

# **Technology, performance and team adaptation to regulation in Formula 1**

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## **Abstract**

This paper looks at how competition, regulation and technology coevolve in Formula 1 and how teams adapt. It does so at two levels: (i) the system level viewing Formula 1 competition as a whole and (ii) the organizational level, viewing team adaptation and car development level. The path this coevolutionary trajectory competition has taken in modern Formula 1 (1970 – 2013), is examined by looking at season results and regulation changes that punctuate its path. The understanding developed through this are summarised in a causal loop diagram and some implications are worked out for the forthcoming 2014 season.

## **1. Introduction**

Formula 1 has come a long way from a humble beginning post World War 2, where the racing season consisted of seven races, with a handful of teams and engineers. Nowadays is a world wide sport with an audience in excess of 500 million spectators (ESPN, 2013). Technology, regulations and the very nature of the sport and demands on teams have changed dramatically. For example the privately owned Williams racing team has grown from 17 people in 1977 to more than 500 in 2013 (WilliamsF1, 2013) and Fiat owned Ferrari current racing team employs more than 900 (Ferrari, 2014). Sponsor money, thus are vital in maintaining such large organizations. A fundamental condition for this, is that the F1 races continue to draw a large worldwide audience each season. A prerequisite for this is intense competition between drivers, teams, technology and maintaining the perception that F1 is the pinnacle of automotive sports.

The present article considers the multi level coevolution of technology, competition and regulation in F1. It presents season results for the period of modern F1 from 1970 to 2013. This is defined by presence of sponsors for the racing teams, the advent of aerodynamic aids to improve handling of the cars and the introduction of turbo engines and ground effect in the late 1970s (Jenkins and Floyd, 2001). During this period, the level of team expenditures in the sport grew considerably, partly because of sponsorship and partly because automotive manufacturers

support F1 teams. This eventually resulted in considerable amounts of money being spent as teams supported by automotive manufacturers are under pressure to win for brand image reasons, and hence tend to spend twice or more the amount of money spend by privately owned teams (Autosport, 2014). The range of development and computational resources available to modern top F1 teams thus is unprecedented.

The regulatory body of F1 Federation Internationale de l'Automobile (FIA) keeps regulations in step with technology evolution as technology enabled the cars to go faster, for example turbo engines produced well over 1000 bhp in the mid1980s. Maximum engine revolutions had reached 19000 rpm or 317 per second in 2006 and were restricted to 18000rpm from 2009 onwards (f1technical.net, 2014). 15 fatal driver accidents, mostly in the 1970s (Wikipedia, 2014), also motivated further regulations to slow cars down and make them safer. Regulations were also introduced because the development and use of electronics and sensors in F1 reached a level during 1992 and 1993 seasons, at which it was perceived to distort the very essence of competition in the sport i.e. the display of driver's prowess and team capabilities, thus making races less appealing to audiences. The value of F1 racing for spectators during the race weekend lies precisely in the display of driving skills unmasked by driver electronic aids. These were eventually banned in the 1994 season.

A further, recent reorientation at the system level that is currently gaining momentum, is due to concern with annual team budget and the energy consumed in each race event and during winter testing. The level of sponsorship that manufacturer owned teams can secure, places F1 under a risk of opening a gap between front and middle field teams and threatening the viability of the sport as the cost entry barrier for new teams is exorbitant. The example of Toyota that entered F1 in 2002 and withdrew in 2009 is characteristic (BBC, 2009). Regulations were also introduced to reduce racing costs related to engines used. For example, in the turbo era teams had separate qualifying and racing engines for each race. In 2009 regulations allowed each driver to use a maximum of 8 engines during the 17 races of the season. Car testing during and between seasons was unlimited but now wind tunnel and on track testing are limited (15000 km during the year) (F1 sporting regulations, 2013). Regulations for 2014 are a further step in this direction with an emphasis on energy recovery systems and hybrid power units that combine turbo and energy recovery systems (F1 season changes, 2014). Furthermore, a cap on team expenditures is being discussed for 2015. Overall, regulations for cost, preseason testing, racing, car and engine

design, and development of energy recovery systems continuously expand and prune the solution space available to engineers from season to season.

