founded in 1758) transferred it's headquarters and research and development department from Oberhausen to Munich.

[7] Plant engineering was originally linked to serving the needs of the maintenance and repair departments. As steel capacity was cut, firms began to market their plant-engineering know-how externally which led to an organisational differentiation and decentralisation that was geared to product markets rather than to internal production processes. Because the plant engineering divisions came under increased pressure to meet the environmental requirements of their customer markets (which in turn were being shaped by the steady

These cases highlight the importance of technological combination to leverage the existing capabilities of the corporation. Firms must leverage new discoveries by finding ways of using them in novel combinations. In such instances, Schumpeter's process of C*reative Destruction* may be thus traded for one of C*reative Accumulation* as firms build on and redefine their existing competencies (Pavitt, 1998).

While these processes of technological shifting and deepening have received considerable attention in the literature, empirical identification of these technologies has proven elusive. The remainder of this paper is concerned with the development and evaluation of these changes. Our concern is to measure how different technologies are *related* to on another and whether this relatedness has increased through time.

2. Data and Methodology

This study uses US patents granted to large US and European firms over the period 1890 – 1995 to calculate technology relatedness. Patents granted by the US Patent and Trademark Office (USPTO) are particularly useful since they classify technologies in a historically consistent manner. We use the 401 patent classes of the USPTO classification system but further collapse these classes into 56 technology sectors (see appendix A for details).

The selection of large firms for the study was made in three groups according to the following criteria. The first group consisted of those firms, which have accounted for the highest level of US patenting since 1969. The second group comprised other British, German or US firms which were historically amongst the largest 200 industrial corporations in each of these countries (based upon Chandler, 1990). Finally, the third group was made up of other companies that feature most prominently in earlier US patent records. Patents for firms in the last group were hand collected from the *US Index of Patents* and *the US Patent Office Gazette* mat the UK Patent Office Library in London.

introduction of environmental regulation), focus was placed upon such technologies. Through time, resources were concentrated upon specific environmental problems associated with the coal and steel industry.

2.1. Measuring technology relatedness

There are essentially two fundamentally different approaches to measures of technological relatedness. The first approach considers relatedness to be an *ex ante* phenomenon and points to the underlying scientific or engineering principles as indicating the degree of relatedness between technologies (e.g. Breschi et al. 1998). The alternative approach is to view relatedness as an *ex post* phenomenon. In this approach, relatedness is not so much an intrinsic feature of specific technologies, but rather a subjective and context specific expression of widened technological capabilities and associated absorptive capacities. Whilst exogenous technological opportunities may encourage the firm to diversify across technologies that are unrelated to the extant competencies of the firm, it is widely acknowledged that existing firm capability is likely to determine the direction of technological diversification. This arises because there is likely to be cognitive limits on what a firm can and cannot do (Cohendet and Llerena, 1997; Patel and Pavitt, 1997; Teece at al., 1994; Granstrand et al., 1997; Cantwell, 1998; Piscitello, 2000).

Teece et al. (1994) examine corporate coherence and develop a survivor (or *ex post*) measure of relatedness. The measure is based on the principle that as a result of competition, inefficient organisational forms will disappear (Stigler, 1961). The underlying assumption therefore is that more related activities will be more frequently combined within the same firm. By extracting the actual patterns of technological activity shared by firms within or between technological sectors, we can ascertain firms' shared perception of complementarity between different pairs of technologies. This observed number of technology combinations (i.e. different pairs of technologies) is then compared to an expected value based upon random combinations of technologies[8]. Relatedness between any two technologies *i* and *j* (R_{ij}) may be therefore arrived at by computing:

$$R_{ij} = \frac{n_{ij} - \mu_{ij}}{\sigma_{ij}} \quad (1)$$

where: n_{ij} = actual number of linkages between technologies *i* and *j*

μ_{ij} = than the expected number of linkages between technologies *i* and *j*

σ_{ij} = standard deviation of the expectation

Using the data described above, the technological relatedness index was calculated for three separate periods – (i) 1890-1932 (ii) 1940-1968 and (iii) 1969-1995.

3. Intra/Inter-Macro Group Technology Relatedness

Calculation of equation 1 above results in a 56x56 matrix for each period, where each element represents the pairwise relatedness for each of the 56 technologies. Summarising these matrices poses obvious difficulties. In analysing these results, we adopt two approaches. First, we focus upon aggregate behaviour and trends by classifying the 56 technologies into 5 broad groups and analyse the broad patterns. These macro groups were identified as Chemical (13 technologies), Mechanical (21 technologies), Electrical/electronic (11 technologies), Transport (7 technologies) and Other (4 technologies) (See Appendix A for details). Second, we use this as a basis to focus upon a more granular summary of the 56x56 matrix using graphics. In what follows, we describe two ways of reporting technological relatedness. Sections 3.1 and 3.2 discuss the aforementioned aggregate findings and sections 3.1.1 and 3.1.2. discuss the more disaggregate results.

The first statistic captures the depth of relatedness across technologies or the frequency with which technology x is combined with technology y. This is measured by calculating the average relatedness across technologies using results in section 2. If these averages increase, it signals increased intensity of relatedness between the two technologies in question or in other words, a higher co-patenting frequency. The second measure attempts to capture the breadth of the relatedness i.e. the degree to which technology x is co-patented with (or *pervades*) an increasing number of other technologies. This is calculated by taking the inverse of the coefficient of variation (1/CV) which, when increasing, signals that greater dispersion in the relatedness of one technology to all others is taking place. Technologies that record an increasing diversification of relatedness (1/CV) through time are classified as *pervasive technologies*.

TABLE 1 HERE

[8] For a more complete description of this measure, please see Appendix B.

From Table 1, it is clear that very strong co-patenting occurs within all macro groups of technologies (i.e. there is high *intra-group* activity). This is particularly evident within the chemicals and electrical/electronics groups. Across the three periods these groups record average relatedness values of approximately 40 and 49 respectively (out of a possible 100). Such strong intra-group co-patenting behaviour is unsurprising given the similarity of technological methods used within these common categories of classification. While the average intra-group activity remains constant through time across the chemicals group and steadily falls within the mechanical group, both the electrical/electronics and transport groups record decreased intra-group activity between periods one and two and a reversal of this trend between the second and third periods.

Turning to the co-patenting activity taking place between these macro groups (i.e. *inter-group* activity), we note the above average relatedness of the mechanical and transport groups to all other groups. For the former, this appears to be driven by historically strong co-patenting with 7members of the transport group, while for the latter, strong linkages to the electrical/electronics group of technologies drives the result.

Aside from the level of inter-group activity, it is also useful to examine changes in those levels across time. These changes represent an opportunity to identify drivers of inter-group activity. These effects are particularly evident for chemical technologies and electrical/electronic technologies. The most marked changes occur for chemicals between period one and two (relatedness increases from –3.4 to 2.3) and electrical/electronic between periods two and three. The remainder of this section examines these broad trends in greater detail.

For the electrical/electronics group, our results suggest that the co-patenting of these technologies with the chemical and transport groups drives the upsurge between periods two and three. Although technologies from the chemicals group are on average, rarely used in combination with electrical/electronics in period one (and indeed period two) a noticeable increase in the incidence of co-patenting between these groups of technologies is apparent in period three. This highlights the horizontal science linkage that emerges between these fields with the emergence of electronics technologies.

In contrast, the transport group records quite a high degree of relatedness to electrical/electronics in the first period but this declines quite dramatically in period two (average relatedness falls from 24.2 to 14.7 and concentration emerges as 1/CV falls from 2.9 to 1.3). Both of these patterns are reversed in period three. We therefore suggest that not only is the upsurge in the relatedness of the electrical/electronic group quite clearly a period three phenomenon, it is predominantly driven by the co-patenting activity of these technologies with the chemical and transport groupings.

We now adopt a finer analysis by focusing upon individual technologies in the electrical sector (section 3.1) and the chemicals sector (section 3.2).

3.1 Electronics/Electrical Group

Using the results generated in section 2, Figure 2 plots the technological relatedness between the eleven electrical/electronic technologies and the forty-five other technologies over the three periods. The former is plotted along the z-axis, the latter along the x-axis and the y-axis records the relatedness value. Positive activity along the z-axis corresponds to positive relatedness between any technology combination (i.e. the computed value between any two technologies lies above the expected value). Higher spikes may be interpreted as indicating more frequent co-patenting between technologies. Activity below the z-axis signals the reverse.

If average relatedness and 1/CV across technology combinations is high, we would expect very high plateaus to be apparent in the figure. If the opposite were the case, low-level plateaus would be seen. Cases where the average is high and the 1/CV is low would result in punctuated, very high spikes and under the opposite scenario, we would once again observe low-level plateaus.

FIGURE 2 HERE

The overall increase in relatedness between the electrical/electronic technologies and the other technological groups between periods two and three is apparent. Moving from part (i) to part (ii) of this figure, one notes the growth in relatedness across many technologies but strong declines across others. It is these declines that drive the average result recorded between period one and two in Table 1[9]. Moving from part (ii) to (iii) one notes the increase in the clustering

[9] Indeed, it is clear from this figure that the *average* group values (Table 1) mask a substantial degree of inter-group co-patenting activity across certain technology combinations through time. It is clear for example, that

of spikes across the electrical/transport space and a flattening of spikes across the electrical/chemical space. As discussed above, this corresponds to an overall increase in relatedness across these groups between these time periods.

3.1.1 Identifying the most Pervasive Technologies

It is apparent from Figure 2 that certain technologies drive the results reported in Table 1. By calculating the relatedness measurements (depth and dispersion) between each of the eleven electrical/electronic technologies and the five macro sectors, these *drivers* can be identified. Table 2 reports the results of this exercise.

TABLE 2 HERE

(a) Intra-group activity

Following the idea that paradigms are likely to be associated with one particular central avenue of technological development, we begin this analysis by focusing upon the technological relatedness recorded within the electrical/electronic group in period one. This intra-group co-patenting appears to be driven by telecommunications (33), other electrical and communication systems (34), special radio systems (35), image and sound equipment (36), semiconductors (40) and office/data processing systems (41). In these instances, average relatedness to other parts of the same group is greater or equal to 50. Similarly these technologies are highly dispersed across the group (although illumination devices (37) is the most pervasive technology within the electrical/electronics group). As will be discussed below, it is predominantly these technologies that underpin the ICT paradigm that unleashes between the second and third periods.

(b) Inter-group activity

As highlighted above, although there was clearly a negative degree of technological relatedness recorded between electrical and chemical technologies in period one, co-patenting across certain combinations nonetheless took place. The electrical technology that may be termed *pervasive* to the chemicals group at this time is identified as photographic equipment (52) and

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despite the absence of relatedness across the electrical/chemical space in period one, the isolated spikes highlight the frequent co-patenting across certain combinations.

this was frequently co-patented with inorganic chemicals (3), photographic processes (6) and cleaning agents (7)[10].

Between period two and three, a large number of electronic technologies become increasingly pervasive across the chemicals group. As can be seen from Table 2, these are semiconductors (40), other general electrical equipment (39) and office/data processing systems (41). Indeed all of these technologies record their strongest growth in relatedness to technologies within the chemicals group. Since the inverted coefficient of variation also rises between these time periods, they are referred to as pervasive technologies within the chemicals group i.e. they are increasingly co-patented with a growing number of chemical technologies[11].

