Technological discontinuities, outsiders and social capital: A case study from Formula 1

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Abstract

Purpose – The purpose of this paper is to examine how and why outsiders, rather than incumbents, are able to take advantage of technological discontinuities.

Design/ methodology/approach – The paper employs a case study of a single innovation that transformed the technology of Formula 1 motor racing.

Findings – The findings show how social capital made up of 'weak ties' in the form of informal personal networks, enabled an outsider to successfully make the leap to a new technological regime.

Practical implications – The findings show that where new product development involves a shift to new technologies, social capital can have an important part to play.

Originality/value – It is widely accepted that radical innovations are often competence destroying, making it difficult for incumbents to make the transition to a new technology. The findings show how the social capital of outsiders can place them at a particular advantage in utilizing new technologies.

Keywords: Innovation; Outsiders; Social Capital; Technological Discontinuities;

Paper type Research paper

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1. Introduction

Studies of a number of industry sectors (Christensen, 1997) have shown that radical innovations are significantly more likely to originate with firms that are outsiders rather than industry incumbents, especially if the innovations involve competence destroying rather than competence enhancing technological discontinuities. However research into this phenomenon has tended to focus on the failings of incumbents rather than the strengths of outsiders.

This study attempts a reassessment by focusing on the role of outsiders. It presents a case study drawn from the world of Formula 1 motor racing described by Jenkins and Floyd (2001: 949) as the, 'pinnacle of automotive technology'. The focus of the study is a single radical innovation, the introduction of the moulded carbon fibre chassis during the 1980s. It aims to analyse the attributes of outsiders that make them well placed, or certainly better placed than their counterparts in incumbent firms, to capitalise on the introduction of path-breaking new technologies. The particular attribute that forms the focus of the study is the social or relational capital of the designers and engineers responsible for the development of Formula 1 racing cars and the circumstances under which this can help them to access external knowledge and expertise that can provide the basis of a new or emerging technological regime.

The study offers the prospect not only of enhancing our understanding of why outsiders are often the ones responsible for bringing about technological discontinuities, it also sheds light on the value of relational capital in connection with innovation and new product development. In the process it highlights the nature of the problems created by technological discontinuities.

The paper is structured in seven sections. Following this introduction, section two outlines the literature on technological discontinuities and social capital, while the third section outlines the methodology employed. Section four reviews earlier technological discontinuities in Formula 1. Section five presents the case study which examines a single radical innovation and the part played by outsiders in bringing it about. Section six analyses the part played by social capital in the innovation process, while the final section outlines the contribution of this case study to our knowledge of competence destroying technological discontinuities.

2. Literature Review

Much technological change is actually incremental, involving relatively modest advances that build on existing practice (Nelson and Winter, 1982). As such it is evolutionary rather than revolutionary. However the process of continuous evolution is punctuated from time to time by discontinuous change (Romanelli and Tushman, 1994) in the form of major technological advances and breakthroughs. These advances and breakthroughs form 'technological discontinuities' (Foster, 1986: 35), that represent a step change as one technology is replaced by another. The result is typically the emergence of entirely new products or substitutes for existing products.

Technological discontinuities disrupt (Christensen, 1997) and set in train a new direction for what Christensen and Rosenbloom (1995: 234) term the 'performance trajectory'. As an existing technology reaches the limits of its S-curve (i.e. the relationship between performance and engineering effort), so a switch to a new S-curve with a new performance trajectory (Foster, 1986) starts to take place (see figure 1). According to Foster (1986) it is this gap between S-curves that constitutes a technological discontinuity. So significant is the technological change associated with the advances and breakthroughs involved that, as Tushman and Anderson (1986: 44) note, 'no increase in scale, efficiency or design can make older technologies competitive with the new technology'. The result is a dramatic improvement in cost, performance or quality over existing products (Anderson and Tushman, 1990). However such breakthroughs occur relatively rarely and are watershed events. Often such is the impact of technological discontinuities on the competitive landscape that they have disruptive effects on the structure of the industry (Ehrnberg, 1995; Mensch, 1979).

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Technological discontinuities are not homogeneous. Tushman and Anderson (1986) distinguish between those technological discontinuities that are 'competence destroying' and those that are 'competence enhancing'. Competence destroying technological discontinuities involve the introduction of technologies that are so fundamentally different from existing ones that they draw on a different technology base, demanding new techniques and know-how and the development of qualitatively new technological capabilities within the innovating firm (Christensen, 1997; Rosenbloom and Christensen, 1994). Thus much of the accumulated expertise associated with a technology that has been built up over many years rapidly becomes obsolete. Competence enhancing discontinuities on the other hand involve technologies which, while they may lead to significant improvements in performance, tend to build on existing know-how and an established knowledge base rather than overturning it. Competence enhancing technological discontinuities may therefore be seen as taking place within what Van De Poel (2000: 384) terms an existing 'technological regime', that is to say existing techniques, know-how and capabilities.

While competence-enhancing technological discontinuities tend to originate with incumbent (i.e. existing) firms, a body of research (Hill and Rothaermel, 2003) points to competence-destroying technological discontinuities being attributable to outsiders rather than incumbents. In industries as diverse as disk drives (Christensen, 1997), mechanical excavators (Christensen, 1997), personal computers (Campbell-Kelly, 2004), jet engines (Constant, 1980), VCRs (Rosenbloom and Cusumano, 1987) and digital imaging (Tripsas and Gavetti, 2000), the lead in developing radical innovations was taken by outsiders, that is new entrants who were not established players in the industry. A study by Tushman and Anderson (1986) found that seven out of 11 competence destroying discontinuities they studied originated from new firms and in a similar study by Utterback (1994) the proportion was 26 out of 31. In contrast both studies found that competence enhancing discontinuities were dominated by incumbent firms.

