FIRST DRAFT: NOT TO BE QUOTED OR CIRCULATED

The Rise and Decline of Fordism and the Sea-Change in the Technological Advantage of Nations

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Abstract

This paper seeks to explain a number of striking and profound changes in the technological advantage and specialisation of nations during the last century; changes which we argue are related. Cantwell's patent data is used as a measure of specialisation and advantage, with the usual caveats. The explanation is mainly in terms of the rise and decline of the 'Fordist' techno-economic paradigm, countries' institutional adaptations to it, and a number of shocks which (arguably) were associated with it. The starting point is the proposition that international differences in patterns of technological specialisation are largely determined by differences in the national environments in which economic agents operate, and thus by the institutional set-up of the national economy. The literature about national systems of innovation (NSI) has emphasised the importance of the national features of an economy for technological improvement, development and implementation. Over time, a change in techno-economic paradigm may change the suitability of a given NSI for success in sectors radically affected by that change. Moreover, such a change in paradigm, by the challenge it poses to existing structures and the crises it may cause, is also likely to bring about changes in NSI which in some countries may be far-reaching. In combination, these changes could be expected, in principle, to lead to profound changes in absolute and relative technological advantage. We argue that such a 'sea-change' in the technological advantage of nations is precisely what they *did* bring about during the 20th century.

The 'mechanical family', at the beginning of the 20th century, was in general an area of German weakness and Anglo-US strength – divergence only increased by the development of Fordist mass production in the US. By the end, the positions had been decisively reversed, due mainly to successful institutional innovation in Germany, with some institutional decay in the US and UK. The key period for this institutional innovation was the latter stage of the 'depression crisis' of the long wave, which fits arguments like those of Perez and Tylecote about the consequences of this crisis. The appearance of the post-Fordist or ICT technological style merely confirmed the superiority of German institutions in this family.

In the 'chemical family' Germany initially was far ahead of both the US and UK: here it was Germany which had made the key institutional innovations – parallel in the public and private sectors – during the 19th century, with the US and UK (in that order) struggling to follow. The US development of petrochemicals as part of the Fordist technological style did much to close the gap, and a further contribution was made by the disruption of German institutions in the long wave depression crisis of the 1930s and 40s. The next key institutional innovations were made gradually in the USA during the 1960s and 70s with the development of venture capital, and when the post-Fordist style arrived it was mainly this which allowed the US, followed by the UK, to get well ahead of the Germans in the highest-technology parts of the family.

The key implication of our findings is that it is very much the institutions of the NSI (broadly defined) which drive technological specialisation, rather than the other way round. They may change – they did change radically in our 3 countries as in others, during the century – but their changes are driven by broad social, political and economic forces, more than deliberate policy.

Section 1. Introduction

The main aim of this paper is to explain a number of striking and profound changes in the technological advantage and specialisation of nations during the last century; changes which we argue are related. The explanation is mainly in terms of the rise and decline of the 'Fordist' techno-economic paradigm[1], countries' institutional adaptations to it, and a number of shocks which (it can be argued) were associated with it. Our starting point is the proposition that technological specialisation is closely related to the institutional set-up of the national economy. International differences in patterns of technological specialisation are largely determined by differences in the national environments in which economic agents operate. The literature about national systems of innovation (NSI) has emphasised the importance of the national features of an economy for technological improvement, development and implementation (Edquist 1997; Freeman 1987, 1995; Lundvall 1992; Nelson 1993; Porter 1990). Over time, a change in techno-economic paradigm may change the suitability of a given NSI for success in sectors radically affected by that change. Moreover, such a change in paradigm, by the challenge it poses to existing structures and the crises it may bring about at various levels (Perez, 1983; Tylecote, 1991), is also likely to bring about changes in NSI which in some countries may be far-reaching. In combination, these changes could be expected, in principle, to lead to profound changes in absolute and relative technological advantage. We shall argue that such a 'sea-change'[2] in the technological advantage of nations – we call it *the* sea-change because we know of no other set of changes so radical - is precisely what they *did* bring about during the 20th century.

The paper makes selective use of the patent database compiled by Professor John Cantwell at the University of Reading, containing patents granted in the US between 1890 and 1990. For the purpose of this paper, we use patents granted to both individual inventors and companies (mainly large firms), classified by host country of research and innovation. According to this classification, patents become indicators of the location of research activities and, consequently, strictly connected to the national system of innovation. Since each patent is classified according to the type of technological activity, in Cantwell's database, the 399 original patent classes identified by the American Patent and Trademark Office (PTO) are grouped into 56 technological sectors, collecting together technologically related patent classes derived from the US patent class system (see Tab. 1). Yet, since we are interested only in some sectors particularly closely related to the rise and decline of Fordism, out of Cantwell's 56 technological sectors, only a minority are here taken into consideration (see Tab. 2).
We are of course aware of the many deficiencies of patent data as an indicator of performance – particularly apparent when looking at individual firms (Archibugi 1992; Basberg 1987; Mansfield 1986; Scherer 1983). We submit that those deficiencies are minimised by aggregation to country level and by taking long periods (our shortest is 12 years). We use accumulated patent stock in 5 historical periods[3]:
- 1890-1914, our 'baseline' period;
- 1915-39, 'early Fordism';
- 1940-64, 'mature Fordism'
- 1965-77, 'late Fordism';

[1] Or 'technological style') in the terms used by Perez (1983) and Tylecote (1991).
[2] If the phrase is unfamiliar to the reader, the reference is to Shakespeare's Tempest:
They have suffered a sea-change
Into something rich and strange.
[3] The historical perspective is safe within the PTO classification because the American PTO reclassified all earlier patents, if a change in the patent classes occurs, in order to keep its classification historically consistent.

- 1978-90, ‘transition from Fordism’.

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Some of the weaknesses in using patent statistics are overcome in this paper with the Revealed Technological Advantage (RTA) index, first used in his pioneering works by Soete (1980, 1987).[i] For a given sector, RTA>1 indicates relative technological advantage in that sector, RTA<1 technological disadvantage. It must be kept in mind that the RTA index is a *relative* measure of the performance of a sector and country, because it compares national patent share in that sector (in the numerator) with patent share across all sectors (in the denominator). When a country shows a technological disadvantage in a particular technological sector (RTA<1), it means that the national share of patenting in that particular technological sector is less than the national share of patenting across all technological sectors. By contrast, patent share is a measure of absolute advantage/disadvantage. However, when making international comparison, as in this case, patent share is not a good indicator to use because the absolute level of patenting is more likely to be influenced by inter-country differences in the propensity to patent (Scherer 1983).