This is particularly apparent in the case of semiconductors. Indeed, coupled with these very high growth technologies, special radio systems (35) and illumination devices (37) may also be classified as *pervasive* not only within the chemicals group but across a wider number of technology sectors. As is evident from Table 2 above (and allied to image and sound equipment (36) and telecommunications (33)), these technologies increase the depth and breadth of their relatedness to the mechanical, transport and 'other' macro groupings between periods two and three. It is the increased corporate activity across such technologies that has been driving the ICT paradigm in the last three decades. This issue is further discussed below.

3.2 The Chemicals Group

In marked contrast to the electrical/electronics technologies, co-patenting of the chemical technologies with the other 43 technologies generally takes place quite infrequently in period one. This is evident from the substantial number of negative values on the y-axis of Figure 3 (part i). However, huge variation across individual pairs of technologies is apparent and pairwise combinations of quite highly related technologies may be seen. In particular, substantial degrees of relatedness can be detected within the chemicals/mechanical space.

[10] This declines however over the following periods. Average relatedness drops 2.9 points and the inverse of the coefficient of variation falls from 0.9 to 0.4. Photographic equipment, while strongly co-patented with members of the chemicals group in period one, is thus one example of a technology that has become less related and less *pervasive* through time. This result is taken from the 56x56 matrix generated in section 2 (full details of the matrices are not reported in this paper).

[11] Mechanical calculator and typewriters (30) may also be classified as becoming increasingly pervasive within the chemicals group.

FIGURE 3 HERE

While period one is characterised by haphazard relationships, it is immediately apparent from Figure 3 that co-patenting of the chemical group with all other technologies rises steadily over the entire 1890-1995 period. This group's substantial increase in relatedness to others through time and, as noted above, particularly to the electrical/electronic group in the third period, is apparent from Figure 3. For a more detailed summary of the aggregate changes in the co-patenting of chemical technologies, we refer the reader back to Table 1.

While lower than the recorded average for the electrical group (Table 1), strong co-patenting is recorded within the chemicals group in period 1. Although co-patenting of the chemical technologies with all other macro groups has been increasing through time, it is most intense between the first and second period (when the average rises from -3.4 to 2.3 points). Relatedness within the group remains fairly stable over the three time periods and appears to be driven by intensive co-patenting of disinfectants and preservatives (8), agricultural chemicals (4) and distillation processes (2) and other chemical fields with other chemical technologies (Table 3 below)[12].

TABLE 3 HERE

The increased relatedness of chemical technologies to all other macro sectors through time appears to be concentrated between period one and two and driven by a number of key technologies. These can be identified by isolating those technologies that recorded the greatest increase in relatedness across all four non-chemical macro sectors. As evidenced from Table 3, these are: photographic processes (6), explosives and composite charges (55) and inorganic chemicals (3).

These technologies record the highest point increase in relatedness (depth and dispersion) across the four macro sectors between period one and two. This is highest in the case of photographic process technology (average relatedness increased by 19.7 points and pervasiveness increased by 1.3 points. Across the chemical technologies therefore, this field was most highly co-patented with outside technologies and managed to pervade an increasing number of exogenous areas between these periods.

The growing relevance of chemical technologies to other areas appears to be driven by co-patenting with the mechanical and transportation (and ‘other’) groups[13].

3.2.2 Identifying the most Pervasive Technologies

While the transport group is recorded as being least related to chemicals in this first period (R = -10), this changes quite dramatically over the 1940-1968 period. As is apparent from Table 3 above, pharmaceuticals and biotechnology (12), explosives and compositions (55), photographic processes (6) and distillation processes (2) are the fields that lie behind the increased co-patenting activity with the transport technologies during this time. These technologies might also be classified *pervasive* since they are co-patenting with a wider range of transport technologies during this period. This trend continues into the third period as further increases in average relatedness and the degree of dispersion are recorded.

A similar pattern is recorded in terms of the mechanical technologies. Although technologies within this group are, on average, infrequently co-patenting with chemicals between 1890 and 1939 (a noticeable exception being agricultural chemicals (4)), they experience high growth thereafter (R increases by 8.4 points, from -1.3 to 7.1 and further to 9.3 in period three). Between periods one and two, this growth is fuelled by increased co-patenting between the mechanical technologies and all members of the chemical group (with interestingly, the noticeable exception of agricultural chemicals) and by all but five of the chemicals group between periods two and three. Above average growth occurs between periods two and three in

[13] Although co-patenting of chemicals with the electrical/electronic group does not increase in aggregate terms between these first two periods, it is important to note the individual combinations of technologies that are highly co-patented across these two macro groups. In Table 3, one notes that between period one and two for example, photographic process technology (6) records the single greatest increase in relatedness to exogenous technologies (increasing from -10 to 9.7). It is the co-patenting behavior with technologies from the electrical/electronic group that drives this result (where average relatedness increases from -9.6 to 21). In addition, as evidenced by the growth in the inverse of the coefficient of variation, photographic process technologies also become increasingly pervasive during this time. A similar result is noted for bleaching and dying technology (10) between period two and three when co-patenting with the electrical/electronics technologies drives the growth in relatedness. While on average therefore, the broad chemical and electrical/electronic technologies are not frequently co-patented with each other between these time periods, there are individual pairs of technologies that stand out against this general rule.

the co-patenting of bleaching and dying technology (10), photographic processes (6) and coal and petroleum products (51) with technologies from the mechanical group.

In terms of dispersion, an above average increase is recorded for inorganic chemicals (3) and photographic processes (6) in period two. These technologies increasingly pervade the mechanical group during this period. In the following period, chemical processes (5) and bleaching and dyeing (10) are used in combination with a growing number of technologies from this group.

In summary, by isolating the largest increases in inter-group co-patenting during the last century, our data shows the dominance of chemical technologies in the earlier years and the strong role played by electronics in the latter years of the twentieth century. Pervasive technologies that emerge out of both of these groups can be summarised as follows:

Group	Pervasive technologies	Co-patented with
CHEMICAL (t1 => t2)	Pharmaceutical & biotechnology (12) Explosives and compositions (55) Photographic processes (6) Distillation processes (2)	TRANSPORT
	Inorganic chemicals (3) Photographic processes (6)	MECHANICAL
ELECTRONIC (t2 => t3)	Semiconductors (40) Other gen. electrical equipment (39) Office/data processing equip. (41)	CHEMICAL
	Semiconductors (40) Other gen. electrical equipment (39) Office/data processing equip. (41) Special radio systems (35) Illumination devices (37) Image and sound equipment (36) Telecommunications (33)	MECHANICAL TRANSPORT OTHER

4. Industry Drivers

In this section we investigate the industrial sectors that are responsible for forging the aforementioned patterns of technological activity. In section 3.11 (b) for example, we reported a substantial increase in the co-patenting of telecommunications (33) with transport technologies between the second and third periods. In this section, we wish to investigate which firms actually drove this result – was it large electrical firms such as Siemens, Philips or Westinghouse Electric or rather, large transportation firms, such as Ford, Fiat or Daimler Benz? Similarly (and indeed perhaps more interestingly), we investigate whether the increased co-patenting across specific technology combinations has been occurring across firms outside of those industries that one intuitively associates with specific technological combinations. Following the above example, one might find that firms from outside both these industries have driven the co-patenting of telecommunications technology with technologies from the transport group. This would further support the view that firms' technological profiles have become increasingly interrelated and that formerly separate industrial sectors are becoming increasingly connected through their technological activity. Evidence that technology combination lies increasingly outside the firm's immediate (or historic) technological/industrial space signals that the prevailing paradigm has widened its sphere of influence and has entered into a mature stage.

To do this we identify the main firms driving the relatedness results, classify each one according to its industrial output and then further allocate it into one of four industrial/corporate groups. These industrial groups are classified as chemical, mechanical, electronic and transportation depending upon the primary line of technological development in each industry (see Table 4 for the breakdown)[14].

4.1 The Electronics Paradigm – the Industrial Drivers

Tables 5 and 6 identify the industries that drove the co-patenting behavior between the electrical/electronic technologies and the chemical and transport groups respectively. As highlighted above, we focus on changes between the second and third periods and isolate combinations that recorded an increase of more than 10 points in their relatedness to each other. The first column highlights the pervasive electrical/electronic technologies and the chemical technologies that drive the result. The second and third columns detail the actual

[14]Note that these industrial groups should not be interpreted in the usual way. As discussed above, each group is initially defined by the characteristics of their output (for example paper or building materials) and then further grouped into sets with some common primary line of technological development (following this example, mechanical engineering). This implies very heterogeneous groupings of many firms. It also implies a very large number of wide ranging firms, therefore the results should be interpreted with caution.

number of firms within each period that co-patent across the specific combination[15]. The remaining columns detail how this co-patenting activity is distributed across the four industrial sectors i.e. which industries drive relatedness between the various technology combinations.

TABLE 5 HERE

In aggregate terms, technology relatedness between the electrical/electronic technologies and the chemical group is driven by high degrees of co-patenting between the associated industries (i.e. electronic and chemical firms). However, it is the mechanical and transport firms that record the greatest increase. This supports the view that the increased linkages between science and technology that characterise the ICT paradigm, are giving rise to further technology fusion across a much wider spectrum of technological activities (Cantwell and Santangelo, 2000). For example, mechanical firms were responsible for 6.3 percent of co-patenting activity across these technologies in period two but this increased to 13.6 percent in the third period. As the total number of occurrences of co-patenting across these technologies increased by 80 percent between the two periods, this corresponds to an above average increase in the involvement of mechanical firms (from 35 to approximately 146 occurrences). Similarly, the transportation firms also increased their involvement with the electrical/electronics and chemicals technologies in period three.[16] The number of occurrences of transport firms patenting across the technology combinations detailed in Table 6 increased from 58 to 177, which again outstripped the increase in total occurrences across these technologies. This dramatic increase in the involvement of these firms in technological fields that might be termed *non-associated* to their industries of activity highlights the degree to which corporate technological profiles are becoming increasingly interrelated[17].

As is evident in Table 5, mechanical firms recorded strong increases in their co-patenting of general electrical equipment (39) and semiconductors (40) research with various technologies from the chemicals group. Firms active within the transport industry recorded their greatest

[15] The aggregation of these results should be interpreted with care. Because each firm may well co-patent across many (if not all) of the listed combinations, by aggregating columns two and three we are essentially inflating the total number of firms involved. Therefore, we interpret the aggregation of these columns as indicating the number of *occurrences* across these technological pairs.

[16] They accounted for 17 percent of total co-patenting activity between these technologies – an increase of 7 percent on the previous period.

[17] Of course, as noted earlier, the technological profiles of individual firms may well diverge from this aggregate picture.

increases by co-patenting special radio systems (35), illumination devices (37) and semiconductors (40) with various chemicals technologies.

TABLE 6 HERE

Table 6 reports on the industrial drivers of the co-patenting activity between the electrical/electronic and the transport group of technologies. Again we see the associated industrial sector dominating the picture and the non-associated industries (chemicals and mechanical) recording increased presence across these technologies through time. This is particularly strong in the case of mechanical firms whose presence across these technology combinations increases by almost 7 percent in the third period.

In what follows, we focus upon the key technological combinations patented by firms operating within the mechanical and transportation industry (i.e. those non-associated industries that recorded increased activity across the electronic/chemical space, see Table 5). By combining information provided in Tables 5 and 6, what might be described as triangular relationships are highlighted between these three macro technology groups under study. These triangles of activity that are forged by transport (mechanical) firms appear to be anchored in electronic technologies 35, 37 and 40 (39 and 40) and encompass various technologies from the chemical and transport groupings. These are highlighted in Figures 4 and 5.