Thus a fundamental question arises about the timing of car development for each season based on regulation changes. In contrast with business firms where sometimes exploration under environmental dynamism is suppressed (Walrave et al., 2011), in F1 exploration of the solution space is continuously ongoing both for the car the team races with and next seasons car. The question is at which point during a season a team will decide to devote its resources for next year's car. The decision rests on whether it expects to win the championship by focusing on developing the car with which it competes in the current season. It is an instance of the exploration vs exploitation dilemma as discussed in the literature (March, 1991). Given the level of competitiveness of the team's car and the anticipated regulation changes for the following season, the question of timing is central for the continued success of the team. If the championship fight is not settled until the last races of the season, then exploration, is suppressed until the championship is decided.

Viewed at the system level, F1 during 1970-2013 has moved from a state where technical solutions, or the solution space, available to engineers to explore and improve the overall performance of the car were limited by materials, technology, the state of knowledge and the resources and computational capacity of teams, i.e. what was possible, to one where the solution space is defined by what is desirable and in agreement with FIA regulations. Thus at the system level F1 has moved from a state of exploratory technology development to a state of directed technological evolution, from largely unrestricted car and engine performance to more restricted competition. This is why the timing of car development is even more important nowadays and puts a premium on team resources. The overall goal for FIA the governing body of F1 is to sustain a high level of competition so that audience interest is kept high. This has two components, a short and a long term one: (i) no team should dominate F1 completely in the short term, and (ii) the cost of competing in F1 should be kept manageable in the long term so that new teams are drawn to the sport and those already competing are not driven out. These goals are conflicting with team goals that aim to win as many races as possible and are prepared to go to any length to achieve that.

The present article is an attempt to put the pieces of this coevolutionary F1 puzzle together and develop a picture with which it will be eventually possible to shed light to the above questions. The following sections discuss F1 regulation, performance and competition and present season results from 1970 to 2013. Trends and patterns evident in the data presented are in support of the qualitative hypothesis that is put forward in the end for how regulation, technology and competition have coevolved in F1.

The rest of the paper is structured as follows. Section 2 presents aspects of technology evolution in F1 and section 4 looks at how performance varies with time in the period from 1970 to 2013. Section 5 looks at how competition varies on an annual basis and section 6 looks at its intensity. Finally section 7 presents some data in order to make the case for path dependency in F1 and the implications of this for the forthcoming 2014 season. Section 8 concludes the paper.

## **2. F1 Regulation**

The controlling organization of the F1 motor racing series is the Federation Internationale de l'Automobile (FIA). It issues, implements and monitors regulation changes. Rule changes control race car performance, race procedures, but also improve competitive balance between the teams (Mastromarco and Runkel, 2004). By improving the competitive balance between teams, uncertainty regarding race results draws spectators to the sport and this in turn draws sponsors. Rule changes season are more likely to be introduced and be comprehensive, when a team has been dominant in the previous season. Mastromarco and Runkel (2004) have shown that a unit increase in the standard deviation of points scored by the teams in a F1 season significantly raises the expected number of rule changes in the next season by about 3%.

Regulation changes, increase the uncertainty of team performance during the season because they change/shift the available solution space for engineers, especially if they are as comprehensive as in 2014 (Figure 1). This inevitably requires that teams experiment with the car's component, adjust their race strategy and the development trajectory of their car. Finally, they can attempt to cooperate at the regulation level in order to influence the way regulations will be shaped in the future. So regulation changes bring forth a response from teams that can potentially manifest in three levels (Jenkins and Floyd, 2001). The example of ground effect in the 1970s is characteristic. At the component and firm level teams adapted to the major potential performance benefits that could be gained and at the system level they agreed on what was

acceptable for competition. For example they banned the exotic Brabham BT46B which used a fan at the rear of the car to generate additional downforce by sucking air from beneath the car.