We focus here on three main areas:
1. assembly-line based mechanical engineering, notably motor vehicles;
2. the chemical industries in general
3. machinery manufacture, excluding electrical equipment.

The first is the greatest of what Perez (1983) would term the *carrier branches* of Fordism: branches which in production and use make intensive use of what in that paradigm are the key factors of production – notably cheap energy in the form of petroleum products and electricity. Their production was the first to be based on the best-known Fordist process, the assembly line. The second, in most of its parts, is also a highly intensive user of energy and/or petroleum products, and is largely based on the other key (but less well known) Fordist process, continuous flow: it can as such be counted as the other great carrier branch of Fordism. The third played a key role in the Fordist style, because it provided its tools, but being generally rather small in scale it was mostly unable to switch to mass production techniques; which made it all the more important in terms of employment and (to a lesser extent) value-added. Using Pavitt’s (1984) taxonomy, the first is ‘scale-intensive’ and belongs to the mechanical family, the second is mostly scale-intensive but partly science-intensive, all of course in the chemicals family, the third is ‘specialised supplier’ and all in the mechanical family. The sea-change we spoke of can be simply summarised: the lead in our mechanical industries – both areas - passed from the UK and US to Germany and Japan. In the chemical industries, on the other hand, it was held by Germany at the beginning in almost all of them, but by the end German dominance was over and its strength was concentrated in the ‘industrial chemical’ core, with the rest dominated by the US, UK and France. We argue that this reversal reflects profound technological and institutional change. (In this, preliminary, paper we ignore France and Japan. Further work will extend the range of countries and include the electrical family.)

The paper is organised as follows: Section 2 gives a brief account of technological change during the 20th century in terms of the succession of techno-economic paradigms or technological styles, following Perez (1983), Tylecote (1991) and Freeman and Louca (2001). Again following these writers, it argues that changes in the ‘socio-institutional framework’, and thus in national systems of innovation, take place largely in response (directly or indirectly) to changes in the techno-economic paradigm, and sketches what these were in our three countries.

Sections 3, 4 and 5 give accounts of the evolution of comparative advantage respectively in mass production engineering, machinery, and chemicals. In each case we follow the same sequence:

- we describe, in more detail than in Section 2, the main changes in the 'technological régimes' of the sectors during the 20th century,
- we show the changes in technological advantage (as registered by patents) between the 5 periods
- we explain the changes in technological advantage in terms of the 'fit' between the countries' national systems of innovation and the ruling technological régime of the sector.

Section 6 reflects on our findings.

Section 2. The Rise and Decline of Fordism and the Evolution of National Systems of Innovation.

Fordism and its effects on the economy

Perez defines a 'technological style' as 'a sort of 'ideal type' of productive organisation or best technological 'common sense' which develops as a response to what are perceived as the stable dynamics of the relative cost structure.' In other words, the basic techniques of production, and methods of organisation, which are seen as the most efficient and profitable, change in response to the appearance of new <u>key factors of production</u> which are

(a) clearly very cheap, by past standards, and tending to get cheaper, and

(b) potentially all-pervasive.

For example, when (as we shall see) the price of steel plummeted after 1850, this had drastic implications for methods of production, throughout the economy. About half a century later, the cheapening of various forms of energy, particularly oil and electricity, played a similar role in the development of the Fordist style. The new 'style' is 'grounded on the introduction of a cluster or constellation of interrelated innovations both technical and managerial which lead to the attainment of a general level of total factor or physical productivity clearly superior to what was 'normal' with the previous technological style'.

The crucial innovations take place in two areas of the economy: the industries which <u>make</u> the key factor(s) of production (Perez calls these the '<u>motive branches</u>') and those which <u>use</u> the key factor(s) most intensively and are the best adapted to the new organisation of production (the 'carrier branches'). (Thus oil refining and electricity generation were 'motive branches' in the Fordist style, while the motor vehicles industry was a 'carrier branch'). The motive and carrier branches are the locomotive of the economy, though once they have got the upswing going, there is a burgeoning of a third category, the 'induced branches", which provide goods and services for which demand is increasing rapidly.

Once a new technological style has arrived, it starts to fan out across the economy: 'As long as the...evolution of the relative costs of various types of material inputs, various types of equipment and different skills follows the expected trends, managers and engineers will apply what becomes the 'technical common sense' to make incremental improvements along the natural trajectories of the technologies in place, or radical technological changes in those branches of production of goods or services which have not yet achieved the 'ideal type' of productive organisation'. Thus from the beginning of the Fordist style, in the USA, 1910-1920, the motor vehicle industry used Fordist technology, like the assembly line, based on dedicated machine tools and similar equipment which could perform single tasks with high speed and accuracy. Improvements to the automobile, and the methods of making it, were (at least until the 1970s) incremental - you had basically the same assembly line system but you made it faster and more automated. But other industries had to make radical changes in order to come into line.

The diffusion of the new style leads to a restructuring of the whole economy, involving
a) A new 'best practice' form of organisation at the firm and/or the plant level;
b) A new 'skill profile', using different proportions of the various categories of labour, and changing the nature of the skills within them: this in turn has implications for the distribution of income;
c) A new 'product mix': those products which use the new key factors intensively will make up a growing proportion of the GNP;
d) New trends in technical change: innovations will be aimed at economising on expensive factors of production through more intensive use of the key factor(s):
e) A new pattern in the location of production: the new structure of relative costs transforms the pattern of 'comparative advantage';
f) Heavy expenditure on *infrastructure* of the kind required by the new style.[2]

By the early 1900s there existed, in the USA, all the preconditions for what we now know as the Fordist techno-economic paradigm. There was an affluent mass market, the Taylorist pattern of work organisation which suited the high degree of division of labour required by the assembly line, the capacity to produce the appropriate machine tools and motors. There were also – increasingly - the cheap petroleum products required to run the motor vehicles, and electricity, not only cheaply produced now, but available, through the distribution grid, where it was needed, to run the motors and 'white goods'. It was time for the appearance of the Fordist paradigm, which could be dated to the year 1915, when Henry Ford opened his first assembly line plant. As for the 'motive branches', improvements in electricity generation led to a fall in the average price of electricity in the USA, between 1902 and 1928, of 41% (31% in constant terms). The price of oil fell: from a peak average of $2.00 per barrel during the 1915-20 period, it dropped to an average of $1.35 per barrel, 1931-35. Advances in refining techniques brought the cost of petroleum products down a good deal faster. These advances, of course, belonged to the chemicals industry, of which oil refining ('petrochemicals') had become a branch. The fundamental advance which diffused through chemicals and analogous industries, as the assembly line diffused through engineering, was continuous flow - not along conveyor belts, but through pipes.