FIGURES 4 and 5 HERE

These broad groupings of firms that primarily depend upon transport or mechanical technologies offer an insight into the increasingly complex web of technological co-patenting. Highlighting some of the more prevalent technological activities of these industries also serves to emphasise the fact that non-associated are actively co-patenting across these technologies.

4.2 The Chemicals Paradigm – the Industrial Drivers

The industries associated with co-patenting of chemical and mechanical technologies between periods one and two are described in Table 7.[18] This is in contrast to the electronics paradigm.

[18] Because of the large overall increase in co-patenting between the chemical and mechanical technologies, we used an intertemporal increase greater or equal to 20 points as the cut off for technology combinations. Since

Chemical firms dominate aggregate co-patenting activity within the chemical/mechanical technological space in both periods. While these firms also dominate across chemical/transport technological space in period two, it is interesting to note the relative dominance of electrical firms (31.9 percent) in co-patenting activity across these technologies in period one.

TABLE 7 HERE

The associated firms dominate activity in the second period across both chemical/mechanical and chemical/transport technological space (representing 59 and 16 percent of aggregate activity in the case of the former and 48 and 20 percent in the case of the latter). In general, the non-associated firms record marginal (if any) increases in their activities across these technology combinations. One noticeable exception is present in the chemical/transport space. Between periods one and two, the mechanical firms record heightened activity across these specific combinations (from 6.3 to 13.6 percent). This reflects the common engineering base of mechanical and transport firms.

TABLE 8 HERE

5. Summary and Conclusions

It is widely believed that technologies are converging. Producing systematic evidence of this convergence is a challenge. In this paper, we attempt to develop measures that capture the relationships between technologies using patent data. These measures result in the identification of *pervasive* technologies.

We started by examining the broad trends within and between our five macro groups and find that chemicals exerted a determining influence in the earlier part of the last century. In the second half of the last century, electronic technologies command this role. Our analysis pinpoints the exact technologies within these macro groups that drove these results. Beyond producing systematic evidence of this received wisdom, we also examined the role of the firm therein. In contrast to evidence found in earlier periods, we find that *non-associated* firms are becoming increasingly responsible for driving technological associations. This would suggest

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these very large increases are not present across chemical/transport co-patenting over the same periods, we conclude that these mechanical technologies are very *pervasive* between these periods one and two.

that further examination of the underlying rationales for these observations should be examined in the future.

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TABLES AND FIGURES

Table 1. Technological relatedness between the macro technology groups 1890 - 1939 (t1); 1940-1968 (t2) and 1969-1995 (t3).

TECHNOLOGY SECTOR	Relatedness	CHEMICALS	MECHANICAL	ELECTRICAL	TRANSPORT	OTHER
CHEMICAL	average	t1: 40.5				
		t2: 40.1				
		t3: 40.5				
	1/CV	t1: 1.6				
		t2: 2.0				
		t3: 2.2				
MECHANICAL	average	t1: -1.3	t1: 23.0			
		t2: 7.1	t2: 21.1			
		t3: 9.3	t3: 17.8			
	1/CV	t1: 0.1	t1: 0.9			
		t2: 0.5	t2: 0.9			
		t3: 0.6	t3: 0.8			
ELECTRICAL	average	t1: -4.3	t1: 12.9	t1: 50.5		
		t2: -4.4	t2: 12.7	t2: 47.7		
		t3: -0.9	t3: 13.7	t3: 47.3		
	1/CV	t1: -0.3	t1: 0.6	t1: 3.2		
		t2: -0.4	t2: 0.8	t2: 3.4		
		t3: -0.1	t3: 0.9	t3: 3.3		
TRANSPORT	average	t1: -10.0	t1: 17.5	t1: 24.2	t1: 46.4	
		t2: -4.3	t2: 14.9	t2: 14.7	t2: 34.1	
		t3: 1.2	t3: 14.7	t3: 19.2	t3: 38.1	
	1/CV	t1: -0.6	t1: 0.9	t1: 2.9	t1: 1.6	
		t2: -0.2	t2: 0.9	t2: 1.3	t2: 1.1	
		t3: 0.1	t3: 0.9	t3: 2.9	t3: 1.3	
OTHER	average	t1: -0.4	t1: 13.2	t1: 10.8	t1: 8.7	t1: 25.5
(Non-Manuf.)		t2: 6.9	t2: 13.2	t2: 12.2	t2: 17.6	t2: 28.9
		t3: 13.5	t3: 11.9	t3: 15.9	t3: 17.5	t3: 30.2
	1/CV	t1: 0.0	t1: 0.9	t1: 0.8	t1: 0.6	t1: 0.7
		t2: 0.6	t2: 1.0	t2: 0.9	t2: 1.1	t2: 0.7
		t3: 1.2	t3: 1.1	t3: 1.6	t3: 1.1	t3: 0.7
Average relatedness		t1: -3.4	t1: 10.6	t1: 9.5	t1: 10.1	t1: 8.1
to 4 macro groups		t2: 2.3	t2: 12.0	t2: 8.0	t2: 10.7	t2: 12.5
		t3: 5.8	t3: 12.4	t3: 10.5	t3: 13.5	t3: 14.7
Average 1/CV		t1: -0.3	t1: 0.6	t1: 0.5	t1: 0.8	t1: 0.6
across 4 macro		t2: 0.1	t2: 0.8	t2: 0.5	t2: 0.7	t2: 0.9
groups		t3: 0.5	t3: 0.9	t3: 0.7	t3: 1.0	t3: 1.2

Table 2 Relatedness between the eleven Electrical/electronic technologies and each macro group

			ELECTRICAL/ELECTRONIC TECHNOLOGIES											
TECHOLOGY GROUP	TECHNOLOGY RELATEDNESS	PERIOD	Mech. calcul. & type writers (30)	Telecomm. (33)	Other elec. & comm. systems (34)	Special radio systems (35)	Image & sound equipment (36)	Illuminatio n devices (37)	Electrical devices & systems (38)	Other general electrical equipment (39)	Semi conductors (40)	Office equip. & data process. systems	Photog. equipment (52)	TOTAL ELECTRICAL/ ELECTRONIC
CHEMICAL	average	t1	-8.8	1.0	-12.0	-1.1	-4.9	-10.9	-13.5	-7.8	2.2	-0.1	9.2	-4.3
		t2	-9.1	0.8	-6.7	-14.7	3.2	-8.5	1.3	-4.2	-17.9	-1.8	8.9	-4.4
		t3	-4.0	-1.8	-9.8	-9.1	1.1	-3.0	-2.1	6.0	1.7	4.3	6.3	-0.9
	1/CV	*t1*	*-0.9*	*0.1*	*-1.0*	*-0.1*	*-0.3*	*-0.9*	*-1.3*	*-0.6*	*0.1*	*0.0*	*0.9*	-0.4
		t2	*-0.6*	*0.1*	*-0.5*	*-0.9*	*0.2*	*-0.5*	*0.1*	*-0.3*	*-1.2*	*-0.1*	*0.5*	-0.3
		t3	*-0.4*	*-0.2*	*-0.7*	*-0.6*	*0.1*	*-0.3*	*-0.2*	*0.4*	*0.1*	*0.4*	*0.4*	-0.1
MECHANICAL	average	t1	14.7	9.7	9.4	9.3	9.6	8.0	16.9	17.1	20.8	9.5	16.4	12.9
		t2	8.4	9.4	17.6	7.9	10.8	11.1	20.7	20.0	8.8	13.3	12.1	12.7
		t3	8.8	13.1	15.0	10.2	15.7	12.0	19.1	20.1	11.4	14.8	10.3	13.7
	1/CV	*t1*	*0.8*	*0.6*	*0.5*	*0.4*	*0.5*	*0.5*	*1.0*	*1.1*	*0.8*	*0.5*	*0.8*	0.7
		t2	*0.5*	*0.6*	*1.1*	*0.5*	*0.7*	*0.7*	*1.1*	*1.2*	*0.6*	*0.9*	*0.8*	0.8
		t3	*0.6*	*0.9*	*0.9*	*0.6*	*1.3*	*0.8*	*1.0*	*1.4*	*0.7*	*1.1*	*0.6*	0.9
ELECTRIC	average	t1	34.3	50.6	50.8	53.3	57.8	47.4	35.4	22.9	49.6	53.5	45.1	45.5
		t2	34.2	51.1	46.9	48.0	49.7	41.0	37.7	29.7	44.5	51.7	32.3	42.5
		t3	34.9	49.8	51.3	41.7	46.2	45.0	37.7	28.4	49.7	45.9	32.4	42.1
	1/CV	*t1*	*2.7*	*2.4*	*4.4*	*2.5*	*2.8*	*4.7*	*4.2*	*2.1*	*2.6*	*3.5*	*2.9*	3.2
		t2	*3.5*	*3.0*	*3.7*	*3.7*	*3.1*	*4.6*	*3.0*	*2.3*	*4.4*	*3.3*	*2.9*	3.4
		t3	*2.6*	*3.5*	*3.6*	*3.2*	*4.5*	*3.9*	*3.5*	*2.8*	*3.6*	*3.3*	*2.3*	3.3
TRANSPORT	average	t1	25.0	19.5	34.4	20.4	25.7	24.6	22.9	20.2	31.0	19.8	23.4	24.2
		t2	10.4	12.8	26.6	15.5	14.3	13.8	17.4	15.1	8.7	15.7	11.9	14.7
		t3	6.8	25.6	26.9	24.7	21.7	20.1	24.9	18.3	19.0	19.1	4.3	19.2
	1/CV	*t1*	*2.0*	*2.4*	*2.4*	*3.3*	*4.0*	*4.3*	*2.7*	*2.0*	*4.1*	*1.8*	*2.4*	2.9
		t2	*0.9*	*0.7*	*2.2*	*0.8*	*0.9*	*1.2*	*2.0*	*2.2*	*0.5*	*1.1*	*1.5*	1.3
		t3	*1.1*	*2.7*	*2.5*	*1.5*	*2.4*	*3.7*	*5.7*	*4.6*	*2.1*	*5.0*	*0.6*	2.9
OTHER	average	t1	9.7	7.9	7.9	7.9	10.7	7.4	18.3	20.6	16.2	4.7	7.4	10.8
		t2	4.4	14.7	18.5	8.7	15.4	12.4	20.3	14.8	5.6	13.1	6.3	12.2
		t3	9.7	19.0	15.3	17.3	17.8	18.1	18.9	16.3	20.6	16.4	6.0	15.9
	1/CV	*t1*	*0.6*	*0.6*	*0.6*	*1.0*	*0.8*	*0.7*	*1.0*	*1.0*	*1.2*	*0.3*	*0.8*	0.8
		t2	*0.4*	*0.6*	*1.4*	*0.7*	*0.7*	*1.2*	*1.9*	*1.8*	*0.5*	*0.7*	*0.7*	1.0
		t3	*1.3*	*1.3*	*1.7*	*1.3*	*1.4*	*2.2*	*1.9*	*1.6*	*2.5*	*1.3*	*0.9*	1.6
TOTAL*	average	t1	9.1	8.6	7.0	7.9	8.0	5.1	9.2	10.7	16.6	7.9	14.6	9.5
		t2	3.3	7.9	12.1	2.6	9.5	6.0	14.5	11.8	0.8	9.3	10.6	8.0
		t3	4.9	11.3	9.7	7.5	12.6	9.5	13.9	15.4	10.6	12.6	7.8	10.5
	1/CV	*t1*	*0.5*	*0.5*	*0.3*	*0.4*	*0.4*	*0.3*	*0.5*	*0.6*	*0.7*	*0.5*	*0.9*	0.5
		t2	*0.2*	*0.5*	*0.6*	*0.1*	*0.6*	*0.3*	*0.8*	*0.7*	*0.0*	*0.6*	*0.7*	0.5
		t3	*0.4*	*0.7*	*0.5*	*0.4*	*0.9*	*0.6*	*0.7*	*1.1*	*0.7*	*1.0*	*0.6*	0.7