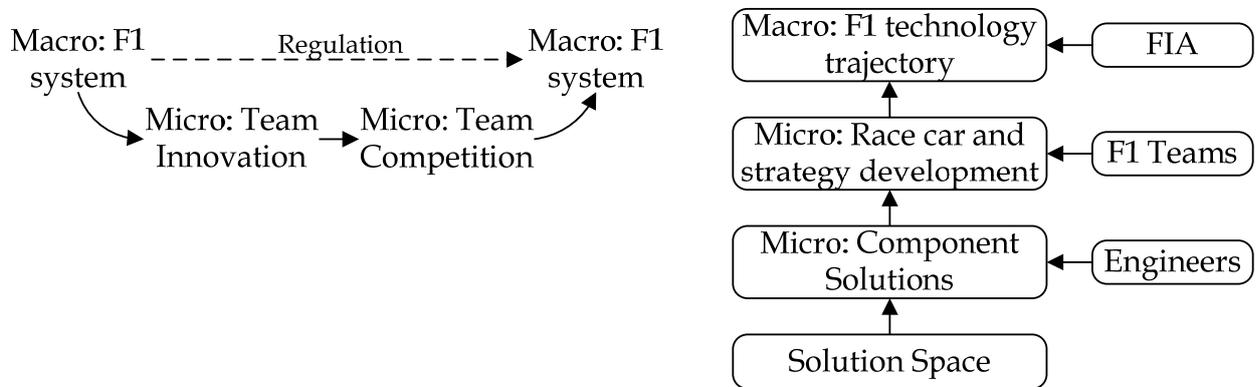


Figure 1 Multi level F1 technology evolution

While competition each year is punctuated by regulation changes, car development does not resume from scratch. There is path dependency stemming from the way that engineers explore the available solution space and technology becoming available to teams (Garud and Karnoe, 2001). Furthermore, as knowledge and resources for racing and technology development are accumulated with each season, the entry threshold for new teams is raised. This has been a recent concern especially after 2008 where adverse financial conditions forced firms like Toyota (BBC, 2009) and BMW out of the sport (Formula1.com, 2009).

### 3. F1 Technology Evolution

Technology in F1 involves the aerodynamics of the chassis, engine and tyres. Most teams do not develop their own engine, they produce the car and have a supply agreement with an engine manufacturer. The advent of Ford DFV engine in the 1970s enabled the entry of numerous teams that competed successfully (Jenkins and Floyd, 2001). It was a reliable, competitive engine that could be acquired at a reasonable price and enabled teams to concentrate valuable resources on the development of the chassis. This is evident in Figure 2 that shows winning teams and winning engines from 1970 to 2013. More teams than engines competed successfully throughout the 1970s until 1983. Consequently, it is not accidental that using the same engine, teams concentrated on aerodynamics which grew considerably during the 1970s.

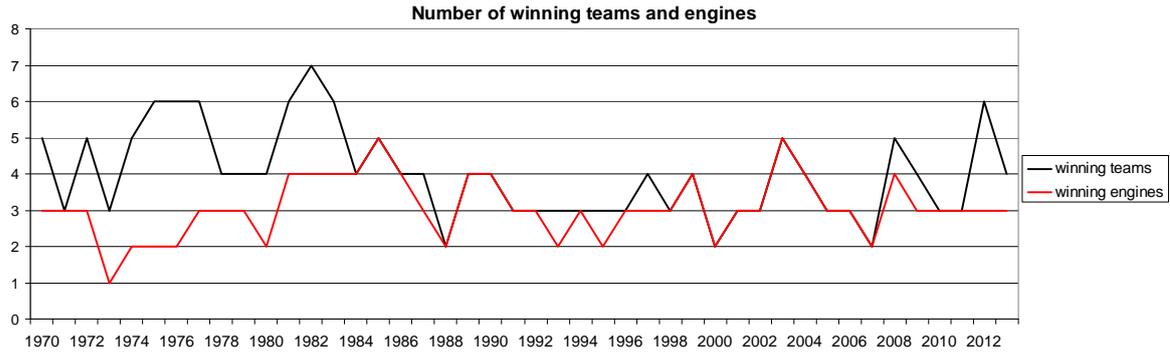


Figure 2 Number of winning teams and engines 1970 – 2013 (source: statsf1.com)