The Separation of Spheres in Fordist Production

Three functions are performed in manufacturing industry:

1. The actual process of manufacture, the physical turning of inputs into outputs;
2. ‘Design', broadly construed to include the whole process of generating new and improved products and processes;
3. 'Coordination' - management, again broadly defined.

One effect of 'Taylorism' was to take much further than previously, the separation of these functions in practice. The small firm at the beginning of the Industrial Revolution had had little 'design' to do, because technology changed slowly, and little 'coordination', because it was small, and both, such as they were, were at least partly the responsibility of skilled workers who were involved in the process of manufacture. Now they were distinct <u>spheres</u>, in Kaplinsky's words, and increasingly important ones. The larger firms became under Fordism, the more 'coordination' was required; the faster technology and products changed - and the pace of change was steadily accelerating - the more 'design' was required. There had always been a tendency, in the previous ('steel and science') techno-economic paradigm, for the scientists and engineers involved in the development of new products and processes to be drawn into the day-to-day problems of production. General Electric and Bell Telephone, in the US, solved this problem in the 1900s by adopting the system pioneered by the German chemicals industry, of separate research and development laboratories, and this was widely copied in the United States in the 1920s - we can call it part of Fordism. There was little in Fordist technology, once the typewriter and the telephone had been exploited, to raise labour productivity in either sphere, design or coordination, so that their share of the labour force, within manufacturing industry, steadily increased.

The limits of Fordism

Fordism - as improved over forty years - offered a marvellously efficient system of mass production. The 'dedicated' machine tool and other machines could be made to require less and less labour and produce at higher and higher rates, thus furthering 'transformation mechanisation' – the first stage of mechanisation, according to Coombs (1983). The assemply line (and continuous flow in chemicals) represented the second stage, transfer mechanisation, the mechanical moving of materials between different stages of transformation. What it still largely lacked was Coombs' third stage, control mechanisation: the substitution of machines for the human brain in the direction and supervision of the productive process. That lack became apparent in the increasing share of non-manual workers in the labour force of the mass-production industries, and in the relatively slow rate of increases of productivity in burgeoning service industries, like banking. It was also reflected in the difficulties of mechanising those engineering industries, mostly making capital goods, which were limited in volume to batch rather than mass production. (In the USA Lund *et al.* (1977) found that over 75% of all metalworking firms were engaged in small batch production, and according to Ayres and Miller (1983) between 50 and 75% of the dollar value of all 'durable' manufactured goods were batch-produced.) Finally, it helped to explain the high *energy-intensity* of Fordist technology, which tended, instead of the subtleties of the human brain and hand, to resort to brute mechanical force, and crude on-off choices.

What was needed, for control mechanisation, was *machine intelligence*: and that was what the next techno-economic paradigm – let us call it post-Fordist - produced. Based on radical discoveries in electronics, an entire constellation of information and communication technology (ICT) developed. Computer-aided manufacturing – starting with computer numerically-controlled machine tools – made it possible to provide a flexible form of mechanisation which unlike Fordist dedicated equipment could cope with short runs. Introduced in the US aircraft industry in the 1950s, it was most obviously useful in those areas where scale of output was too small to justify Fordist equipment. It was however introduced in the 1970s into the motor industry by the big Japanese firms there, initially to mechanise their smaller suppliers – before they recognised the advantages of using it in place of Fordist equipment on their own assembly lines. Computer-aided design soon mechanised much of the design process, and was joined with computer-aided manufacturing in CAD-CAM. Meanwhile the scope for applying ICT to the whole process of coordination was increasingly recognised, culminating in the development and diffusion of the Internet.

Arguably (according to Tylecote, 1991, but not Freeman and Louca, 2001) biotechnology could be seen too as part of the 'post-Fordist' paradigm. In at least one of the high technology sectors, pharmaceuticals, it had by the end of our period become a key and pervasive technology. (See Orsenigo, 1989).

Institutional changes in response to Fordism – and post-Fordism.

We can see that the interaction between technological change and institutional change in the country which introduced Fordism, was a complex one. One or two variables – the natural resource endowment, for example, which gave the United States cheap petroleum and cheap electricity – are completely exogenous. The existence of a very large middle class able to afford Fordist goods from the beginning, has institutional causes but none worth exploring in this (NSI) context. The fact that this middle class sent its children (at least its sons) to university and that this resulted in an ample supply of graduate engineers, does impinge on the NSI. It was this combination of two types of labour in good supply and amenable to management's wishes - graduate engineers and semi-skilled, mostly immigrant, labour – which was brought together most productively under Fordism, that is to say under Fordist mass production. The ample supply of chemical engineers (an occupation invented in the USA) had a similar role in the development of the petrochemical industries. Not only was the natural resource endowment of Germany quite different from that of the United States (having the most expensive coal of the three countries and no oil, or any control over any); so also was its supply of labour. Its relative poverty and inequality of income limited its supply of graduates, on the one hand. On the other hand, it was not – least of all in the depressed 1920s, 30s and 40s – a country of immigration. There was thus no large supply of semi-skilled workers available at (for the country) low wages. On the contrary, there was an alarmingly cohesive urban labour force led by skilled craft workers (*Facharbeiter*) whose role in industry was entrenched. These were not people to be brushed out of the way in the introduction of Fordist technology, and no-one, not even the Nazis, seriously attempted to do so.[ii]

In the end, a historic compromise was made, at the end of the 1940s. The strength of the reborn unions, led by skilled workers (but including all manual skill levels), was recognised by employers at every level – employers' association and enterprise. The principle of cooperation in raising productivity and skill levels and developing new products, was accepted as central. As Wolfgang Streeck (1991) has shown, this deal created a new technological dynamic within German industry. So far as Fordist technology was concerned, the compromise meant that it could be introduced in a thoroughgoing way, but with extensive modification to allow for and take advantage of higher skill levels on the shop floor, and make production workers and those who had risen from the shop floor to become '*graduierte ingenieuren*' (graduate*d* engineers – who had studied on day release and night school) key participants in a process of incremental innovation.

Meanwhile a quite different compromise had been made in the United States. The semi-skilled workers who had been putty in management's hands in the early days of Fordism, formed and joined the new unions of the Confederation of Industrial Organisations (CIO) during the 1930s and 40s. In the 1950s the advancing tide of unionisation stopped and fell back, with union density thenceforth declining continuously to a strikingly low level (below 10%) by the end of the century, but the bastions of scale-intensive Fordist technology remained unionised. Management kept control over the assembly lines, but at the price of conceding wages which were well above the economy average. The Fordist workplace of the United States, post-war, was no place for creative experimentation which would give shop floor workers more skills and therefore more power.