Outsiders are defined by Van de Poel (2000) as being individuals or firms outside an existing system of interaction (i.e. network) within which technological development takes place. As such they typically do not share the guiding principles about the design and development of the technology concerned. The guiding principles represent an existing technological regime associated with a particular product and the technology that lies at its heart. Very often these guiding principles are implicit and followed by actors on the basis of habit or tacit knowledge. No matter how they are formed, outsiders will tend to be people or organisations that in some way, perhaps by virtue of their prior experience, do not entirely share the guiding principles associated with a particular technology.

A variety of explanations have been offered to explain why it is that competence destroying technological discontinuities tend to be pioneered by outsiders. In general these explanations have focused on incumbent firms and the difficulties they encounter when faced with a new and radically different technology. Among the most widely cited explanations for incumbents failure to innovate are organisational inertia that may constrain the actions of incumbents, economic incentives that lead incumbents to favour incremental rather than radical innovation, and the tendency for incumbents to focus on meeting the needs of existing customers rather than exploring new applications (Hill and Rothaermel, 2003). The factors identified as leading outsiders to pioneer radical innovations tend to be the converse of those that constrain incumbents. Hence the absence of internal inertia and the freedom to focus on new market niches without worrying about existing customers, are cited as advantages that outsiders possess (Hill and Rothaermel, 2003), as is the incentive to invest in unproven technologies as a means of getting round barriers to entry. One of the few studies to take a different line is that by Van de Poel (2000: 389) who suggests that outsiders benefit from not knowing the rules or conventions of an established technological regime, and are thus not likely to be constrained by them. Linked to this factor is the possibility that because they are not part of an existing technological regime outsiders may possess social or relational capital, frequently cited as an important factor in innovation (Conway, 1997), that is more diverse than that of incumbents.

Social, or relational capital, is defined by Nahapiet and Ghoshal (1998) as the potential resources that are available through the network of relationships that an individual possesses. These resources comprise both people and knowledge/ information. Hence social capital comprises two key dimensions (Schiuma, et al., 2008), a structural element – knowing the right people (Burt, 2005) and a content element – knowing people with the right knowledge/ information (Adler and Kwon, 2002). The structural element of social capital derives from the way individuals can benefit from having more diverse contacts by virtue of the range of different networks (i.e. groups) with which they are associated. Individuals whose contacts span a number of different groups or networks will tend to possess greater social capital in terms of the breadth of knowledge to which they potentially have access, compared to those whose networks are confined to just one or a small number of groups. Burt (2005) suggests that having contacts that span several different networks or groups provides scope for what he terms 'brokerage', that is facilitating the transfer of knowledge between groups. The significance of this for innovation is illustrated by the example that Burt (2005: 73) cites of Eugene Stoner, who was able to combine contacts from his experience as an ordnance technician in the US Marines with contacts from his time at the aerospace contractor Fairchild, in the development of a revolutionary new ultra-light assault rifle, the M-16.

There is considerable debate about the nature of the linkages associated with social capital, in particular over the relative benefits of strong and 'weak ties'. The latter comprise informal links that are not well established, with infrequent contact and little or no emotional commitment. Though one might intuitively expect such links to be of limited value because of their informal nature, in fact Granovetter (1973) has shown that the diversity associated with weak ties can be an invaluable source of knowledge. Similarly Hayton (2005:149) notes that the greater the diversity of an individual's experience, the more diverse the sources of social capital, which can provide 'access to a broader range of social and professional networks from which new ideas can be acquired'. Studies of the biotechnology industry (Rickne, 2006; Shan et al., 1994; Powell et al., 1996) have shown how in science-based businesses in particular, the quality of social capital in the form of well developed networks, is often linked to firms' performance in terms of innovation.

Thus those placed outside or at least on the periphery of an industry or sector, may actually be well placed in terms of social capital when it comes to innovation. With more diverse experience, more diverse links/contacts, albeit weak ones, when competence destroying discontinuities occur they may be better placed than those within a well established technological regime, because their social capital may provide the means of accessing external knowledge and expertise that may provide the basis of a new or emerging technological regime.

3. Methodology

The study presented here is based on a single case, a research approach that has been used extensively in the analysis of decision making processes (Allison, 1971; Vaughan, 1996). The unit of analysis is a radical innovation that formed a competence destroying technological discontinuity, something that is comparatively rare even in a technology-led sector like Formula 1. The innovation in question was one of a small number of radical innovations to have transformed Formula 1 in the last 60 years. As such it represented a major technological discontinuity which had far reaching consequences.

The case study was derived from documentary sources, located in the public domain. This did not prove problematic since as Lazonick and Prencipe (2005: 502) note, 'in the age of the internet one can go quite far in doing company level research…by relying on publicly available information'. Furthermore the sporting nature of the sector means that, as earlier researchers (Henry and Pinch, 2000; Jenkins and Floyd, 2001; Jenkins, 2010) have noted, large quantities of high quality data are available.