However, gradually technology evolution in F1 changed and became more integrated in 1984-2012 there are as many winning cars as there are engines on most seasons. Looking at the period between 1967 and 1982, Jenkins and Floyd (2001) argue that when the costs and difficulty associated with transferring component knowledge between firms is low as was the case with the Ford engine, technologies tend to coevolve across firms. This increases the likelihood of industry dominance for a technology. When this becomes difficult technologies tend to evolve within firms, leading to competing technologies across firms and increasing the likelihood of a technology's dominance within the firm. A condition for this is that regulations must allow such divergent paths of development.

An illustrative example is the introduction of ground effect with Lotus 79 which won the constructors championship in 1978. This was possible to implement because of the small size of the Ford DFV compared to Ferrari's flat V12. Initially Lotus disguised the use of ground effect claiming that the car's performance was due to some novel differential. However, once the basic principles of the ground effect were understood, they were immediately imitated by other teams using the Ford DFV and in 1980 Williams won the constructors championship using ground effect and the same engine with Lotus which was not as successful as taking the concept further. However, while the basic principles were understood by all teams and the technology at the component level became transparent, this led to some different integration with complementary components at the car design level as different engines for example Ferrari, placed different demands on car design (Jenkins and Floyd, 2001). Hence ground effect became dominant but was also applied differently depending on how it was integrated to race car design. Knowledge regarding the ground effect thus became more tacit (Nonaka, 1994), while at the same time teams explored more of the solution space available to them.

A second example is the coanda effect that was introduced in 2011 by Red Bull in an effort to increase downforce by directing exhaust airflow over the diffuser at the rear of the car. By 2012 all top teams had adapted their cars to take advantage of the effect and FIA subsequently issued regulations to restrict it (Formula1, 2011). The final example is the reintroduction of turbos in Formula 1 from 2014 onwards. This in effect renews the momentum of technological coevolution across teams by making some engine components compulsory and thus transparent to everybody. Like a river running downstream regulation shifts it banks and thus applies water pressure in a different direction.

This shift from winning technology being transferable to being inaccessible, is illustrated in Figure 3 where from 1970 up to 1982 there are more winning teams and new winning teams i.e. teams that had not a win in the previous season, compared to late 1980s and 1990s. Up to 1983 there is at least one new winning team per season. After that the pattern is interrupted and with the exception of 1996-1998, there is an alternating pattern between seasons with new winners and those that are dominated by past winners. Notice also that the number of winning teams after 1985, remains low until 2002 and only then it rises up to 6 teams i.e. to 1970s levels.

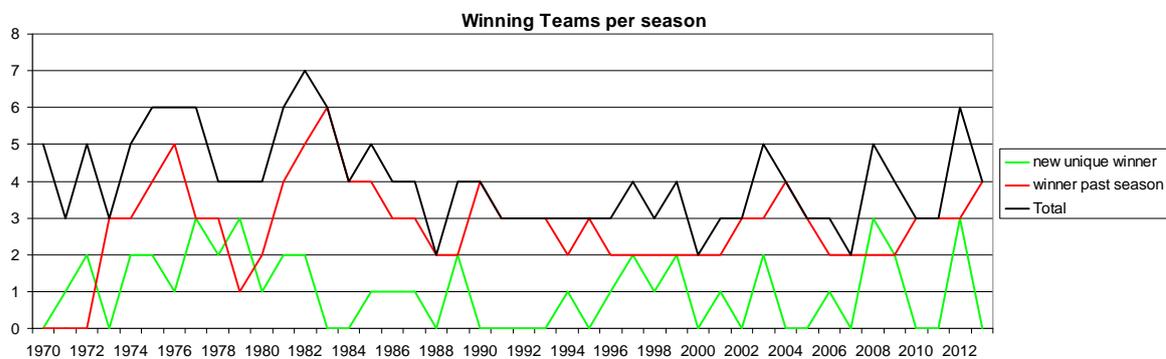


Figure 3 Number of new and past winners per season 1970 – 2013 (source: statsf1.com)