* Total relatedness between electric/electronic technologies and the four macro sectors

Table 3 Relatedness between the thirteen Chemical technologies and each macro group

			CHEMICAL TECHNOLOGIES													
TECHOLOGY GROUP	TECHNOLOGY RELATEDNESS	PERIOD	Distillation processes (2)	Inoganic chemicals (3)	Agricul. chemicals (4)	Chemical processes (5)	Photo. processes (6)	Cleaning agents (7)	Disinfect. & preserv. (8)	Synthetic resins & fibres (9)	Bleaching & Dying (10)	Other organic compounds (11)	Pharm. & Biotech. (12)	Coal & Petroleum products (51)	Explosives compos. & charges (55)	TOTAL CHEMICAL
CHEMICAL	average	t1	39.4	42.3	33.2	28.0	32.4	44.7	0.0	45.6	39.8	50.4	48.2	44.6	22.3	36.2
		t2	44.8	43.7	39.3	23.9	18.6	40.3	18.8	40.8	32.5	41.5	43.8	45.1	23.8	36.1
		t3	39.9	42.2	45.4	13.5	26.9	38.2	29.8	39.2	37.3	45.0	41.0	42.1	22.8	36.7
	1/CV	t1	2.1	2.2	2.1	1.6	1.6	2.1	0.0	2.1	2.1	2.2	2.5	2.0	1.8	1.6
		t2	2.8	2.7	2.2	1.9	2.5	2.3	1.6	2.5	2.2	2.5	2.3	2.2	2.4	2.0
		t3	2.6	3.4	3.2	2.1	2.8	2.7	2.2	2.5	2.6	2.4	2.3	2.8	2.9	2.2
MECHANICAL	average	t1	1.7	-2.4	7.0	2.3	-8.6	0.4	0.0	4.7	-10.3	-3.7	-8.2	1.8	-2.0	-1.3
		t2	9.0	16.0	0.3	9.0	9.7	9.2	11.0	11.5	-0.5	2.0	-1.7	7.4	9.4	7.1
		t3	13.1	14.1	4.1	13.2	15.2	12.7	10.6	7.9	6.3	2.0	2.0	12.5	6.9	9.3
	1/CV	t1	0.1	-0.1	0.5	0.1	-0.5	0.0	0.0	0.2	-0.5	-0.2	-0.4	0.1	-0.1	-0.1
		t2	0.5	1.3	0.0	0.6	0.7	0.6	0.8	0.6	0.0	0.1	-0.1	0.5	0.6	0.5
		t3	0.8	0.8	0.2	1.2	0.9	0.9	0.8	0.4	0.4	0.1	0.1	0.8	0.5	0.6
ELECTRICAL / ELECTRONIC	average	t1	-9.4	-0.1	-7.2	9.0	-9.6	15.2	0.0	-0.6	-17.0	-4.7	-18.9	-1.4	-10.4	-4.3
		t2	-11.1	4.8	-17.0	8.3	21.0	-2.0	4.2	-6.0	-23.0	-13.8	-17.5	-7.9	2.6	-4.4
		t3	1.8	-1.1	-10.7	10.7	18.7	3.6	1.3	-5.1	-5.2	-14.6	-10.5	-5.7	4.7	-0.9
	1/CV	t1	-0.9	0.0	-0.6	0.8	-0.8	1.2	0.0	0.0	-1.7	-0.4	-1.8	-0.1	-3.0	-0.3
		t2	-0.8	0.5	-1.6	0.9	1.3	-0.2	0.4	-0.6	-1.7	-1.0	-1.6	-0.7	0.2	-0.4
		t3	0.1	-0.1	-1.2	1.2	1.5	0.5	0.1	-0.8	-0.6	-1.5	-1.1	-0.5	0.6	-0.1
TRANSPORT	average	t1	-17.2	-2.4	-11.2	1.0	-16.6	1.5	0.0	-7.7	-21.0	-12.9	-27.1	-6.3	-10.2	-10.0
		t2	-4.7	0.0	-11.2	-0.3	-4.3	-2.5	3.6	0.9	-11.8	-12.8	-13.1	-2.3	1.8	-4.3
		t3	6.7	3.5	-10.4	7.9	6.5	9.1	2.6	2.2	-8.3	-6.1	-8.8	0.5	10.4	1.2
	1/CV	t1	-1.1	-0.2	-0.7	0.0	-1.4	0.1	0.0	-0.4	-1.1	-0.7	-2.0	-0.6	-0.9	-0.6
		t2	-0.2	0.0	-0.6	0.0	-0.4	-0.1	0.2	0.0	-0.6	-0.5	-0.6	-0.1	0.1	-0.2
		t3	0.4	0.2	-0.6	0.7	0.5	0.4	0.2	0.1	-0.5	-0.3	-0.5	0.0	1.5	0.1
OTHER	average	t1	-1.3	0.3	4.1	6.4	-6.3	-0.3	0.0	2.2	-6.0	-0.7	-9.4	-0.4	6.8	-0.4
		t2	6.8	6.8	7.9	8.7	3.5	4.9	12.2	11.8	1.3	-0.2	-0.8	8.3	18.5	6.9
		t3	18.9	16.2	10.9	13.4	12.5	15.3	13.5	13.9	9.6	10.2	7.5	17.9	16.3	13.5
	1/CV	t1	-0.4	0.1	0.7	0.5	-0.7	0.0	0.0	0.2	-1.2	-0.1	-1.4	-0.1	0.5	0.0
		t2	0.5	0.3	0.8	0.8	0.5	0.3	1.4	0.7	0.1	0.0	-0.1	0.9	1.7	0.6
		t3	1.1	0.9	1.0	1.0	1.6	0.8	1.3	0.8	0.8	1.3	1.1	1.2	2.8	1.2
TOTAL*	average	t1	-4.5	-1.6	0.1	4.2	-10.0	4.3	0.0	1.1	-13.3	-5.2	-14.1	-0.5	-4.6	-3.4
		t2	1.4	9.7	-5.3	7.3	9.7	4.0	8.2	5.3	-7.9	-4.6	-7.5	2.0	7.3	2.3
		t3	9.7	8.7	-1.4	11.7	14.4	10.0	7.2	4.2	1.3	-2.8	-2.4	6.4	7.8	5.8
	1/CV	t1	-0.3	-0.1	0.0	0.3	-0.7	0.3	0.0	0.1	-0.7	-0.3	-0.8	0.0	-0.3	-0.3
		t2	0.1	0.6	-0.3	0.5	0.6	0.2	0.6	0.3	-0.4	-0.2	-0.4	0.1	0.5	0.1
		t3	0.6	0.5	-0.1	1.1	1.0	0.7	0.6	0.2	0.1	-0.1	-0.1	0.4	0.7	0.4

* Total relatedness between Chemical technologies and the four macro sectors

Table 4 Industries classification based on corporate output

CORPORATE OUTPUT	
1. Food 2. Drink 3. Tobacco 6. Metals 7. Mechanical Engineering 14 Paper products 15. Printing & publishing 17. Non-metallic mineral products 19. Professional scientific instruments 20. Other manufacturing	MECHANICAL INDUSTRY
4. Chemicals 5. Pharmaceuticals 18. Coal and petroleum products 13. Textiles	CHEMICAL INDUSTRY
8. Electrical equipment 9. Office equipment	ELECTRICAL INDUSTRY
10. Motor vehicles 11. Aircraft 12. Other transport equipment 16. Rubber products	TRANSPORT INDUSTRY

Table 5 Industries that drive co-patenting of electrical/electronic and chemical technologies between periods two and three