A range of documentary sources were used. As others (Henry and Pinch, 2000) have noted specialist periodicals in this field offer a wealth of material that can provide a valuable 'behind the scenes' perspective on Formula 1. Consequently the first and most extensively used source was the searchable digital archive of the specialist periodical, Motor Sport, covering a 40 year period from 1960 – 1999. This archive includes detailed reports on every Formula 1 race over this period, as well as articles on particular constructors, technical analysis and in-depth interviews of key individuals such as designers, team principals and technical staff. Using this, data about the development of Formula 1 chassis technology was extracted. This was supplemented by further data, much of it technical in nature, gathered from specialist technical publications such as Racecar Engineering, Professional Engineering and Engineering Failure Analysis, which had in turn been identified from online databases including Business Source Complete and ScienceDirect. In addition a number of other specialist periodicals such as F1 Racing and Classic Cars, as well as specialist websites such as F1complete.com, were also consulted.

The data gathered in this way was supplemented by corroborative material gathered from specialist texts documenting various aspects of Formula 1. These fell into one of two broad categories, those that were essentially of a technical nature examining aspects of Formula 1 technology (Henry, 1988; Wright, 2001) and historical studies. The latter comprised biographies of designers (Crombac, 1996; Ludvigsen, 2010), corporate histories of Formula 1 teams/constructors and suppliers (Nye, 1984: Robson, 1999) and studies of the motor sport industry in the UK (Aston and Williams, 1996; Beck-Burridge and Walton, 2000). In general the data gathered from these sources was used to cross-reference that gathered earlier, although it also provided a substantial amount of contextual detail, which helped to place the development of carbon fibre applications in a broader context.

Having amassed a substantial body of data in this way it was then subjected to content analysis (Bryman and Bell, 2007) using a simple manual coding system based on critical incidents, key actors, and inter-personal links in relation to the development of chassis technology. From this a timeline tracing the historical path around the focal event – the introduction of the first moulded carbon fibre chassis in Formula 1 was produced which in turn formed the basis of the narrative for the detailed in-depth case study.

Documentary sources like other forms of data have their limitations. Two key issues in terms of the quality of evidence provided by such sources are, as Scott (1990: 6) notes, authenticity, and credibility. Authenticity is a matter of ensuring that the evidence is genuine and actually is what it purports to be, while credibility is a matter of ensuring that the events described are believable and can be taken at face value.

The use of a number of different types of document ensures the quality of the evidence used. The various types of document used were written by specialist technical authors and journalists, many of whom have previously worked in the sport often in a technical role. As a result they know and have worked with many of the individuals and teams they write about. This close contact and engagement helps to ensure they provide an authentic (i.e. genuine) account of events. Similarly because the audience for these documents is made up largely of followers of the sport, with detailed knowledge of technical issues and personalities and a propensity for detailed scrutiny, credibility is not an issue either.

A particular benefit of the multiplicity of different documentary sources used is that it allows the events described to be placed in the longer term context of the development of Formula 1 chassis technology, and in the process provides insights into the long term dynamics of the technological discontinuities themselves.

4. Technological discontinuities in Formula 1 chassis technology

The chassis represents a key part of a racing car, since it is the central load bearing structure (Gilchrist and Curley, 1999). Until the 1940s virtually all racing cars employed a twin beam structure (see table 1) comprising two longitudinal steel beams or tubes linked by cross members (Tipler, 2001). This was the same design used by road cars at the time and by trucks even today. Though strong, this type of structure was heavy and prone to flexing when cornering at speed. Although this detracted from the car's handling, pre-war racing was primarily about engine power (Jenkins, 2010) .

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The late 1940s saw the first technological discontinuity in chassis design with the first series produced racing car, the Italian Cisitalia D46 designed by Giovanni Savonuzzi (Ludvigsen, 2010), utilizing a tubular steel spaceframe chassis. This radical innovation dispensed with the two longitudinal members in favour of a multi-tubular welded structure comprising small diameter steel tubes. The spaceframe retained the requirement for a separate body, but it was light, strong and cheap and easy to construct and rapidly became the norm in Formula 1 during the 1950s.

Throughout the 1950s and early 1960s the tubular steel spaceframe reigned supreme (Tipler, 2002). But a shift to less powerful engines in 1961, forced designers to place greater emphasis on chassis technology (Jenkins, 2010). Innovation came not from established teams like Ferrari but a relative newcomer, Lotus. Developed in great secrecy (Crombac, 1996), on the 18th May 1962 (Tipler, 2002: 28) the team's young designer Colin Chapman unveiled the Lotus 25, a car with an entirely new kind of chassis, employing a riveted monocoque structure (Jenkinson, 1962), in which the aluminium skin itself was made to carry the structural load. Chassis and body formed a single integrated structure as on an aircraft (Constant, 1980). Not only was the Lotus 25 chassis radically different in structural terms from the tubular steel spaceframes then in use, utilizing a different material, aluminium sheet, and fabricated using aircraft style riveting (Ludvigsen, 2010), it provided greater rigidity for less weight (Jenkinson, 1962).

It soon became apparent that Chapman had 'stolen a march on his rivals' (Tipler, 2002: 28). The riveted monocoque structure was not only lighter than a conventional tubular steel spaceframe, it also possessed exceptional torsional rigidity (Tipler, 2002), which in turn made the tyres work more efficiently thereby significantly improving the car's handling. In its first season the Lotus 25 suffered with minor technical problems, but the following year Jim Clark won seven out of ten Formula 1 world championship races, giving Lotus its first constructor's title (see table 2). Such was the car's dominance that over four seasons from 1962 to 1965 Lotus won 19 of the 39 world championship races (Crombac, 1996: 119). Where Chapman led the Formula 1 community quickly followed (Aird, 2010).