#### 4. F1 performance

Absolute race car performance in F1 is reflected in qualifying results. It is logical that in years where regulations remain relatively stable, technology development converges on engineering solutions and qualifying results of the cars will be more closely matched. This is illustrated in Figure 4 and 5 which show average time difference in seconds in top 10 qualifying positions and standard deviation in each season from 1970 to 2013. These are complementary to Figure 3 in the sense that in the 1970s where a lot of teams were competing and winning, their performance in qualifying is closely matched. Performance is again closely matched in 1997-2003 seasons

where in the aftermath of major changes in 1994, teams had managed to explore most of the solution space available to them. The performance gap is then increasing from 2004 onwards when the pace of regulation changes increased and only teams with the required resources were able to keep up with car development.

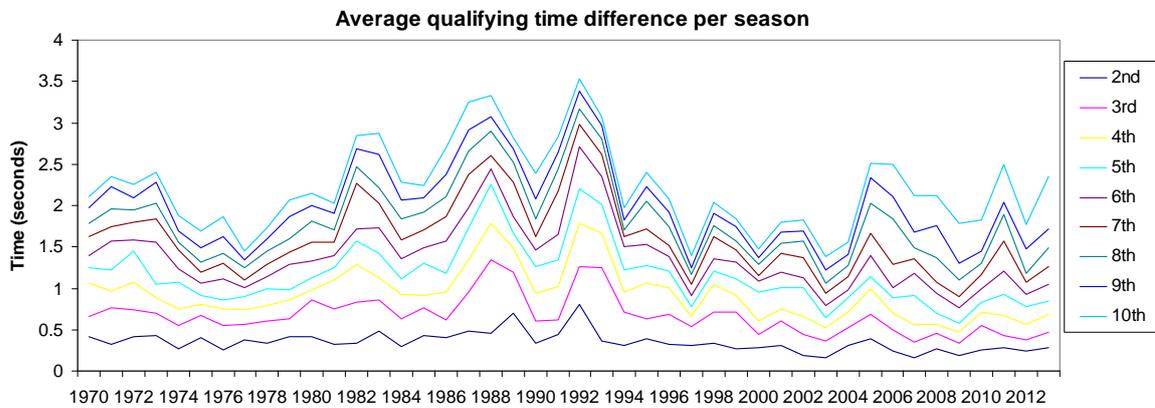


Figure 4 Average qualifying time difference from pole position 1970-2013 (source: statsf1.com)

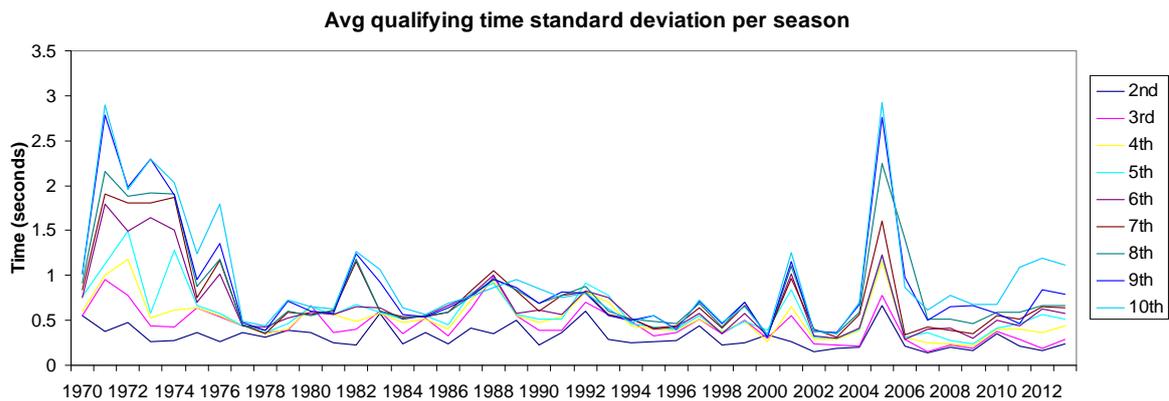


Figure 5 Standard deviation of qualifying times difference from pole position 1970-2013 (source: statsf1.com)