The motor firms of the UK were set up, for the most part, in Southern locations like Dagenham (Ford) and Oxford (Morris) which were well away from the heartlands of unionism and able to draw on a supply of agricultural workers who were initially almost as pliable as their US counterparts, thus to construct a passable imitation of US Fordism. Much as in the United States, however, unionisation gradually took hold, but to rather different effect: by the 1950s the unions, notably their lay officers within the plant, the shop stewards, were beginning increasingly to challenge and usurp managerial prerogatives[4]. What American managers feared, had by the late 1960s become British reality.

The science base

The German dyestuffs manufacturers in the late 19th century demonstrated the relevance of science in the chemical industry and both by close connections with university scientists and engineers, and by funding in-house R&D, they made the most of it. By 1914 the indigenous UK chemicals industry, by contrast, had almost disappeared, to be replaced by subsidiaries of Continental firms and new firms set up by immigrant Continental entrepreneurs. The USA lay between Britain and Germany in the alacrity with which its firms used science and connections with university scientists, though it was similar to Germany in its willingness to fund in-house R&D (see the GE and Bell examples mentioned above). Both countries naturally took Germany as a model for their development of university science, though there were important institutional differences between the German and Anglo-American models of university. The German university was and is an organ of the state, which (given the power of the Prussian state and the privileges of its senior servants is no small matter: the privileges by law and custom of German professors are awesome. British and American universities, on the other hand, are more autonomous institutions, which may account for the greater flexibility with which they have developed[5]. They had in common with Germany the principle that university academics were teachers *and* researchers, which in the US and UK guaranteed a large and continuous expansion of the science base, through the 20th century, as student numbers rose. The German science base was severely damaged by Nazi persecution of the Jews, and afterwards by the war. The flexibility of US universities – led by private universities, Stanford first – was shown in their role in supporting technological entrepreneurship from the 1950s and 60s onwards; British universities followed the US lead some twenty years later. German universities were very firmly not commercial organisations, and although in the creative period in the aftermath of the last war they were involved in developing various forms of state-sponsored cooperation with industry, they were not free to take commercial initiatives themselves – nor were professors free to do so. The relative inflexibility of the German universities was also shown in the relationships among disciplines: first, multi-disciplinary co-operation was even less 'done' than in the US and the UK, and second, old hierarchies of prestige like the superiority of chemists over biologists persisted after they had become quite inappropriate.

Craft unions

The aversion of US employers to unions, particularly the old craft unions which were the dominant form of labour organisation in the US and UK at the beginning of the 20th century, might suggest that they have always played a negative and obstructive role in the US and UK systems of innovation. This is not at all true, and certainly not in the old pre-Fordist craft-dominated industries like shipbuilding and machine tools, as Lazonick has shown (reference to add). The craft unions controlled and encouraged the system of skill building, through apprenticeship, and through the union's control of employment (no union card, no job) a time-served apprentice would become a craftsman and get a job anywhere in the industry – thus diffusing technical knowledge among firms within what the recent literature would describe as

[4] Worse, they did so on the basis of multi-unionism in most big firms: the various craft unions (electricians, engineers) plus one or two 'general' unions for the semi-skilled.

[5] The US state universities are, moreover, state not federal universities, which means that there are 50-odd sources of innovation and emulation at work all the time.

an occupational community of practice. The knowledge was not for the most part firm-specific and it was thus not appropriate for the firm to contribute heavily to its acquisition: it was the apprentice who bore the cost by working with and for the craftsman for next to nothing. There was however, in the US and UK, at no point a thorough modernisation of this system to introduce more systematic methods of learning, and accordingly it became more and more out of date, with the firm seeking to supplant it by more systematic knowledge held at a higher level. In Germany, on the other hand, this was exactly what took place in the 'historic compromise' of the late 1940s, which formed the basis of Streeck's (1991) 'diversified high quality production' paradigm.

The difference in approach to skill formation on the shop floor became more important as the Fordist techno-economic paradigm gave way to ICT-based technology. As Barry Wilkinson (1983) already recognised, there were essentially two ways to introduce computer numerically controlled (CNC) equipment in manufacturing: the 'de-skilling', Taylorist route, by which the relevant IT skills were held by specialists off the shop floor; and the 'shop-floor focused' route, by which as much as possible was done by skilled manual workers on the shop floor. No prizes, of course, for guessing which way the US and UK on one hand, and the Germans (and Japanese) on the other, went. Experience has shown ever since – and we show below – which works better.

Financial and corporate governance systems

Tylecote and Conesa (1999), and Lindblom, Sandahl, Tylecote and Visintin (2003) have shown how much of technological advantage can be explained by the financial and corporate governance systems; corporate governance being broadly construed to include all structures and relationships of power and influence, over and on management. The present and recent FCGS of the US and the UK can be contrasted very sharply with that of Germany (and Japan): in the first pair the FCGS is *outsider-dominated*, with the 'outsiders' predominantly, and increasingly, 'new institutional shareholders' such as pension funds, mutual funds and insurance companies. In Germany (and Japan) by contrast, the FCGS is (or at least has been until very recently) definitely insider-dominated. The German insiders include families – not only in small firms but across the vital 'Mittelstand', a category which includes some very large firms like Bosch and BMW. Banks are/have been also key insiders, with active or passive control in many of the largest firms. So are related firms, particularly suppliers and customers – there is a very high degree of cross-holding in German industry. Finally, in a broad definition of corporate governance one must include employee and union power, notably through the extensive legal structures of co-determination (which takes us back to Streeck and the historic compromise).

This contrast is not inscribed in the rock of ages. Even in the 1920s matters looked very different. Chandler and others have chided the British industrial capitalists of the early 20th century for their extreme reluctance to share control with outside sources of finance – thus inhibiting their expansion (a characteristic now to be found in the family firms of Northern Italy (Lindblom et al., 2003)). The early-20th century contrast is not only with Germany, but with the United States, where very large, well-funded, technically progressive firms were built up quickly, relying not only on the stock exchange but on big banks for finance. Meanwhile in Germany, for all the conspicuous co-operation of big banks with big industry described by Jeidels (1906), there was difficulty for small and medium enterprises in getting loans.

What happened? Max Planck said, when asked how he changed his opponents' minds: 'I didn't. They died.' The same happened to the stubborn industrial capitalists of the North of England.