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The introduction of powerful turbocharged engines in the 1970s formed the precursor to a third technological discontinuity. Teams reliant on the conventionally aspirated Cosworth DFV V8 engine found themselves under pressure (Henry, 1988), leading them to look to technical ingenuity in chassis design to remain competitive. Thus was born the era of 'ground effects', where designers used the shape of the underside of the car to create downforce that would improve a car's cornering ability. In the process designers made the chassis ever narrower, but this weakened the car's torsional rigidity and thus its handling. To overcome this, designers were forced to consider new materials and one of the materials they looked to was carbon fibre. As with previous technological discontinuities, the development of the carbon fibre moulded chassis was a radical innovation pioneered by an outsider.

5. The case of the McLaren MP4/1

4.1 The introduction of carbon fibre into Formula 1

Among the first applications of carbon fibre was in 1968, when Rolls-Royce announced that its RB-211 engine being developed for the Lockheed L1011 Tristar airliner would use lightweight carbon fibre fan blades. Unfortunately the carbon fibre fan blades proved unable to meet the required simulated 'bird strike' tests and eventually had to be abandoned (Spinardi, 2002: 385) in favour of conventional titanium fan blades. However despite this setback during the 1970s carbon fibre gradually became more widely available. Roger Sloman, who had set up the Advanced Composites Group (ACG) at Derby in 1972, became a strong advocate of the potential of carbon fibre for motor sport applications and during the course of the decade several teams experimented with carbon fibre, but always as a reinforcement rather than a structural element of a racing car chassis.

Radical innovation finally appeared on the 6th March 1981 (Nye, 1984: 221), when the world's first racing car with a complete carbon fibre chassis was unveiled to the press at a rain soaked Silverstone circuit in Northamptonshire. That car was the Marlboro McLaren MP4/1 and it had taken almost two years to develop. This revolutionary car was the product of the new McLaren International Formula 1 team formed in September 1980 from a merger of Ron Dennis's Project 4 Racing Formula 2 team and the McLaren Formula 1 team (Cooper, 1999). No longer was carbon fibre used to support and reinforce an aluminium monocoque structure, this time the structure was entirely moulded carbon fibre.

The carbon fibre McLaren MP4/1 was followed within a week by the unveiling of another carbon fibre Formula 1 car, the new Lotus 88 (Ludvigsen, 2010: 189) designed by Colin Chapman. However although the chassis was of carbon fibre it relied on fabrication techniques that borrowed heavily from existing methods used for aluminium monocoque structures. While the McLaren MP4/1's moulded carbon fibre structure rapidly became the dominant design for Formula 1 chassis and McLaren in turn became the most successful constructor of the 1980s and 1990s (see table 3), Lotus's rather less ambitious construction methods proved to be a 'technological cul-de-sac' (Savage, 2010: 106), and the team never again won the constructors' title finally exiting the sport in 1994.

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4.2 John Barnard

The architect of this technological discontinuity was McLaren's young chief designer, John Barnard. Born in 1946, Barnard gained an engineering diploma from Watford College of Technology and then worked as an industrial designer for the UK based electrical company, GEC, where he designed machines for making light bulbs.

In 1968 at the age of 22, Barnard joined Lola Cars as a junior designer (see table 4), working alongside Patrick Head, who would go on to design Formula 1 cars for the Williams team (Taylor, 2012). Lola, founded by Eric Broadley in 1958 was not a Formula 1 team, instead it was a racing car constructor building cars for a variety of types of racing. One of the fields in which Lola was prominent at the time was sports and GT cars, and among Broadley's designs were the Le Mans winning Ford GT40, designed in partnership with the Ford Motor Company, and the Lola T70 (Scorah, 2010: 62). By the late 1960s when Barnard joined Lola, Broadley was heavily into racing in the US (Scorah, 2010), Lola designs having won both the Indianapolis 500 and the new CanAm sports car series in 1966. The latter was one of the most innovative forms of racing at the time, and among the developments it produced were the first cars with wings and the first engines to utilize turbocharging.

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In 1972 Barnard broke into Formula 1 when he moved to McLaren and for the next three years worked with chief designer Gordon Coppuck on the design of the Formula 1 World Championship-winning McLaren M23. However Barnard's efforts were not confined to Formula 1. While at McLaren he continued his involvement with racing in the United States, though this time with open wheel racing in the form of Indycars. He was closely involved in the design of McLaren's M16 car, which with its pioneering wedge shape and side radiators derived from the Lotus 72 Formula 1 car, proved very stable at high speed on oval tracks in the US, winning the Indianapolis 500 in 1972, 1974 and 1976.

Barnard's success in Indycars led to him being hired in 1975 as a designer for the California based Vels Parnelli Jones Racing Team (Kirby, 2010). The Barnard designed VPJ6B, was a trail-blazing design that instead of being powered by the venerable Meyer & Drake Offenhauser engine which had dominated open wheel racing in the United States since the 1930s (Robson, 1999), used the new Cosworth DFX engine (Kirby, 2010), a re-engineered version of the British Cosworth DFV engine (Robson, 2007) that dominated Formula 1 at the time. De-stroked to 2.65 litres and turbocharged, the Cosworth DFX proved highly successful, rapidly rendering the Offenhauser engines obsolete. In the hands of Al Unser and Danny Ongais, the VPJ6B dominated Indycar racing between1976 and 1978 (Kirby, 2010).