ELECTRICAL/ELECTRONIC TECHNOLOGIES			INDUSTRY									
	Total Firms (no.)		CHEMICAL		MECHANICAL		ELECTRICAL		TRANSPORT		TOTAL	
			(% firms in each industry)								%	
1. Mechanical Cal. & Typewriters (30)	t2	t3	t2	t3	t2	t3	t2	t3	t2	t3	t2	t3
Pharma. & Biotech. (12)	2	13	0.0	23.1	0.0	15.4	100.0	61.5	0.0	0.0	100.0	100.0
Bleaching & Dying (10)	1	5	0.0	20.0	0.0	20.0	100.0	60.0	0.0	0.0	100.0	100.0
Agricultural Chemicals (4)	0	4	0.0	50.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	100.0
Cleaning Agents & other com. (7)	6	15	0.0	13.3	0.0	13.3	100.0	73.3	0.0	0.0	100.0	100.0
Average			*0.0*	*26.6*	*0.0*	*12.2*	*75.0*	*61.2*	*0.0*	*0.0*		
2. Special Radio Systems (35)												
Distillation Processes (2)	*1*	6	0.0	0.0	0.0	16.7	100.0	33.3	0.0	50.0	100.0	100.0
Bleaching & Dying (10)	*2*	6	0.0	16.7	0.0	0.0	50.0	50.0	50.0	33.3	100.0	100.0
Pharma. & Biotech. (12)	4	16	0.0	12.5	0.0	0.0	100.0	50.0	0.0	37.5	100.0	100.0
Average			*0.0*	*9.7*	*0.0*	*5.6*	*83.3*	*44.4*	*16.7*	*40.3*		
3. Illumination Devices (37)												
Synthetic resins and fibers (9)	29	43	34.5	25.6	13.8	18.6	31.0	32.6	20.7	23.3	100.0	100.0
Chemical processes (5)	40	60	25.0	20.0	15.0	18.3	40.0	35.0	20.0	26.7	100.0	100.0
Cleaning Agents & other com. (7)	32	48	31.3	22.9	15.6	16.7	31.3	35.4	21.9	25.0	100.0	100.0
Pharma. & Biotech. (12)	*17*	32	*58.8*	37.5	*17.6*	15.6	*23.5*	28.1	*0.0*	18.8	100.0	100.0
Other organic compounds (11)	25	33	40.0	33.3	16.0	15.2	32.0	30.3	12.0	21.2	100.0	100.0
Bleaching & Dying (10)	9	15	88.9	53.3	0.0	13.3	11.1	20.0	0.0	13.3	100.0	100.0
Agricultural Chemicals (4)	8	13	87.5	69.2	0.0	7.7	12.5	15.4	0.0	7.7	100.0	100.0
Average			*52.3*	*37.4*	*11.2*	*15.1*	*25.9*	*28.1*	*10.7*	*19.4*		
4. Other general Equipment (39)												
Distillation Processes (2)	*25*	37	76.0	62.2	16.0	21.6	4.0	5.4	4.0	10.8	100.0	100.0
Bleaching & Dying (10)	19	31	73.7	67.7	10.5	16.1	5.3	9.7	10.5	6.5	100.0	100.0
Coal & Petroleum products (51)	33	95	72.7	38.9	9.1	27.4	6.1	17.9	12.1	15.8	100.0	100.0
Agricultural Chemicals (4)	22	125	81.8	32.0	4.5	30.4	4.5	19.2	9.1	18.4	100.0	100.0
Cleaning Agents & other com. (7)	57	100	45.7	60.9	19.3	23.9	17.5	4.3	17.5	10.9	100.0	100.0
Chemical processes (5)	73	124	*36.9*	79.5	*19.3*	12.8	*23.3*	5.1	*20.5*	2.6	100.0	100.0
Average			64.5	56.9	13.1	22.0	10.1	10.3	12.3	10.8	100.0	100.0
5. Semiconductors (40)												
Cleaning Agents & other com. (7)	20	42	25.0	19.0	5.0	9.5	45.0	42.9	25.0	28.6	100.0	100.0
Distillation Processes (2)	4	12	*75.0*	50.0	*0.0*	16.7	*25.0*	16.7	*0.0*	16.7	100.0	100.0
Synthetic resins and fibers (9)	18	35	27.8	22.9	0.0	8.6	50.0	40.0	22.2	28.6	100.0	100.0
Chemical processes (5)	29	50	20.7	18.0	6.9	10.0	51.7	46.0	20.7	26.0	100.0	100.0
Other organic compounds (11)	*16*	28	37.5	28.6	0.0	10.7	50.0	35.7	12.5	25.0	100.0	100.0
Pharma. & Biotech. (12)	10	27	60.0	33.3	0.0	11.1	40.0	33.3	0.0	22.2	100.0	100.0
Bleaching & Dying (10)	6	12	66.7	50.0	0.0	16.7	16.7	25.0	16.7	8.3	100.0	100.0
Explosive compositions & Ch. (55)	3	7	*66.7*	42.9	*0.0*	0.0	*0.0*	0.0	*33.3*	57.1	100.0	100.0
Agricultural Chemicals (4)	4	11	75.0	63.6	0.0	9.1	25.0	18.2	0.0	9.1	100.0	100.0
Coal & Petroleum products (51)	8	13	50.0	46.2	0.0	15.4	25.0	15.4	25.0	23.1	100.0	100.0
Average			50.4	37.4	1.2	10.8	32.8	27.3	15.5	24.5		
6. Office Equip. & Data processing (41)												
Bleaching & Dying (10)	8	23	*50.0*	65.2	*25.0*	13.0	*12.5*	13.0	*12.5*	8.7	100.0	100.0
Distillation Processes (2)	15	32	80.0	62.5	13.3	21.9	6.7	6.3	0.0	9.4	100.0	100.0
Coal & Petroleum products (51)	19	37	*63.2*	62.2	*10.5*	18.9	*10.5*	5.4	*15.8*	13.5	100.0	100.0
Agricultural Chemicals (4)	11	28	*90.9*	78.6	*0.0*	10.7	*9.1*	7.1	*0.0*	3.6	100.0	100.0
Average			*71.0*	*67.1*	*12.2*	*16.1*	*9.7*	*8.0*	*7.1*	*8.8*		
Aggregate average involvement by each industry			39.7	39.2	6.3	13.6	39.5	29.9	10.4	17.3		

Table 6 Industries that drive co-patenting of electrical/electronic and transport technologies between periods two and three

ELECTRICAL/ELECTRONIC TECHNOLOGIES	Total Firms (no.)		INDUSTRY								TOTAL	
			CHEMICAL		MECHANICAL		ELECTRICAL		TRANSPORT		%	
			(% firms in each industry)									
1. Telecommunications (33)	t2	t3	t2	t3	t2	t3	t2	t3	t2	t3	t2	t3
Other transport equip. (47)	6	31	0.0	12.9	0.0	22.6	66.7	19.4	33.3	45.2	100.0	100.0
Motor vehicles (43)	8	23	0.0	0.0	12.5	21.7	25.0	26.1	62.5	52.2	100.0	100.0
Rubber and plastic products (49)	8	50	0.0	24.0	12.5	20.0	25.0	28.0	62.5	28.0	100.0	100.0
Railways and railway equip. (46)	8	24	0.0	12.5	12.5	25.0	62.5	29.2	25.0	33.3	100.0	100.0
Average			*0.0*	*12.4*	*9.4*	*22.3*	*44.8*	*25.7*	*45.8*	*39.7*		
2. Special Radio Systems (35)												
Other transport equip. (47)	8	22	0.0	9.1	37.5	13.6	50.0	27.3	12.5	50.0	100.0	100.0
Ships & marine propulsion (45)	7	16	0.0	0.0	0.0	6.3	57.1	62.5	42.9	31.3	100.0	100.0
Railways and railway equip. (46)	7	18	0.0	5.6	0.0	16.7	71.4	38.9	28.6	38.9	100.0	100.0
Motor vehicles (43)	7	17	0.0	0.0	0.0	17.6	28.6	35.3	71.4	47.1	100.0	100.0
Average			*0.0*	*3.7*	*9.4*	*13.6*	*51.8*	*41.0*	*38.8*	*41.8*		
3. Image and Sound Equip. (36)												
Other transport equip. (47)	7	32	0.0	15.6	0.0	18.8	57.1	18.8	42.9	46.9	100.0	100.0
Rubber and plastic products (49)	22	55	36.4	27.3	4.5	20.0	36.4	25.5	22.7	27.3	100.0	100.0
Average			*18.2*	*21.4*	*2.3*	*19.4*	*46.8*	*22.1*	*32.8*	*37.1*		
4. Illumination Devices (37)												
Rubber and plastic products (49)	29	49	34.5	22.4	17.2	20.4	27.6	28.6	20.7	28.6	100.0	100.0
Other transport equip. (47)	12	29	0.0	10.3	25.0	10.3	33.3	20.7	41.7	58.6	100.0	100.0
Ships & marine propulsion (45)	11	21	18.2	23.8	9.1	0.0	36.4	47.6	36.4	28.6	100.0	100.0
Average			*17.6*	*18.9*	*17.1*	*10.3*	*32.4*	*32.3*	*32.9*	*38.6*		
5. Electrical Devices & Systems (38)												
Rubber and plastic products (49)	50	90	42.0	33.3	20.0	27.8	16.0	15.6	22.0	23.3	100.0	100.0
Other transport equip. (47)	18	46	0.0	13.0	22.2	28.3	22.2	15.2	55.6	43.5	100.0	100.0
Motor vehicles (43)	15	36	0.0	2.8	33.3	30.6	13.3	19.4	53.3	47.2	100.0	100.0
Average			*14.0*	*16.4*	*25.2*	*28.9*	*17.2*	*16.7*	*43.6*	*38.0*		
6. Other general Equipment (39)												
Rubber and plastic products (49)	54	97	40.7	35.1	22.2	30.9	14.8	14.4	22.2	19.6	100.0	100.0
Average			*40.7*	*35.1*	*22.2*	*30.9*	*14.8*	*14.4*	*22.2*	*19.6*		
7. Semiconductors (40)												
Rubber and plastic products (49)	18	40	22.2	20.0	5.6	12.5	44.4	35.0	27.8	32.5	100.0	100.0
Other transport equip. (47)	8	22	0.0	13.6	12.5	9.1	50.0	27.3	37.5	50.0	100.0	100.0
Ships & marine propulsion (45)	8	17	12.5	11.8	0.0	0.0	50.0	58.8	37.5	29.4	100.0	100.0
Average			*11.6*	*15.1*	*6.0*	*7.2*	*48.1*	*40.4*	*34.3*	*37.3*		
8. Office Equip. & Data processing (41)												
Rubber and plastic products (49)	32	75	37.5	30.7	15.6	26.7	25.0	18.7	21.9	24.0	100.0	100.0
Other transport equip. (47)	10	37	0.0	10.8	20.0	24.3	40.0	16.2	40.0	48.6	100.0	100.0
Ships & marine propulsion (45)	15	29	40.0	31.0	6.7	10.3	26.7	34.5	26.7	24.1	100.0	100.0
Average			*25.8*	*24.2*	*14.1*	*20.4*	*30.6*	*23.1*	*29.5*	*32.3*		
Aggregate average involvement by each industry			16.0	18.4	13.2	19.1	35.8	27.0	35.0	35.5		

Table 7 Industries that drive co-patenting of chemical and mechanical technologies between periods two and three