Their families were gradually absorbed into the non- or anti-industrial gentry, their firms merged, with progressive dilution of family control, and so 'the City' – the financial institutions of the City of London - got their firms in the end. Changes in the US were more sudden. As Mark Roe (1994) has argued, there was longstanding concern about the economic and political power of 'trusts' – concentrations of industrial and bank capital – which came to a head after 1929, when some of these concentrations showed their fragility and contributed thereby (it was generally believed) to the depth of the Depression. Accordingly the Glass-Steagall act of 1933 put severe restrictions on the industrial activities of banks. This, with other legislation, gave the situation described in Roe's title: Strong Managers, Weak Owners. The same situation was reached in Britain without legislation, because the City of London (which by mid-century was the only serious financial centre in the country – quite different from the 19th century situation) had never had, or sought, extensive control over industry. When, by the new institutional shareholders' gradual accumulation of shares, it got the opportunity for it, it had little idea what to do with it.

Meanwhile the German FCGS was moving in the opposite direction. The big German banks did not collapse in the Depression and their control over industry was not reduced. On the contrary, insolvent firms traded debt for equity and the banks' grip was thereby tightened. The industrial resurgence after the Second World War was overwhelmingly financed by bank debt – and in order for this to be extended across the whole range of small and medium firms, the new German provincial (Laender) governments set up public sector banks – Landesbanken – with the munipalities setting up their own lowest tier – Sparkassen. Much of the new debt went to new firms set up by entrepreneurs, thus producing a new generation of dynamic family-owned firms, much as in the original 'Gruenderzeit' (founder time) of the Industrial Revolution.

This is not the end of the financial and corporate governance story. The US FCGS generated new insiders. In the areas (parts of California, New England, and later Texas) on the leading edge of scientific advance and of the development of what would be the main ingredients of post-Fordist technology, a new institution developed in the 1950s and 60s: venture capitalists of varying types[iii] who tend not only to provide risk capital but also to take an active role in corporate governance. They funded high technology entrepreneurship by academics and spin-offs from established high-technology firms. The UK, as is its way, copied the US; inaccurately at first, with so-called venture capitalists who lacked technological expertise; latterly – by the end of the century - more accurately (BVCA, 2002). Germany, having a financial and corporate governance system which had covered itself with glory for thirty or forty years after its recent reform, was naturally much less quick to follow.

Institutional changes, summarised

We have surveyed, in this section, a remarkable pair of opposite transformations. Germany began the 20th century with an NSI extremely well suited for success in high technology, science-intensive industries such as much of the chemical and electrical sectors of the time. Its suitability for what might be called medium-technology industries was much more questionable. At this point the entrepreurial industrial capitalists, and craft unions, of the industrial districts of the North of England and Scotland were in their heyday, and it could well be argued that for medium technology industries they had just the recipe; the British NSI was well-suited to these sectors. Institutionally the US at this point was somewhere between the two. By the last quarter of the century, the boot was on the other foot – or rather, each boot was on another foot. The German NSI was now beautifully adapted to medium-technology industries, in which manual workers needed to gradually accumulate skills on the shop floor, while engaged owners and bankers should work patiently over decades to support incremental technological improvements and the cultivation of suppliers, customers and employees. These were precisely the characteristics in which the US and UK NSIs were deficient, but they (as Soskice, 1997 and Lindblom *et al*, 2003, have argued) have NSIs rather well adapted to the high technology sectors of the present day.

Section 3. Fordist mass production

The development of the automobile industry occurred at the end of the 19th century. From then on, constant interest was shown in automobile-related technology. Total patent activity showed very high growth rate in '42: internal combustion engine' and '43: motor vehicles' – the typical Fordist mass production sectors – up to the 1915-39 period (Tab. 3). The following two periods witnessed a relative decrease in patenting activity in these technologies, thus indicating the decline of technological opportunities in Fordist mass production. Yet, in the last period, 1978-90, there was a renaissance of research activities – especially in '42: internal combustion engine'.[iv] This area was initially (i.e. in the 1920s) dominated by the US, for reasons which are well known (e.g. from Tylecote, 1991, ch.2, and Freeman and Louçã, 2001). The institutional characteristics of the US in this area are also well known: Taylorised methods were applied to the assembly line in the US, with strong emphasis on discipline and hierarchy, and a key role for engineers and semi-skilled workers. The division of labour on the line into simple jobs linked to dedicated equipment allowed employers to use non-union semi-skilled labour and free themselves of the grip of the craft unions. The shortage of skilled labour led American entrepreneurs and engineers to seek for production techniques that would substitute machinery for labour. The use of interchangeable parts was essential for this purpose. The introduction of interchangeable components of engineering products, that means the first true application of mass production techniques, was due to Ford in his Highland Park Plant in Detroit. Therefore, although the US did not lead Europe in the early days of the automobile industry because almost all the early inventions and innovations were made in Germany and France, the Ford assembly line established both the philosophy and the practice of mass production as an archetypal twentieth-century American technology (Freeman and Soete 1997). Tab 4. shows the American technological advantage in both '43: motor vehicles' and '47: other transport equipment', up to the 1940s, and the constant decline of the US technological advantage in the following periods.

The original US version of Fordist technology and organisation was fairly faithfully copied in France (which was strongest in Europe to start with in motor vehicles) and not very faithfully copied in Britain. The British industry had had a slow start compared to the French one largely due to legal restrictions collectively known as Red Flag legislation, (Laux 1992). Yet, well before the outbreak of the First World War, most of the British automobile companies were set up[6]. Although America continued to dominate in mass-produced automobiles, the demand for trucks and motorised military equipment, as well as the development of the tractor for use in Britain's agriculture, laid the base for the nation's vehicle industry (Chandler 1990). Given the size of the mechanical industries in Britain in the early 20th century, there was a large pool of mechanical engineering expertise from which individuals could emerge who might contribute inventively to the sector – which at this point made little demand on the science base: individual creativity was at first enough. Accordingly, Britain managed to achieve strong technological

[6] In 1896, Daimler and Rover were established; in 1899, the Lanchester Engine Company; in 1901, Vickers, producing cars at that time, and Dennis, specialised in trucks; in 1903, Standard Motor Company; in 1904, Rolls Royce; in 1905, Vauxhall and Austin.

advantage in all three technological sectors related to Fordist mass production up to the 1940s, although at a decreasing rate (Tab. 5).