Another aspect of F1 performance is the average speed in qualifying. Figure 6 shows some iconic F1 circuits for which there is continuous data and a clear upward trend is evident in all of them. Sudden kinks in the graphs are explained by weather in particular year, change in track length (Figure 7) or the introduction of chicanes as in the case of Imola (Figure 8).

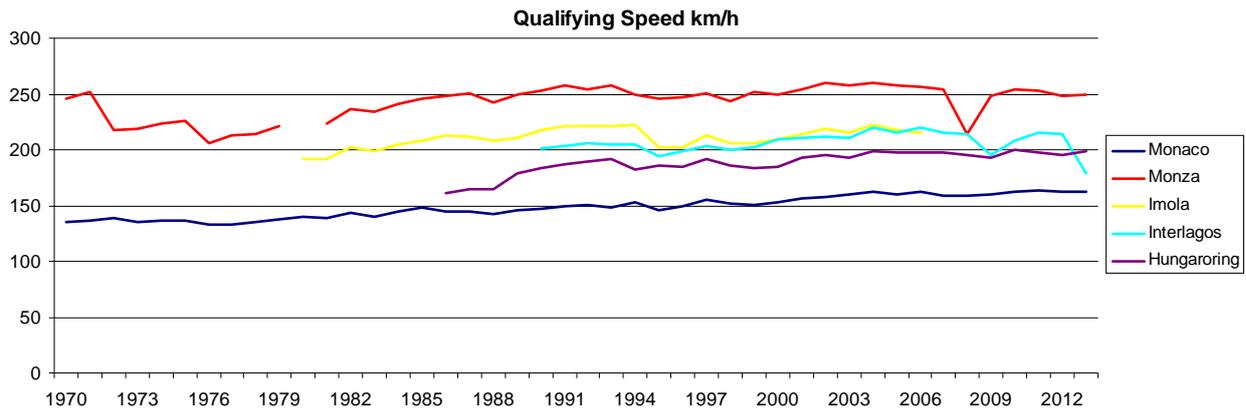


Figure 6 Average qualifying speed in traditional F1 circuits (source: chicanef1.com)