CHEMICAL TECHNOLOGIES	INDUSTRY											
	Total Firms (no.)		CHEMICAL		MECHANICAL		ELECTRICAL		TRANSPORT		TOTAL	
			(% firms in each industry)								%	
	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2
1. Distillation processes (2)												
Assembly & mat. handling equip. (20)	3	28	66.7	78.6	33.3	14.3	0.0	3.6	0.0	3.6	100.0	100.0
Textile & clothing machinery (25)	2	18	50.0	72.2	50.0	16.7	0.0	5.6	0.0	5.6	100.0	100.0
Average			*58.3*	*75.4*	*41.7*	*15.5*	*0.0*	*4.6*	*0.0*	*4.6*		
2. Inorganic chemicals (3)												
Assembly & mat. handling equip. (20)	11	44	36.4	54.5	18.2	20.5	36.4	18.2	9.1	6.8	100.0	100.0
Metallurgical processes (13)	15	45	20.0	55.6	46.7	20.0	26.7	17.8	6.7	6.7	100.0	100.0
Miscell. metals products (14)	16	42	56.3	52.4	12.5	21.4	25.0	19.0	6.3	7.1	100.0	100.0
Other instruments & controls (53)	16	44	50.0	54.5	18.8	20.5	25.0	18.2	6.3	6.8	100.0	100.0
Other specified machinery (28)	15	47	53.3	57.4	13.3	19.1	26.7	17.0	6.7	6.4	100.0	100.0
Agricultural equipment (21)	0	8	0.0	50.0	0.0	25.0	0.0	0.0	0.0	25.0	0.0	100.0
Other general ind. Equip. (29)	18	45	55.6	55.6	16.7	20.0	22.2	17.8	5.6	6.7	100.0	100.0
Metal working equip. (17)	14	40	42.9	50.0	21.4	22.5	28.6	20.0	7.1	7.5	100.0	100.0
Food & Tobacco (1)	2	22	100.0	63.6	0.0	22.7	0.0	13.6	0.0	0.0	100.0	100.0
Printing & publishing (26)	5	16	20.0	31.3	20.0	31.3	60.0	37.5	0.0	0.0	100.0	100.0
Paper making appartus (18)	9	35	55.6	54.3	0.0	25.7	33.3	17.1	11.1	2.9	100.0	100.0
Non-metallic mineral prods. (50)	18	45	55.6	55.6	16.7	20.0	22.2	17.8	5.6	6.7	100.0	100.0
Average			*45.5*	*52.9*	*15.3*	*22.4*	*25.5*	*17.8*	*5.4*	*6.9*		
3. Chemical processes (5)												
Assembly & mat. handling equip. (20)	21	74	19.0	40.5	33.3	18.9	23.8	21.6	23.8	18.9	100.0	100.0
Textile & clothing machinery (25)	9	37	11.1	43.2	33.3	16.2	33.3	16.2	22.2	24.3	100.0	100.0
Printing & publishing (26)	9	28	11.1	25.0	33.3	28.6	33.3	42.9	22.2	3.6	100.0	100.0
Non-metallic mineral prods. (50)	27	73	33.3	41.1	25.9	20.5	22.2	19.2	18.5	19.2	100.0	100.0
Miscell. Metal products (14)	28	72	32.1	37.5	25.0	19.4	25.0	22.2	17.9	20.8	100.0	100.0
Metallurgical processes (13)	26	69	26.9	39.1	30.8	20.3	23.1	20.3	19.2	20.3	100.0	100.0
Average			*22.3*	*37.8*	*30.3*	*20.7*	*26.8*	*23.7*	*20.6*	*17.9*		
4. Photographic processes (6)												
Other instruments & controls (53)	2	25	50.0	44.0	50.0	12.0	0.0	40.0	0.0	4.0	100.0	100.0
Metallurgical processes (13)	2	24	50.0	45.8	50.0	12.5	0.0	37.5	0.0	4.2	100.0	100.0
Electrical lamp manuf. (24)	0	7	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
Printing & publishing (26)	2	16	50.0	31.3	50.0	12.5	0.0	56.3	0.0	0.0	100.0	100.0
Miscell. Metal products (14)	2	22	50.0	13.6	50.0	40.9	0.0	40.9	0.0	4.5	100.0	100.0
Building mats. & processing equip. (19)	0	12	0.0	25.0	0.0	25.0	0.0	41.7	0.0	8.3	0.0	100.0
Assembly & mat. handling equip. (20)	2	24	50.0	41.7	50.0	12.5	0.0	41.7	0.0	4.2	100.0	100.0
Non-metallic mineral prods. (50)	3	24	66.7	45.8	33.3	12.5	0.0	37.5	0.0	4.2	100.0	100.0
Other general ind. Equip. (29)	3	23	66.7	39.1	33.3	13.0	0.0	43.5	0.0	4.3	100.0	100.0
Metal working equip. (17)	2	22	50.0	40.9	50.0	13.6	0.0	40.9	0.0	4.5	100.0	100.0
Average			*43.3*	*32.7*	*36.7*	*15.5*	*0.0*	*48.0*	*0.0*	*3.8*		
5. Cleaning agents & other comp. (7)												
Miscell. Metal products (14)	19	57	47.4	45.6	10.5	19.3	26.3	17.5	15.8	17.5	100.0	100.0
Paper making appartus (18)	9	45	55.6	53.3	11.1	24.4	33.3	15.6	0.0	6.7	100.0	100.0
Assembly & mat. handling equip. (20)	14	59	28.6	49.2	14.3	18.6	35.7	16.9	21.4	15.3	100.0	100.0
Metal working equip. (17)	17	56	35.3	46.4	17.6	19.6	29.4	16.1	17.6	17.9	100.0	100.0
Metallurgical processes (13)	19	57	36.8	45.6	15.8	19.3	31.6	17.5	15.8	17.5	100.0	100.0
Food & Tobacco (1)	2	28	100.0	64.3	0.0	21.4	0.0	10.7	0.0	3.6	100.0	100.0
Textile & clothing machinery (25)	7	32	14.3	50.0	14.3	18.8	42.9	15.6	28.6	15.6	100.0	100.0
Average			*45.4*	*50.6*	*11.9*	*20.2*	*28.5*	*15.7*	*14.2*	*13.4*		

Table 7 (continued)

6. Disinfectants & preservatives (8)												
Mining equipment (23)	0	6	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Food & Tobacco (1)	0	6	0.0	83.3	0.0	16.7	0.0	0.0	0.0	0.0	0.0	100.0
Paper making appartus (18)	0	7	0.0	85.7	0.0	14.3	0.0	0.0	0.0	0.0	0.0	100.0
Agricultural equipment (21)	0	3	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Average			*0.0*	*92.3*	*0.0*	*7.7*	*0.0*	*0.0*	*0.0*	*0.0*		
7. Synthetic resins & fibers (9)												
Assembly & mat. handling equip. (20)	12	60	33.3	48.3	16.7	18.3	25.0	15.0	25.0	18.3	100.0	100.0
Metal working equip. (17)	14	57	42.9	43.9	14.3	19.3	21.4	15.8	21.4	21.1	100.0	100.0
Miscell. Metal products (14)	17	58	52.9	44.8	11.8	19.0	17.6	15.5	17.6	20.7	100.0	100.0
Metallurgical processes (13)	16	57	43.8	45.6	12.5	19.3	25.0	15.8	18.8	19.3	100.0	100.0
Food & Tobacco (1)	2	29	100.0	58.6	0.0	24.1	0.0	10.3	0.0	6.9	100.0	100.0
Average			*54.6*	*48.3*	*11.0*	*20.0*	*17.8*	*14.5*	*16.6*	*17.3*		
8. Bleaching & Dying (10)												
Food, drink & tobaco equipment (15)	0	4	0.0	25.0	0.0	25.0	0.0	25.0	0.0	25.0	0.0	100.0
Textile & clothing machinery (25)	2	19	50.0	68.4	50.0	15.8	0.0	5.3	0.0	10.5	100.0	100.0
Non-metallic mineral prods. (50)	5	25	80.0	76.0	20.0	12.0	0.0	4.0	0.0	8.0	100.0	100.0
Metallurgical processes (13)	4	22	75.0	72.7	25.0	13.6	0.0	4.5	0.0	9.1	100.0	100.0
Average			*51.3*	*60.5*	*23.8*	*16.6*	*0.0*	*9.7*	*0.0*	*13.2*		
9. Other organic compounds (11)												
Assembly & mat. handling equip. (20)	10	54	40.0	55.6	10.0	13.0	20.0	16.7	30.0	14.8	100.0	100.0
Textile & clothing machinery (25)	6	31	16.7	51.6	16.7	16.1	33.3	12.9	33.3	19.4	100.0	100.0
Average			*28.3*	*53.6*	*13.3*	*14.5*	*26.7*	*14.8*	*31.7*	*17.1*		
10. Pharmaceuticals & biotech. (12)												
Textile & clothing machinery (25)	2	23	50.0	65.2	50.0	13.0	0.0	13.0	0.0	8.7	100.0	100.0
Paper making appartus (18)	4	32	75.0	75.0	25.0	9.4	0.0	12.5	0.0	3.1	100.0	100.0
Food, drink & tobacco equipment (15)	0	12	0.0	33.3	0.0	25.0	0.0	33.3	0.0	8.3	0.0	100.0
Building mats. & processing equip. (19)	0	12	0.0	33.3	0.0	25.0	0.0	33.3	0.0	8.3	0.0	100.0
Average			*31.3*	*51.7*	*18.8*	*18.1*	*0.0*	*23.1*	*0.0*	*7.1*		
11. Coal & petroleum products (51)												
Textile & clothing machinery (25)	3	19	33.3	68.4	0.0	15.8	66.7	10.5	0.0	5.3	100.0	100.0
Assembly & mat. handling equip. (20)	7	33	57.1	72.7	0.0	9.1	28.6	6.1	14.3	12.1	100.0	100.0
Other instruments & controls (53)	10	63	70.0	39.7	0.0	50.8	20.0	3.2	10.0	6.3	100.0	100.0
Metallurgical processes (13)	10	34	70.0	73.5	0.0	8.8	20.0	5.9	10.0	11.8	100.0	100.0
Average			*57.6*	*63.6*	*0.0*	*21.1*	*33.8*	*6.4*	*8.6*	*8.9*		
12. Explosive compositions & charges (55)												
Mining equipment (23)	0	8	0.0	87.5	0.0	0.0	0.0	0.0	0.0	12.5	0.0	100.0
Power Plants (31)	0	10	0.0	80.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	100.0
Metal working equip. (17)	1	11	100.0	81.8	0.0	0.0	0.0	0.0	0.0	18.2	100.0	100.0
Other instruments & controls (53)	1	11	100.0	81.8	0.0	0.0	0.0	0.0	0.0	18.2	100.0	100.0
Other general indus. Equip. (29)	2	12	100.0	83.3	0.0	0.0	0.0	0.0	0.0	16.7	100.0	100.0
Miscell. Metal products (14)	2	12	100.0	83.3	0.0	0.0	0.0	0.0	0.0	16.7	100.0	100.0
Textile & clothing machinery (25)	1	10	100.0	90.0	0.0	0.0	0.0	0.0	0.0	10.0	100.0	100.0
Metallurgical processes (13)	2	12	100.0	83.3	0.0	0.0	0.0	0.0	0.0	16.7	100.0	100.0
Assembly & mat. handling equip. (20)	1	11	100.0	90.9	0.0	0.0	0.0	0.0	0.0	9.1	100.0	100.0
Average			*77.8*	*84.7*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*15.3*		
Aggregate average involvement by each industry			43.0	58.7	16.9	16.0	13.3	14.9	8.1	10.4		

Table 8 Industries that drive co-patenting of chemical and transport technologies between periods two and three

CHEMICAL TECHNOLOGIES			INDUSTRY									
	Total Firms (no.)		CHEMICAL		MECHANICAL		ELECTRICAL		TRANSPORT		TOTAL	
			(% firms in each industry)								%	
1. Distillation processes (2)	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2
Ships & marine propulsion (45)	0	9	0.0	66.7	0.0	22.2	0.0	11.1	0.0	0.0	0.0	100.0
Internal combustion engine (42)	1	10	100.0	90.0	0.0	0.0	0.0	*10.0*	0.0	0.0	100.0	100.0
Rubber & plastic products (49)	4	27	75.0	77.8	25.0	14.8	0.0	3.7	0.0	3.7	100.0	100.0
Other transport equipment (47)	0	4	0.0	0.0	0.0	50.0	0.0	25.0	0.0	25.0	0.0	100.0
Average			*43.8*	*58.6*	*6.3*	*21.8*	*0.0*	*12.5*	*0.0*	*7.2*		
2. Inorganic chemicals (3)												
Rubber & plastic products (49)	*10*	41	40.0	56.1	10.0	22.0	40.0	14.6	10.0	7.3	100.0	100.0
Internal combustion engine (42)	6	15	16.7	60.0	16.7	13.3	66.7	13.3	0.0	13.3	100.0	100.0
Railways & railway equip. (46)	7	11	14.3	9.1	28.6	27.3	57.1	36.4	0.0	27.3	100.0	100.0
Average			23.7	41.7	18.4	20.9	54.6	21.4	3.3	16.0		
3. Agricultural chemicals (4)												
Ships & marine propulsion (45)	0	8	0.0	75.0	0.0	12.5	0.0	0.0	*0.0*	12.5	0.0	100.0
Average			0.0	75.0	0.0	12.5	0.0	0.0	*0.0*	12.5	0.0	100.0
4. Chemical processes (5)												
Ships & marine propulsion (45)	4	19	0.0	31.6	25.0	10.5	75.0	21.1	0.0	36.8	100.0	100.0
Average			0.0	31.6	25.0	10.5	75.0	21.1	0.0	36.8		
5. Photographic processes (6)												
Railways & railway equip. (46)	0	5	0.0	20.0	0.0	0.0	0.0	60.0	0.0	20.0	0.0	100.0
Internal combustion engine (42)	0	6	0.0	16.7	0.0	0.0	0.0	66.7	0.0	16.7	0.0	100.0
Other transport equipment (47)	0	4	0.0	0.0	*0.0*	*0.0*	0.0	75.0	0.0	25.0	0.0	100.0
Aircraft (44)	0	7	0.0	14.3	0.0	0.0	0.0	85.7	0.0	0.0	0.0	100.0
Average			0.0	12.7	0.0	0.0	0.0	71.8	0.0	15.4		
6. Cleaning agents (7)												
Rubber & plastic products (49)	13	54	30.8	51.9	15.4	20.4	38.5	13.0	15.4	14.8	100.0	100.0
Ships & marine propulsion (45)	4	16	0.0	37.5	0.0	12.5	75.0	18.8	25.0	31.3	100.0	100.0
Railways & railway equip. (46)	8	14	12.5	7.1	12.5	28.6	62.5	35.7	12.5	28.6	100.0	100.0
Average			14.4	32.2	9.3	20.5	58.7	22.5	17.6	24.9		
7. Disinfectants & preservatives (8)												
Internal combustion engine (42)	0	5	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Ships & marine propulsion (45)	0	4	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Rubber & plastic products (49)	0	7	0.0	85.7	0.0	14.3	0.0	0.0	0.0	0.0	0.0	100.0
Average			0.0	95.2	0.0	4.8	0.0	0.0	0.0	0.0		
8. Synthetic resins & fibers (9)												
Rubber & plastic products (49)	12	58	33.3	48.3	16.7	19.0	25.0	13.8	25.0	19.0	100.0	100.0
Ships & marine propulsion (45)	2	16	0.0	37.5	0.0	12.5	100.0	12.5	0.0	37.5	100.0	100.0
Internal combustion engine (42)	4	18	25.0	50.0	0.0	5.6	75.0	16.7	0.0	27.8	100.0	100.0
Railways & railway equip. (46)	6	13	16.7	7.7	0.0	23.1	66.7	38.5	16.7	30.8	100.0	100.0
Average			18.8	35.9	4.2	15.0	66.7	20.4	10.4	28.8		
9. Bleaching & dying (10)												
Railways & railway equip. (46)	0	4	0.0	25.0	0.0	25.0	0.0	25.0	0.0	25.0	0.0	100.0
Other transport equipment (47)	0	4	0.0	0.0	0.0	25.0	0.0	25.0	0.0	50.0	0.0	100.0
Ships & marine propulsion (45)	0	5	0.0	20.0	0.0	20.0	0.0	20.0	0.0	40.0	0.0	100.0
Average			0.0	15.0	0.0	23.3	0.0	23.3	0.0	38.3		