Tab.6 shows the lack of German technological advantage in automobile-related technology up to the 1940s. Despite the head start that Germany achieved in engine technology in the previous century, with German inventors such as Nicolaus August Otto, Gottlieb Daimler, and Rudolf Diesel, the Germans were not able to develop these inventions commercially (Laux 1992). At the outbreak of the First World War, the German automobile industry was still in its infancy. In 1913, the two largest German producers, Daimler and Benz, produced only high-price luxury automobiles, disregarding completely mass-production. Chandler (1990) emphasises the role of the domestic market, still too small and with a ratio of automobiles to inhabitants still far below that of the US and Britain.

As we saw above, there appears to have been strong aversion in the 1920s and 30s among German firms – and particularly their skilled workers - to mass production in its original formulation. This was a key factor in wartime under-production; the Tiger tanks, for example, were superb, but they were not mass-produced and there were far too few of them. However, the new German NSI, or the sub-system of it developed for Fordist mass production, turned out to be superior to the original US version, and provided a vital element in the rise to dominance of these countries in the Fordist mass production sectors.

For the first time, in the 1940-64 period, Germany showed technological advantage in our Fordist mass production sectors (Tab. 6). A dream of Adolf Hitler had been to provide Germany with a 'people's car' (Volkswagen) that would play the role of the Model T in the US. The Second World War broke out before this dream could be realised, on the basis of Ferdinand Porsche's design, thus stopping further research. From its ruins after the war, the German automobile industry reached brilliant success with remarkable speed, led by Volkswagen and the famous Beetle, and its RTA for the Fordist vehicle industries confirms this (Tab.6).

A key advantage of the Germans (and the Japanese) was the strength of inter-firm relationships in these countries – in the German case notably including horizontal relationships among competing firms in a sector. (Strong inter-firm relationships are always a big asset where there is a filiere involving extensive vertical disintegration of production, which is typical of assembled products.) Another key external relationship is with banks. The growth of German heavy industry in the late 19th century had depended heavily on close relationships with banks, which provided exceptional amounts of capital with (by conventional standards) dangerous proportions of debt in firms' financing; in return, as Jeidels (1906) showed, the two-tier board structure was developed and used to provide them with exceptional degrees of oversight and control. It was only in the 1920s, when it became clear that heavy investment was needed to give economies of scale (Chandler 1990), that the big banks (*Grossbanken*) became closely involved with the motor industry. Thus when the Deutsche Bank moved out of oil in 1925, it turned to automobile and airplane engines by financing Daimler-Benz and BMW. In the post-war years the Deutsche Bank had a close relationship with Daimler-Benz, and from the late 1970s a 25% shareholding which gave it effective control. BMW as a Bavarian firm depended heavily on bank financing from the two public sector Bavarian banks set up after the war. (VW, with dominant shareholdings held by the Lower Saxony provincial government and Federal government, was always assured of adequate financing from public sector banks.) The motor industry, as a 'scale-intensive' – capital-intensive – industry, benefited greatly from ample bank funding – combined with shrewd bank oversight.[7]

Meanwhile, the US and British vehicle industries had found themselves in a situation of slow institutional regression. They were fully affected by the development described in Section 2 of inhibiting systems of industrial relations, and shared also in the evolution of corporate governance arrangements unsuitable for medium technology industries. In the US, the Ford family was left to control the Ford company, and thus the firm depended on the suitability of the current crop of Fords. General Motors had risen to dominance of the world motor industry under the wise control of Pierre du Pont (of the DuPont chemical firm), an insider *par excellence*. Legal pressures forced the sale of the DuPont shareholding in the 1950s, and GM then became a prime example of management control within an outsider-dominated financial system. The motor car manufacturers of the UK went the same way voluntarily: the heirs of the entrepreneurs who built up Morris and Austin and Rover, made little attempt to maintain control. By the end of our period (1978-90) all the US and UK RTAs in these sectors were below 1.

Section 4. Machinery industries

The machinery industries had been a key, dynamic branch ever since the beginning of the industrial revolution. By the end of the 19th century, it was electrical equipment which showed the most dynamic growth, but nonetheless the non-electrical areas on which we focus in this paper, continued to prosper, and the arrival of the Fordist techno-economic paradigm must have contributed to their vigour. However, Tab. 3, shows that the machinery industries stopped holding the highest technological opportunities by the beginning of the 1940s. The total number of patents has been declining ever since, representing the senescence of the Fordist technological régime.

The machinery industries were as of 1910-20 dominated by the UK and the US (Tabs. 4 and 5). The historical reasons for this include the industrial lead of these two countries in the machinery-*using* areas. At the turn of the century, the pattern of American technological specialisation reflected the geographical expansion over a vast continent, rich in natural resources. Research was especially dedicated to technology related to the agricultural sector, mainly farm machinery and equipment.[v] Furthermore, after 1880, McCormick Harvesting Machine became industry's leader in the production of agricultural machinery and Ford started to diversify and produce tractors by the turn of the century. Research was also dedicated to the creation of infrastructure such as railways, roads, bridges, and tunnels, which were necessary in a country where the communities are separated by large space.

Many authors have stressed the importance of the machine tools sector in the American profile of specialisation. Rosenberg (1963, 1976) shows how the pattern of American technological specialisation has its roots in the specialisation of woodworking machines, occurring in the first half of the nineteenth century due to the local abundance of timber supply. Along the same lines, von Tunzelmann (1995) shows how industrialisation in the US was led by the machine tool industry due to the cheap land, cheap timber and cheap water available to the country. Moreover, the federal policy of founding public universities close to commercial opportunities led to the creation of good educational support for the engineering, mining and metallurgical industry. This gave the US the leadership in engineering and metallurgical knowledge well before the turn of the century (David and Wright 1995).

[7] Close bank-industry relationships in Japan played a similar role in the rise of the Japanese motor industry.

Moreover, the US could enjoy a long traditional advantage in what Chandler (1990) calls the 'American system of manufacturing', which was characterised by three interrelated and important investments, manufacturing, marketing and management. Wherever machines were produced in sufficient numbers, the 'American system' applied the mass-production methods of fabricating and assembly using fully interchangeable parts and gave the US such powerful advantages that they dominated the world markets of standardised industrial machinery for decades (Tab. 4).

The heritage from the Industrial Revolution, which saw the UK as the technological leader, had its influence. Before the First World War, as Table 5 shows, the country was specialised in technology related to the production of different kinds of machinery. The evidence from the patent data is confirmed by Chandler's (1990) historical account that, at the turn of the century, Britain had an important machinery industry where most of the largest companies had been established to produce for the industry of the First Industrial Revolution.

In the late 19th century the UK had been able to maintain its advantage over Germany in mechanical engineering in general because this area (unlike chemicals and electricals) did not make heavy use of the science base (then a German advantage over the UK) either as producer of research or of graduates. New knowledge and new human capital could be developed very effectively within the firm by cooperation between engineer-managers and craftsmen, who in turn taught apprentices.