Barnard thus rapidly built himself a reputation in Indycar design, leading to an approach in 1978 from Jim Hall to join his Chaparral team based in Midland, Texas. Hall had been a dominant force in US sports car racing during the 1960s as a driver, designer and team owner. His Chaparral cars had even enjoyed considerable success in endurance racing in Europe. Returning to racing in 1978, Hall switched from sports cars to Indycars and recruited Barnard to design a new car for him. This was to be yet another in a long line of innovative Chaparral cars. The Barnard designed Chaparral 2K, like its predecessors heralded the introduction of new technology, being the first car to introduce 'ground effects' to Indycar racing (Couldwell, 2003: p140) and the success of the Chaparral 2K marked Barnard out as a 'revolutionary designer' (Fearnley, 2011: 65).

4.3 The MP4/1 carbon fibre chassis

The success of the Chaparral 2K in the US drew Barnard to the attention of Ron Dennis of the Project 4 Racing team which ran March chassis in Formula 2 and 3. Though his Project 4 Racing Team was enjoying considerable success in Formula 2, Dennis was keen to compete in Formula 1 as his next step. Thus during the latter part of 1979 Dennis approached Barnard about a potential Formula 1 project. Barnard for his part had what Henry (1988: 23) describes as, 'his own pet theories about manufacturing an all carbon fibre composite chassis'. So it was that Barnard returned to the European racing scene at the start of 1980 (Cooper, 1999).

In order to optimise ground effects, Barnard reasoned that his design needed to employ the narrowest possible chassis cross section. As he explained, 'I wanted to get the bottom of my chassis down to not much bigger than the driver's bum' (Cooper, 1999: 306). However a narrower chassis meant a potentially less rigid chassis because a narrow section aluminium monocoque would be inclined to flex. Retaining torsional stiffness presented the designer with little option but to use a material other than aluminium. Thin gauge steel was the logical choice but it implied a weight penalty. Barnard however was keen to try carbon fibre. Barnard was attracted to carbon fibre, which at that time was used almost exclusively in aerospace applications (Savage, 2007), postulating that it could offer a huge step forward both in chassis stiffness and weight reduction. While several Formula 1 designers, as noted earlier had used carbon fibre in their designs, no one had ever used it other than as a reinforcement for another material. There were many within Formula 1 who were sceptical of the scope for using carbon fibre for structural applications in a racing car. In the late 1970s the material had a poor reputation in terms of its ability to withstand impact, the result of highly publicised problems with aero engine applications at Rolls-Royce, and the in-service failure of early race components (Savage, 2010). Barnard's detractors initially at least dismissed the idea of using such a brittle material in race car construction. Hence building a chassis comprised entirely of carbon fibre was at the time a very bold step. As Cooper (1999: 307) suggests perhaps only a person like John Barnard with limited experience of Formula 1 'was cocky enough to take such a gamble'.

Convinced that it was possible to produce a chassis from carbon fibre, Barnard was faced with the problem of how to get it built, since the team clearly had no manufacturing capability where carbon fibre composite was concerned. What made the situation more difficult was that Barnard didn't just want to build a chassis from carbon fibre, he wanted to create a complete moulded monocoque, but in order to do so, a dramatic shift in the current approach to manufacturing composite materials was required (Jenkins, 2010). Other designers in Formula 1 had experimented with carbon fibre, using flat carbon panels for instance in place of flat aluminium panels (Fearnley, 2011). But this amounted to no more than using carbon fibre to reinforce an existing aluminium monocoque structure. Barnard's approach was radically different. He planned to make the entire chassis from carbon fibre and to produce it as a single moulding. This was an entirely different design principle compared to earlier attempts at using the material. The potential advantage of moulding was that it would provide a more complete composite structure that would be stronger and therefore could be of lighter construction. To achieve this Barnard proposed to construct the new chassis using layers of pre-impregnated carbon fibre moulded around a large cast and machined aluminium mandrel. The structure would then be cured under pressure in a large autoclave (Wright, 2001). Finally the mandrel would be dismantled and removed via the cockpit aperture. At the time it was unusual to fabricate a relatively large structure from carbon fibre composite in this way. Lacking this capability and the resources to acquire it, sub-contracting chassis manufacture was the only option. Despite leading-edge work being undertaken in the UK aerospace industry, there was no interest in this kind of project from established UK companies. According to Barnard, 'Over here they either said it was too much for them, or that we were, in fact, mad' (Cooper, 1999: 307). Thus fabrication of the new moulded carbon fibre composite chassis presented a major obstacle. Barnard had to look further afield (Jenkins, 2010) and help came from one of his contacts from his earlier involvement in Indycar racing in America (see table 4), Steve Nichols, who pointed Barnard towards Hercules Aerospace in Salt Lake City, Utah.