Table 8 (continued)

10. Other organic compounds (11)												
Ships & marine propulsion (45)	1	14	0.0	42.9	0.0	14.3	100.0	21.4	0.0	21.4	100.0	100.0
Average			*0.0*	*42.9*	*0.0*	*14.3*	*100.0*	*21.4*	*0.0*	*21.4*		
11. Pharmaceuticals & Biotech (12)												
Ships & marine propulsion (45)	0	11	0.0	54.5	0.0	18.2	0.0	18.2	0.0	9.1	0.0	100.0
Rubber & plastic products (49)	4	36	75.0	75.0	25.0	8.3	0.0	11.1	0.0	5.6	100.0	100.0
Railways & railway equip. (46)	0	6	0.0	16.7	0.0	16.7	0.0	50.0	0.0	16.7	0.0	100.0
Other transport equipment (47)	0	7	0.0	0.0	0.0	28.6	0.0	42.9	0.0	28.6	0.0	100.0
Internal combustion engine (42)	1	10	100.0	90.0	0.0	0.0	0.0	10.0	0.0	0.0	100.0	100.0
Average			*35.0*	*47.2*	*5.0*	*14.4*	*0.0*	*26.4*	*0.0*	*12.0*		
12. Coal & Petroleum products (51)												
Ships & marine propulsion (45)	2	10	0.0	60.0	0.0	20.0	100.0	10.0	0.0	10.0	100.0	100.0
Rubber & plastic products (49)	*7*	32	57.1	71.9	0.0	9.4	28.6	6.3	14.3	12.5	100.0	100.0
Internal combustion engine (42)	*4*	11	*25.0*	72.7	*0.0*	0.0	50.0	9.1	25.0	18.2	100.0	100.0
Average			*27.4*	*68.2*	*0.0*	*9.8*	*59.5*	*8.4*	*13.1*	*13.6*		
13. Explosive compositions & charges (55)												
Internal combustion engine (42)	0	6	0.0	66.7	0.0	0.0	0.0	0.0	0.0	33.3	0.0	100.0
Ships & marine propulsion (45)	*0*	4	0.0	75.0	*0.0*	0.0	*0.0*	0.0	0.0	25.0	0.0	100.0
Rubber & plastic products (49)	*2*	12	100.0	83.3	*0.0*	0.0	*0.0*	0.0	0.0	16.7	100.0	100.0
Aircraft (44)	*0*	3	*0.0*	33.3	*0.0*	0.0	*0.0*	0.0	0.0	66.7	0.0	100.0
Average			*25.0*	*64.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*35.4*		
Aggregate average involvement by each industry			14.5	47.8	5.2	12.9	31.9	19.2	3.4	20.2		

FIGURE 1 Innovation Waves (adapted from Freeman and Perez, 1988)