As we saw above, the German 'historic compromise' of the late 1940s provided institutions – both in industrial relations and in finance and corporate governance - very well adapted to the requirements of medium- (or medium-high) technology sectors such as machinery. New and old machinery firms blossomed in the 1950s, producing for German lead customers with which they had close links, and supported by the new regional and local public sector banks. The shift is apparent by the middle of the 60s, when Germany, for the first time, achieved relative technological advantage in some machinery industries (Tab. 6). In others, mostly ones producing for non-manufacturing sectors in which it was relatively weak, its RTA remains below one to the end of our period: but in almost every case it was moving up steadily.

Meanwhile in the UK and the US (*vide* Lazonick *et al*. on machine tools) the sector-wide institutions failed to evolve with the sector, and instead regressed. The decline in the UK was clear-cut: having had relative technological advantage in most machinery sectors in our first two periods, it had it in only four by the last period. The US maintained and even increased its relative technological advantage in sectors like construction and excavating equipment where it was dominant downstream, but in most manufacturing equipment sectors it fell back somewhat (Tab. 4).[8]

Section 5. Chemicals

The chemicals industries were as of 1910 dominated by German, and to a lesser extent Swiss and Swedish, firms. Freeman (1982) emphasises the importance that the dyestuff industry of the late nineteenth century had for the German chemical industry. Some other authors, such as

[8] The US machinery industries, towards the end of our period, do not conform very well to the general thrust of our argument. The US is large enough to have a diversity of institutional forms, and preliminary work suggests that much of the US machinery industry is scattered across the mid-West in small towns where the conditions for the cumulative development of shop-floor expertise remain favourable. We plan to investigate this further.

Henderson (1975) Landau and Rosenberg (1992) emphasise the influence of the military sector on the development of the chemical industry. Two historical reasons can also explain the German specialisation in chemical technology. The first is the importance of the education system, heavily subsidised by the state to ensure a supply of well-trained chemists, together with the fact that Germany was the only country with a well-developed education system even before industrialisation. (Berlin University was founded in 1809/1810 and the German PhD degree system was adopted by American institutions before the turn of the century.) The second reason relates to an abundance of natural resources, notably coal, iron ore, and potash. Before the First World War the organic chemical industry of most countries was still embryonic. (What the UK had of it was almost entirely composed of subsidiaries of German, Swiss and Swedish firms, and firms set up by Continental entrepreneurs.) Yet, within 4 years, the US, the UK and to a lesser extent France, Italy and Japan created their own organic chemical industry (Haber 1971).

The 1915-39 period witnessed the development of the chemical industry almost world-wide. Industrial chemicals show the highest growth rate of total patenting activity (Tab. 3). The big chemical firms were the ones accounting for the highest share of total US patenting in the interwar period (Cantwell and Barrera 1998). Among the biggest, there were the American Du Pont, the German IG Farben, the British ICI (formed from the 'non-British' elements mentioned above) and the Swiss CIBA. In the interwar period, consumer chemicals boomed mainly due to the increasing demand for soap, detergents, cleaning agents, etc. (Tab. 3). During the 1930s, American, German and other European chemical firms developed new detergents thanks to the increased chemical knowledge and to the ability to exploit economies of scope by developing completely new products. In this period, also science-based chemicals flourished (Tab.3). Until the First World War, the pharmaceutical industry was a by-product of the German dyestuff industry and a worldwide synthetic drug industry was not forged until the 1930s (Davis 1978). The increasing patenting activity in agricultural technology was also related to use of pesticides, which increased dramatically in the interwar period (Peel 1978). Again in the 1940-64 period, the chemical industries taken together witnessed the highest growth rate in total patenting activities, thus indicating the importance of these industries worldwide. This same trend can be witnessed in the 1965-77 period; but in the latest period (1978-90), the highest patenting activity can be found only in science-based chemicals.

From the 1915-39 period the US moves up very rapidly on the basis of petrochemicals, using continuous-flow technologies and taking advantage of the very large economies of scale in this area, as in the Fordist mass production sectors (Tab. 4). In fact, the Americans 'invented' the *chemical engineering* profession: in the 1920s, MIT introduced a separate course of study with a separate department. However, it was only after the Second World War that American-style chemical engineering became really successful and was later copied by German universities (Landau and Rosenberg 1992). After the Second World War, the international petrochemical industry was dominated by Standard Oil of New Jersey and Standard Oil of Indiana, which both developed many new processes related to catalytic and thermal cracking (Chapman 1991). In the US pattern of technological specialisation, petroleum led the way because of its abundance and because of the development of the automobile industry. The American chemical industry became almost a by-product of the general petroleum refining industry (Nelson and Wright 1994). Moreover, the US gained new technological advantage in consumer chemicals. The increased market needs, especially after the shortage caused by the Second World War, worked as an inducing mechanism for the largest American chemical companies to diversify in the production of new soap, detergents, washing powder (Chandler 1990). This new American profile of specialisation confirms Porter's (1990) suggestion that, after the Second World War, the US reinforced its leadership in mass production technology and especially in consumer chemicals, due to the ability of the American companies to exploit the large domestic market. (Tab. 4).

From the 1930s onwards, Germany begins to lose, by contrast, because of the severe Nazi damage to its science base – and the gift of the Jewish diaspora to other countries, particularly the US and UK. In chemistry, the queen of the sciences in Germany, this damage was slowly repaired after the war; however in the biological and bio-medical fields relevant to agrochemicals and (above all) pharmaceuticals, Germany never caught up with the US and UK. Likewise the opening of trade under the post-war Pax Americana made the basis of petrochemicals – cheap petroleum – available equally to Germany, Japan and others.