Hercules was a chemical company that moved into carbon fibre when it took out a licence for a carbon fibre manufacturing process from the British company Courtaulds in 1969 (Dyer and Sicilia, 1990). The Hercules Aerospace division participated in several missile programmes during the 1970s including Trident, MX and Pershing II, providing lightweight carbon composite casings which housed the missile's propellant. By the later 1970s it had moved into aircraft components and structures that used significant amounts of carbon fibre. Major applications for Hercules Aerospace included the F-18 fighter where 10 per cent of the airframe was carbon fibre and the AV8B vertical takeoff aircraft where 28 per cent of the airframe was made of carbon fibre (Dyer and Sicilia, 1990: 412). In 1978 Hercules severed its relationship with Courtaulds and instead entered a joint venture with the Japanese firm Sumitomo. Having acquired the ability to make the raw material for carbon fibre production, Hercules was by 1980 the world's only fully integrated carbon fibre producer. As an integrated producer Hercules Aerospace was able to develop a capability to fabricate specialist low volume aerospace structures, and it had an R & D section set up to carry out one-off odd jobs. One high profile example was the experimental *Voyager* aircraft made almost entirely of carbon fibre, in which pilots Dick Rhutan and Jeanna Yeager made the first flight around the world without stopping or refuelling.

As a leading aerospace carbon fibre composite manufacturer, Hercules Aerospace had access to the most advanced manufacturing techniques available for producing large moulded structures (Wright, 2001), so Barnard was soon on a plane to the US complete with a one third size wind tunnel model and the drawings for the new chassis (Cooper, 1999). Hercules agreed to take the job, effectively becoming a sub-contractor for monocoque construction. The one piece moulded design proved so successful that it remained virtually unchanged for six racing seasons (Gilchrist and Curley, 1999).

The fact that McLaren had developed the first moulded monocoque gave it a major technological advantage. Barnard's design had double the torsional stiffness and a substantially increased ground effects area, while at the same time being lighter (Fearnley, 2011). This contributed to its winning the 1984 and 1985 World Championships (see table 3). Despite the reservations of many of their competitors, the McLaren MP4/1 design proved so successful that it was copied in one form or another by every other Formula One team (Savage, 2010). In fact Barnard's concept, which many had doubted in the early days, in time became the industry standard.

6. Analysis: The role of Social Capital

The Project 4 team that John Barnard joined in 1980 was effectively an outsider as far as the close-knit Formula 1 community was concerned, the team being described by one commentator as, ‘a fledgling team whose budget was far from secure’ (Cooper, 1999: 309). If the team was an outsider, so too was its team owner Ron Dennis and its chief designer John Barnard. Although he had been a mechanic with the Cooper and Brabham teams in the late 1960s, for almost a decade Dennis had been out of Formula 1 running cars in Formula 2 and 3, first with Rondel racing and latterly with his own Project 4 team (Collings, 2002). Similarly Barnard’s career had effectively involved just one stint in Formula 1. Almost from the start the main focus of Barnard’s work had been the racing scene in the US (see figure 2). Even when working for British teams and constructors like Lola and McLaren, Barnard’s focus had largely been on US-based race series like CanAm and Indycars, and latterly he had been working for American teams based in the US. Consequently his reputation as a designer up to this point, was very much based on successful Indycar projects.

Another factor that made the Project 4 team an outsider was its youth. Both Dennis and Barnard were in their early 30s. This, plus the fact that it was a newcomer, placed Project 4 very much on the periphery of the ‘small world’ (Henry and Pinch, 2000: 200) of Formula 1. A world in which as Cooper, (1997: 60) notes ‘every one knows every one and most have worked with each other too’. Dennis and Barnard in contrast, were unusual in that much of their prior experience had been in other forms of racing.

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As an outsider, the structure of Barnard’s social capital was uncharacteristic of Formula 1 designers of the period. In structural terms his network of personal contacts was more diverse than was normally the case. Not only that, it also extended to groups well beyond the normal confines of the Formula 1 community, to cover other categories of racing particularly in the US. These categories of racing represented different groups or networks of racing personnel located geographically and technologically at a distance from Formula 1.

Figure 2 shows that Barnard's personal network included a number of the leading designers and team owners of the period. From Formula 1 there were designers like Gordon Coppuck of McLaren and March and Maurice Philippe of Lotus and Tyrell, as well as Patrick Head of Williams, with whom Barnard had worked at Lola. However it included a much more eclectic mix of people than just those from Formula 1. There was Eric Broadley of Lola, one of the most influential racing car designers of the period, responsible for a wide range of cars spanning almost all categories of racing in Europe and the US. Significantly Broadley's company Lola Cars was not a racing team but a constructor producing cars for sale to a wide range of customer teams. Unlike other leading designers of the period, like Colin Chapman of Lotus and Tony Rudd of BRM, Broadley had strong connections with the US racing scene.

From his years working in the US, Barnard's network also included a number of leading figures from the American racing scene. Jim Hall of Chaparral was not only a team owner and former driver, but one of the most innovative racing car designers of the 1960s, with significant innovations to his credit including glass fibre chassis construction and the semi-automatic gearbox. He was also the first designer to make serious use of aerodynamics. Hall's Chaparral 2F 'wing' car of the 1960s was instrumental in bringing aerodynamics to Formula 1 (Buijs, 1988). Also included in Barnard's network was Parnelli Jones a leading Indycar driver and owner of one of the most successful teams of the 1970s and 1980s.

Nor was Barnard's network of contacts confined to leading designers and team owners, for having worked in the US for several years he was able to draw on a wealth of contacts at all levels of the sport. Hence it would be fair to say that in structural terms Barnard's network was much more diverse than that of his contemporaries in Formula 1 (see figure 2). It extended to all three of the principal branches of motor sport, namely Formula 1, Indycars and sports/GT cars. Hence in Burt's (2005: 17) terminology Barnard's social capital provided a 'bridge' between different groups or networks. This potentially provided Barnard with a greater breadth of knowledge than most of his fellow designers. It placed him in a position where in structural terms he could engage in 'brokerage' (Burt, 2005:73), that is moving knowledge familiar in one group to a second group unaware of it, such as between the Indycar racing community in the US and the Formula 1 community in Europe.