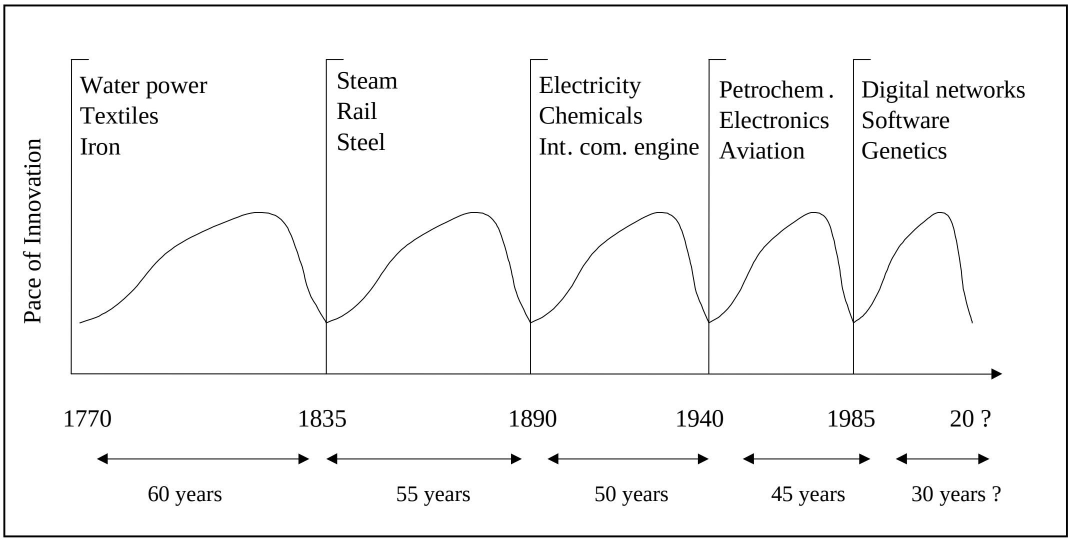


FIGURE 2 Changing relatedness of Electrical to other technologies

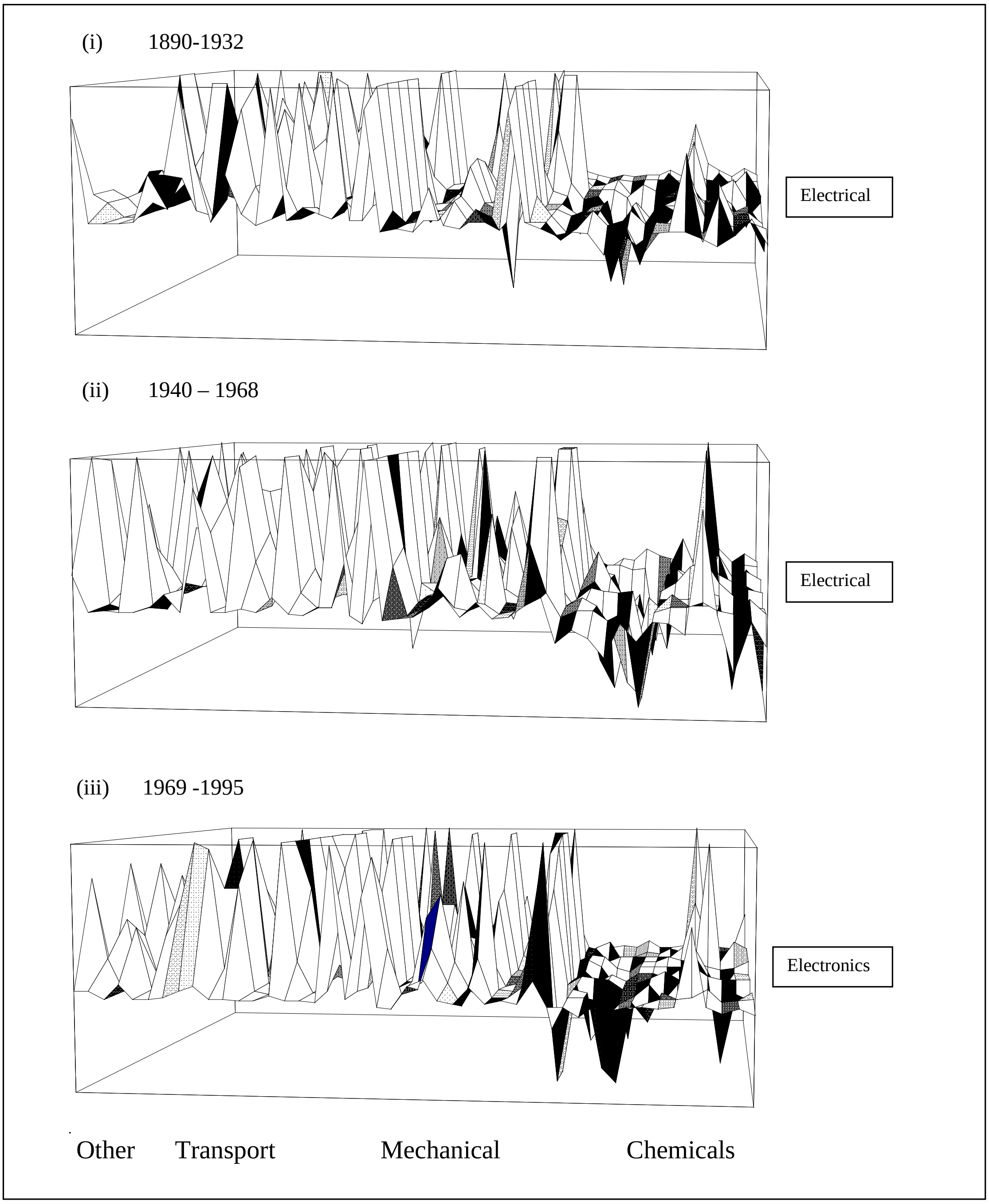


FIGURE 3 Changing relatedness of Chemical to other technologies

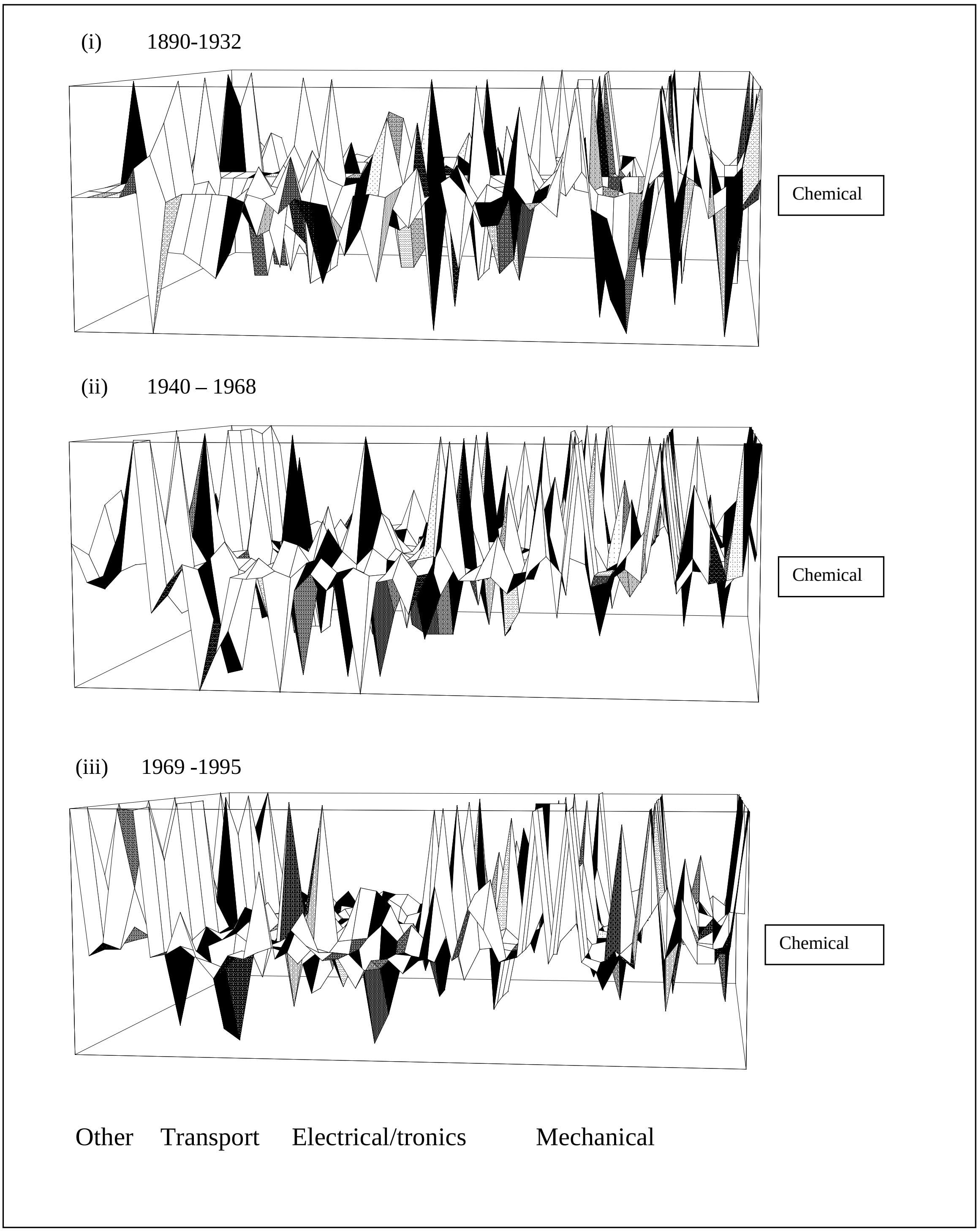
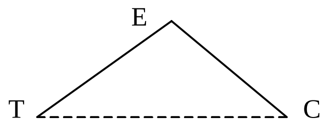


FIGURE 4 Technological interaction within the transportation industry, 1969-95.

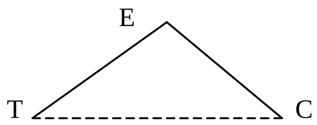
(a) Special Radio Systems [35]



Other transport equipment [47]
Ships & marine propulsion [45]
Railways & railway equipment [46]
Motor vehicles [43]

Distillation processes [2]
Bleaching & dying [10]
Pharmaceuticals & biotechnology [12]

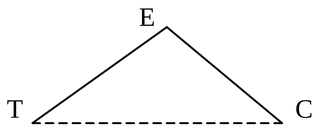
(b) Illumination devices [37]



Rubber & plastic products [49]
Other transport equipment [47]
Ships & marine propulsion [45]

Synthetic resins & fibers [9]
Chemical processes [5]
Cleaning agents & other compositions [7]
Pharmaceuticals & biotechnology [12]
Other organic compounds [11]
Bleaching & dying [10]
Agricultural chemicals [4]

(c) Semiconductors [40]



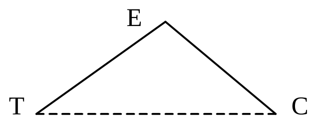
Rubber & plastic products [49]
Other transport equipment [47]

Cleaning agents & other compositions [7]
Distillation processes [2]
Synthetic resins & fibers [9]
Chemical processes [5]
Other organic compounds [11]
Pharmaceuticals & biotechnology [12]
Explosive compositions & charges [55]
Agricultural chemicals [4]

Note: the dashed line between the transport technologies (T) and chemical technologies (C) highlights the indirect linkage forged between these technologies. From table 9 we see that co-patenting occurred across a number of these T-C combinations between periods one and two. Assuming path dependence in the process, it is likely that a number of these linkages Become direct through co-patenting behavior in period three.

FIGURE 5 Technological co-patenting within the Mechanical industry (1969-95).

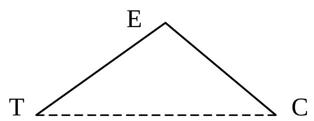
(a) Other general electrical equipment [39]



Rubber & plastic products [49]

Distillation processes [2]
Bleaching & dying [10]
Coal & petroleum products (51)]
Agricultural chemicals [4]
Cleaning agents & other compositions [7]
Chemical processes [5]

(b) Semiconductors [40]



Rubber & plastic products [49]

Cleaning agents & other compositions [7]
Distillation processes [2]
Synthetic resins & fibers (9)
Chemical processes [5]
Other organic compounds [11]
Pharmaceuticals & biotechnology [12]
Bleaching & dying [10]
Explosive compositions & charges [55]
Agricultural chemicals [4]
Coal & petroleum products (51)]

APPENDIX A

CODE	DESCRIPTION	MACRO SECTOR
2	Distillation processes	CHEMICAL
3	Inorganic chemicals	CHEMICAL
4	Agricultural chemicals	CHEMICAL
5	Chemical processes	CHEMICAL
6	Photographic processes	CHEMICAL
7	Cleaning agents and other compositions	CHEMICAL
8	Disinfectants and preservatives	CHEMICAL
9	Synthetic resins and fibres	CHEMICAL
10	Bleaching and dying	CHEMICAL
11	Other organic compounds	CHEMICAL
12	Pharmaceuticals and biotechnology	CHEMICAL
51	Coal and petroleum products	CHEMICAL
55	Explosive compositions and charge	CHEMICAL
1	Food and Tobacco	MECHANICAL
13	Metallurgical processes	MECHANICAL
14	Miscell. metal products	MECHANICAL
15	Food, drink and tobacco equipment	MECHANICAL
16	Chemical and allied equipment	MECHANICAL
17	Metal working equipment	MECHANICAL
18	Paper making apparatus	MECHANICAL
19	Building material and processing equipment	MECHANICAL
20	Assembly and material handling equipment	MECHANICAL
21	Agricultural equipment	MECHANICAL
22	Other construction and excavating equipment	MECHANICAL
23	Mining equipment	MECHANICAL
24	Electrical lamp manufacturing	MECHANICAL
25	Textile and clothing machinery	MECHANICAL
26	Printing and publishing	MECHANICAL
27	Wood working tools and machinery	MECHANICAL
28	Other specified machinery	MECHANICAL
29	Other general industrial equipment	MECHANICAL
31	Power plants	MECHANICAL
50	Non metallic mineral products	MECHANICAL
53	Other instruments and controls	MECHANICAL
30	Mechanical calculators and typewriters	ELECTRONIC
33	Telecommunications	ELECTRONIC
34	Other electrical communication systems	ELECTRONIC
35	Special radio systems	ELECTRONIC
36	Image and sound equipment	ELECTRONIC
37	Illumination devices	ELECTRONIC
38	Electrical devices and systems	ELECTRONIC
39	Other general electrical equipment	ELECTRONIC
40	Semiconductors	ELECTRONIC
41	Office equipment and data processing systems	ELECTRONIC
52	Photographic equipment	ELECTRONIC
42	Internal combustion engines	TRANSPORT
43	Motor vehicles	TRANSPORT
44	Aircraft	TRANSPORT
45	Ships and marine propulsion	TRANSPORT
46	Railways and railway equipment	TRANSPORT
47	Other transport equipment	TRANSPORT
49	Rubber and plastic products	TRANSPORT
32	Nuclear reactors	OTHER
48	Textiles, clothing and leather	OTHER
54	Wood products	OTHER
56	Other manufacturing (non industrial)	OTHER

APPENDIX B

Teece et al. (1994) methodology for calculating technological relatedness.

Formally, a sample of N firms is selected. Because un-diversified companies shed no light upon firm relatedness (i.e firms that do not patent beyond the core technology), one must differentiate between 'presence' and 'absence' in a technological sector[19]:

jn = 1 if firm n is active in technology j
= 0 if firm n is not active in technology j

The number of technologies in which firm n records a presence is described as:

$$J_n = \sum_j C_{jn} \qquad (1)$$

The number of technologies in which an industry with n members records a presence is:

$$P_j = \sum_n C_{jn} \qquad (2)$$

Consider N_{ij} represents the number of firms, that are active in technologies i and j

where: $N_{ij} = \sum_n C_{in} C_{jn}$ (3)

This count of joint occurrences of technology i and j can be used to construct a measure of relatedness. Two samples are drawn from the population of N firms. The first sample of size n_i is generated and these firms are assigned activity in technology i whilst firms in the second sample (n_j) are assigned activities in technology j. We assume that n_i and n_j are fixed. Because this involves sampling without replacement, the number of firms that are active in both technologies (x_{ij}) are distributed as a hypergeometric random variable.

[19] In this study, we only include firms that record a minimum of 500 patents within each time period. In addition, we define 'presence' as occurring if the firm holds a minimum of 5 patents in any of the 56 technology sectors. While various different cut off points were tested, we found that these cut off points enabled the most meaningful measurement of the relatedness index.

$$\Pr[X_{ij} = x] = f(x, N, n_i, n_j) = \binom{n_i}{x}\binom{N-n_i}{n_j-x} \Big/ \binom{N}{n_i} \quad (4)$$

Therefore with population N, the expected value and variance are computed as:

$$\mu_{ij} = E(x_{ij}) = n_i n_j / N \quad (5)$$

$$s^2_{ij} = \mu_{ij} \left(1 - \frac{ni}{N}\right)\left(\frac{N-nj}{N-1}\right) \quad (6)$$

If the actual number of linkages between technologies *i* and *j* (n_{ij}) is larger than the expected number (μ_{ij}), then the two technologies are highly related. The degree to which technologies are related can be measured therefore by a relatedness measure (R):

$$R_{ij} = (n_{ij} - \mu_{ij}) / \sigma_{ij} \quad (7)$$

where: n_{ij} = actual number of linkages between technologies *i* and *j*

μ_{ij} = than the expected number of linkages between technologies *i* and *j*

σ_{ij} = standard deviation of the expectation