In the post-war period it becomes important to distinguish between

- (on the one hand) all kinds of industrial chemicals (roughly, C2, C3, C5, C6, C8, C9, C10, C11) in which not only a strong science base in chemistry but the strong inter-firm relationships mentioned above, assisted Germany. Only in C5 (photographic chemistry, where the collapse of the camera industry in the face of Japanese competition must be blamed) was German RTA below 1 in the last period; and in most of these sectors it had risen after a post-war dip. The US and UK performance in these sectors is patchy: relatively strong just after World War 2, presumably largely because of German weakness, and then mostly falling back, with most of the RTAs in the last period below 1.
- on the other hand pharmaceuticals, agrochemicals, and consumer chemicals (C12, C4, C7) where (in all cases) mass marketing rather than firm-firm relationships apply for selling, and (in the first two cases) there is a steady shift towards the biomedical sciences and away from a primary dependence on the chemistry science base. In the pharmaceuticals and biotechnology areas – the highest technology ones - the relevance of the science base is, moreover, greatest. German performance in agricultural chemicals was by the end almost as good as in 1915-39, but this was far from the case in the other two sectors. The UK, by contrast, shows improving performance in each successive period after 1915-39, in all three sectors, taking it from RTAs well below 1 to RTAs well above it. The US, as with machinery, 'misbehaves' a little: only in consumer chemicals does it maintain a RTA above 1 in the last two periods. Here we must say that the patenting data is clearly misleading. Histories of the pharmaceutical industry clearly show the US industry, in the 78-90 period, moving into the dominant position in the world which it clearly now enjoys (Ramirez & Tylecote, 2003). Pharmaceuticals is now deeply affected by the development of biotechnology, and through it by the revolution in financial provision for high technology represented by the development of venture capital, in the USA.

Section 6. Reflections

We should note first that the significance of our data, and of our arguments, changes during the period, because of the spread of multinational firms:

- Overwhelmingly, at the beginning, the patents we are examining are taken out from country X by firms based in country X, producing in country X though to an important extent for export (or they are taken out by individuals, not firms at all). Where we see a high degree of technological specialisation we then expect it to be matched by exports from the specialised countries – though no doubt limited by tariff protection. This tariff protection provides a position from which firms in the then-weaker countries can challenge the currently dominant countries' firms.
- One can define an intermediate position, typical in most sectors for most of the period since 1965, in which many, perhaps most of the patenting firms are multinational in terms of

production, but overwhelmingly patenting from 'home' (Patel 1995, Patel and Pavitt 1991). Firms based in weaker countries have, then, less chance to hide and to 'fight another day'. A high degree of technological specialisation may not then be matched by such a high degree of specialisation of production – not new, but true for a new reason.
- One may in some sectors (e.g. pharmaceuticals) have reached, by the end of the period, a position where the patenting as well as the production is largely multinational: i.e. firms based in country X carry on key innovative activities in country Y (as well as producing there) and accordingly patent from there. (See Ramirez and Tylecote, 2003.)

It follows that the connection between our figures for technological specialisation (dependent variable) and the fit between NSI and technological regime (independent variable(s)) is less straightforward at the end of the period than at the beginning – essentially because the relevant system of innovation becomes less and less national.

Nonetheless, the contrasting evolutions of Germany, on the one hand, and the US and UK on the other, are very striking. The 'mechanical family', at the beginning of the 20th century, was in general an area of German weakness and Anglo-American strength – a divergence only increased by the development of Fordist mass production in the US. By the end of the period the positions had been decisively reversed, due mainly to successful institutional innovation in Germany, with some institutional decay in the US and UK. The key period for this institutional innovation was the latter stage of the 'depression crisis' of the long wave, which fits Tylecote's (1991) argument. The appearance of the post-Fordist or ICT technological style merely confirmed the superiority of German and Japanese institutions in this family.

In the 'chemical family' Germany initially was far ahead of both the US and UK: here it was Germany which had made the key institutional innovations – parallel in the public and private sectors – during the 19th century, with the US and UK (in that order) struggling to follow. The US development of petrochemicals as part of the Fordist technological style did much to close the gap, and a further contribution was made by the disruption of German institutions in the long wave depression crisis of the 1930s and 40s. The next key institutional innovations were made gradually in the USA during the 1960s and 70s – late upswing and early downswing in the long wave – with the development of venture capital, and when the post-Fordist style arrived it was mainly this which allowed the US, followed by the UK, to get well ahead of the Germans in the highest-technology parts of the family.

One implication of our findings is that (at least if one takes long enough time periods) the relationship between sectoral specialisation and the institutions of the NSI is not simply one of positive feedback, in which one gets the institutions one needs in order to manage the sectors in which one is specialised. The institutions on which we have laid stress are not ones which are easily amenable to 'functional' change, partly because it is sometimes far from clear what changes would be functional, and partly because the interests of the individual players in the system are at variance with those of the system as a whole. (To take the example of the British motor vehicle industry, in its period of steepest decline in the 1960s and 70s, it may have been perfectly clear to most of those involved that the German motor industry's system of industrial relations was much superior to the British: that didn't make them able, or for the most part inclined, to copy it. On the contrary, for at least the first half of that period the direction of change was the opposite.) It is very much the institutions which drive the specialisation, rather than the other way round.

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(to be completed)

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[i] Since the development of the index, many authors have used it as an index of technological specialisation. The Science Policy Research Unit (SPRU) at the University of Sussex has extensively used this index for international comparison among countries (see Patel and Pavitt 1987, 1989, 1994; Pavitt and Patel 1988). At the University of Reading, Professor John Cantwell has extensively used this index (Cantwell 1991, 1992, 1995). The RTA index of a country in a particular technological sector is given by the national share of patenting in a particular sector divided by its national share of total patenting in all sectors. The RTA index is defined as follows:

$$RTA_{ij} = (P_{ij} / \sum_i P_{ij}) / (\sum_j P_{ij} / \sum_i \sum_j P_{ij})$$

where P_{ij} is the total number of patents of country *i* in sector *j*. The numerator represents the national share of country *i* in sector *j* and the denominator is the national share of country *i* across all sectors. As to American innovative activities, due to the choice of the US as recipient country, the RTA index is here calculated in two different ways. The American index is calculated relative to total US patenting, while all the other RTA indices are calculated relative to total foreign patents granted in the US to the residents of foreign (i.e. non-US) countries. Therefore, it must be kept in mind that the international comparison does not really compare like with like. However, this problem cannot be avoided or solved.

[ii] It might be imagined that totalitarian dictatorships remould all existing institutions to their will and convenience. Not so: there are limits which in their 12 years the Nazis certainly respected. Two key areas of society which were decidedly anti-Nazi – manufacturing industry, at least on the shop floor, and the Navy – were left very much alone on the understanding that they would get on with their jobs.

[iii] The main categories are informal venture capital (or 'business angels') – rich individuals with personal experience of the sector who play a key role early on; and formal venture capital – organisations with varying quantities and sources of funds who provide successively larger tranches of capital later on.

[iv] This was mainly due to the large Japanese companies, which entered the automobile industry in those last decades. By using the same database, Cantwell (1992) finds a strict relationship between the patenting activities of the largest Japanese companies and the rise of the total patent growth rate in these same technological sectors.

[v] The foundation of the current system of public support to higher education was laid down during the nineteenth century as a way to finance research for the agriculture sector (Mowery and Rosenberg 1993).