Barnard's social capital was not merely structural in terms of a wide and eclectic mix of people. In terms of content his diverse range of contacts represented valuable sources of knowledge not just in relation to Formula 1 technology but other classes of racing and other technologies as well. His time at Lola had provided Barnard with a breadth of knowledge about all aspects of racing that he himself acknowledged saying of his time at Lola, 'those years were irreplaceable for the experience and knowledge I gained in all aspects of racing car design and operation' (Couldwell, 2003: 139). It was significant that Barnard joined Broadley's company at a time when it was becoming much more involved in racing in the US. When Barnard moved to the US in the mid-1970s he brought about some of the most significant innovations in Indycar racing. His VPJ6 car brought about a major change in Indycar racing being the first to use a British Cosworth DFX engine instead of the ubiquitous home-produced Offenhauser unit that had been used sine the 1930s, thereby starting a trend that all other teams quickly followed. Similarly Barnard's Chaparral 2K was not only highly successful, it was also the first Indycar design to make effective use of 'ground effects', an achievement that led to Barnard being awarded the prestigious Louis Schnitzer design award in 1979.

All of the individuals identified so far were leading designers or team owners with whom Barnard had worked and from whom he had acquired specialised knowledge. However there were many other individuals from diverse backgrounds with whom Barnard was acquainted through his work. These individuals represented what Granovetter (1973) terms 'weak ties', being more informal and casual acquaintances. They included people like Patrick Head whom Barnard had worked with as a junior designer at Lola. It was through Head that Barnard heard that Ron Dennis was looking for a designer for his Project 4 team and that he was planning to move up to Formula 1 (Cooper, 1999). In addition Head was by this time a leading designer himself, recognised as the most successful proponent of 'ground effects' through his Williams FW07 design, a car described by Peter Wright of Lotus as, ' the definitive ground effects car' (Wright, 2001: 307).

Two other individuals with whom Barnard had 'weak ties', proved particularly important in enabling him to access knowledge and expertise about carbon fibre. The first was a contact that Barnard had at British Aerospace. British Aerospace were using carbon fibre to manufacture nacelles that housed Rolls-Royce jet engines (Cooper, 1999), and it was through visiting the company's Weybridge site that Barnard learnt about the properties of carbon fibre. The second individual was Steve Nichols, the shock absorber engineer whom Barnard knew from his Indycar days (Cooper, 1999: 307). Nichols was from Utah (Hilton, 1989: 209) and had spent the first four years of his career after graduating from university, working for Hercules Aerospace in Salt Lake City. Given Hercules' expertise in carbon fibre noted earlier, Nichols not only had a high level of knowledge and expertise about the properties of carbon fibre, he was also knowledgeable about manufacturing techniques and well aware of Hercules Aerospace's capabilities, particularly when it came to producing large moulded structures in carbon fibre (Cooper, 1999). Hence Nichols proved a vital link both in enabling Barnard to acquire knowledge of carbon fibre, and, given the difficulties the team encountered in finding a company to produce a large carbon fibre moulding in the UK, in locating a company willing and able to fabricate Barnard's new chassis design.

Thus 'weak ties' within his network of colleagues, former colleagues and acquaintances, proved absolutely vital in enabling Barnard to bridge the gap between existing chassis technology and the requirements of carbon fibre construction. Significantly the other team to make the leap to a carbon fibre chassis at this time was Lotus who were very much an insider within Formula 1. They used a quite different construction technique that relied on 'cut and fold' methods borrowed directly from the existing aluminium chassis technology. This approach, which retained the construction methods used by the existing technological regime though with new materials, proved less satisfactory and ultimately proved to be a 'technological cul-de-sac' (Savage, 2010: 106), since as Lotus's Peter Wright later acknowledged 20 years later in a major study of Formula 1 technology, 'the techniques used by McLaren showed the future' (Wright, 2001: 317).

7. Discussion and Conclusion

Technological discontinuities loom large in the innovation literature (Christensen, 1997; Foster, 1986) and considerable attention has focused on technological discontinuities that are competence destroying. However much of the research effort has gone into analysing why incumbents fail to pioneer discontinuities, rather than why outsiders succeed. It is no coincidence that the subtitle of Christensen's (1997) definitive study of competence destroying technological discontinuities is entitled, 'When New Technologies Cause Great Firms to Fail'. The literature tends to portray the success of outsiders in pioneering radical innovations in terms of the failings of incumbent firms, rather than a function of the attributes and actions of outsiders. This study attempts a re-appraisal. It does so by looking not at the negative features of incumbents but rather at the positive features of outsiders. It focuses on the attributes of outsiders, in particular their social capital and how this can be used to provide them with what Foster (1986) terms 'the attacker's advantage' in the management of innovation and the development of new technology..

The study focuses on a major technological discontinuity in the high technology world of Formula 1, namely the introduction of carbon fibre composite and the development of the world's first racing car to employ a moulded carbon fibre chassis. In this instance, while several established and successful teams in Formula 1 had made limited use of this new material, the leap to using carbon fibre involving completely different construction techniques that bore no resemblance to the methods employed in the industry at the time, was pioneered by an outsider, a team new to Formula 1 (certainly in terms of personnel if not name).

In making this leap the case study clearly shows how social capital was a decisive factor. Social capital provided the means to make the required technological leap. The contrast between McLaren and Lotus, is stark. Lotus, an incumbent team, which until this point had been highly successful, also pioneered the use of carbon fibre in chassis construction but relied on knowledge and construction methods that borrowed heavily from existing technology, leading to what ultimately proved a technological cul-de-sac. Barnard at McLaren on the other hand, through the use of his more diverse social capital was able to bridge the gap between existing practice in the Formula 1 community and specialist aerospace applications where carbon fibre mouldings were being used. What was particularly important was the capacity that social capital provided for ‘bridging’ between these two knowledge communities, thereby allowing Barnard to benefit from weak ties.

Previous research has highlighted the importance of social capital in sectors such as science based industries where access to knowledge is critical. This study suggests that social capital is in fact more widely applicable. Its particular contribution is in relation to research into competence destroying technological discontinuities, where it provides a badly needed change of focus, away from incumbents and their failings, and towards outsiders and the factors that make them well placed to pioneer radical innovations. The study points to outsiders’ social capital being a particularly valuable asset by virtue of its structural characteristics and the diverse contacts it embraces.

It would clearly be inappropriate to generalize from a single case and one could argue that the highly competitive, technology laden world of Formula 1 is unusual and untypical of industry practice in other less glamorous sectors. However these potential limitations are more than offset by the in-depth nature of the case study which provides a valuable insight into why and how outsiders are often well placed when it comes to the application and implementation of new technologies, something that has infrequently been demonstrated in the past .

This clearly has important implications for future research and points to the need for further in-depth studies in other sectors focused not just on the role of outsiders but in particular on the nature of their social capital and how they use it. Similarly it also has implications for managerial practice surrounding the management of technology, highlighting as it does the potential value of social capital based on diversity of experience, in circumstances where managers find themselves faced with technological discontinuities and need to find ways of bridging old and new technological regimes.

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Table 1
Technological discontinuities in Formula One chassis design

Date	Chassis type	Material	Construction	Manufacturer/ Designer	Technological Discontinuity
1900s-1940s	Twin beam	Steel	Bolted	traditional	n/a
1950s-1960s	Tubular space frame	Steel	Welded	Cisitalia (Savonuzzi)	Competence enhancing
1960s-1980s	Stressed skin monocoque	Aluminium	Riveted	Lotus (Chapman)	Competence enhancing
1980s-present	Moulded monocoque	Carbon fibre	Autoclave (baked)	McLaren (Barnard)	Competence destroying

Table 2
Formula One Constructors Championship 1961-1980

Year	Winning Constructor	Lotus Position	Lotus points
1961	Ferrari	2nd	32
1962	BRM	2nd	37
1963	Lotus	1st	58
1964	Ferrari	3rd	40
1965	Lotus	1st	56
1966	Brabham	5th	21
1967	Brabham	2nd	50
1968	Lotus	1st	62
1969	Matra	3rd	47
1970	Lotus	1st	59
1971	Tyrell	5th	21
1972	Lotus	1st	62
1973	Lotus	1st	92
1974	McLaren	4th	42
1975	Ferrari	7th	9
1976	Ferrari	4th	29
1977	Ferrari	2nd	62
1978	Lotus	1st	86
1979	Ferrari	4th	39
1980	Williams	5th	14

Source: Ludvigsen (2010)

Table 3
Formula One Constructors Championship 1981-90

Year	**Winning Constructor**	**McLaren Position**	**McLaren points**
1981	Williams	6th	28
1982	Ferrari	2nd	69
1983	Ferrari	5th	34
1984	McLaren	1st	143.4
1985	McLaren	1st	90
1986	Williams	2nd	96
1987	Williams	2nd	76
1988	McLaren	1st	199
1989	McLaren	1st	141
1990	McLaren	1st	121

Source: F1complete (2011)

Table 4
John Barnard's design career 1968-86

Team/ Constructor	**Team Principal**	**Date**	**Race Series**	**Car**
Lola Cars	Eric Broadley	1968-72	Can-Am Formula 5000	T260 T330
McLaren	Teddy Mayer	1972-75	Formula 1 Formula 5000 Indycar	M23 M25 M16
Parnelli	Parnelli Jones	1975-78	Indycar	VPJ6B
Chaparral	Jim Hall	1978-79	Indycar	2K
Project 4/McLaren Int.	Ron Dennis	1980-86	Formula 2 Formula 1	Superseded MP4/1

Figure 1
S-curves and Technological Discontinuities

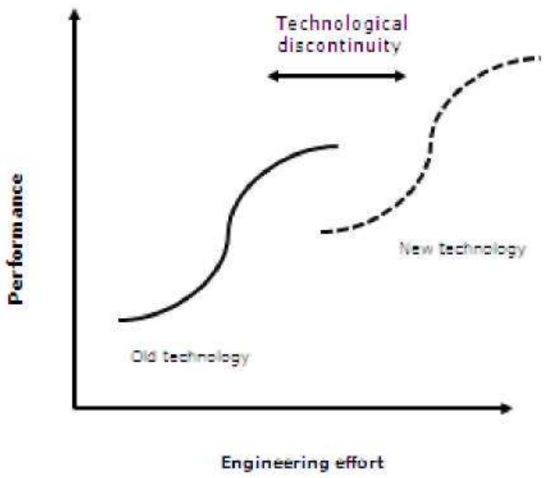

Figure 2
John Barnard's Personal Network (1980)