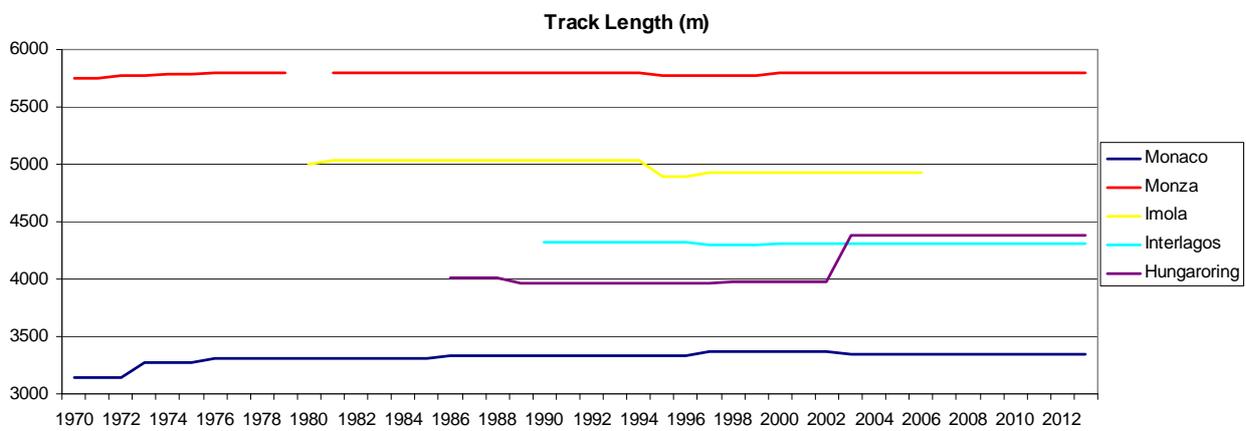


Figure 7 Track length changes in F1 circuits (source: chicanef1.com)

The case of Imola can be used to convey a sense of the pace at which technology in F1 moves forward and makes cars faster every year. Looking at Figure 8 a sudden kink is evident in year 1994. That fateful year saw the deaths of Roland Ratzenberger and Ayrton Senna during the race weekend. It prompted changes to regulations and the introduction of a chicane in the Tamburelo corner where the accident had happened. As expected this lowered average speeds around the track in 1995. However, in the course of the decade average qualifying speed and times got back to the prior levels. This is even more impressive when taking into account the reduction in engine size from 3.5 to 3 litres in 1995 and a progressive increase in car weight from 515 kg in 1994 to 695 kg in 2004. The loss in size was compensated by increasing rpm from 14300 to 19000 in 2004 an impressive 32.9% increase (F1technical, 2014).

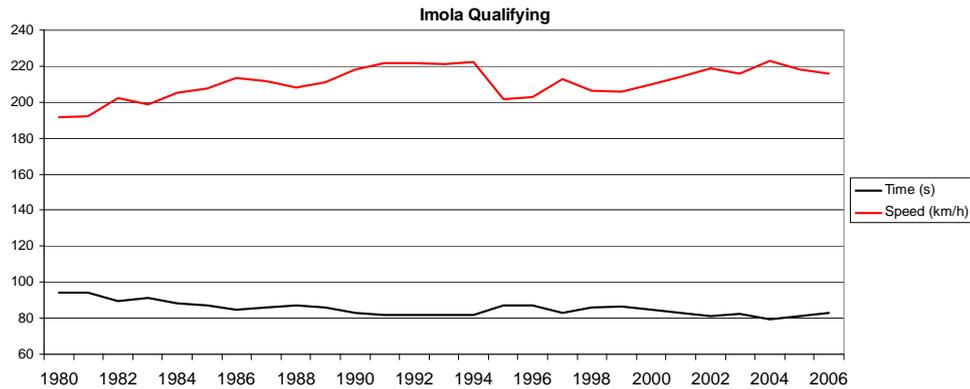


Figure 8 Time and average qualifying speed of pole position in Imola (source chicaneF1.com)

## 5. F1 competition

F1 teams compete by entering two cars in each race event. Each event lasts three days with testing and qualifying in the first two days and racing in the third. Driver and team points are awarded at the end of the race and points tally determines the champions at the end of the year.

Competition is driven by the relative level of car performance which in turn is driven by the revenue coming mainly coming from team sponsors. The leading teams receive substantial support from companies of the automobile industry (Ferrari, BMW, Renault) (Mastromarco and Runkel, 2004). The FIA shares a part of its broadcasting revenue with the racing teams according to their rankings at the end of the season. This covers about 20% of total team costs. Teams use these resources to develop and test their cars, improve their facilities and hire top engineers. A smaller number of car manufacturers and private team owners can muster the combination of entry level required resources which has steadily grown. This is reflected in reduced team turnover and the limited number of F1 teams at present which is nearly 50% of what was in 1970s and 1980s (Figure 9). The same holds for F1 engines (Figure 10). So there is a smaller gap in top car qualifying performance (Figure 4) and at the same time the extremely high requirements placed on teams result in a smaller number of teams competing in F1. Some privately owned teams have also begun to diversify offering solutions based on their F1 competences (McLaren Applied Technologies, 2014; WilliamsF1.com, 2014).

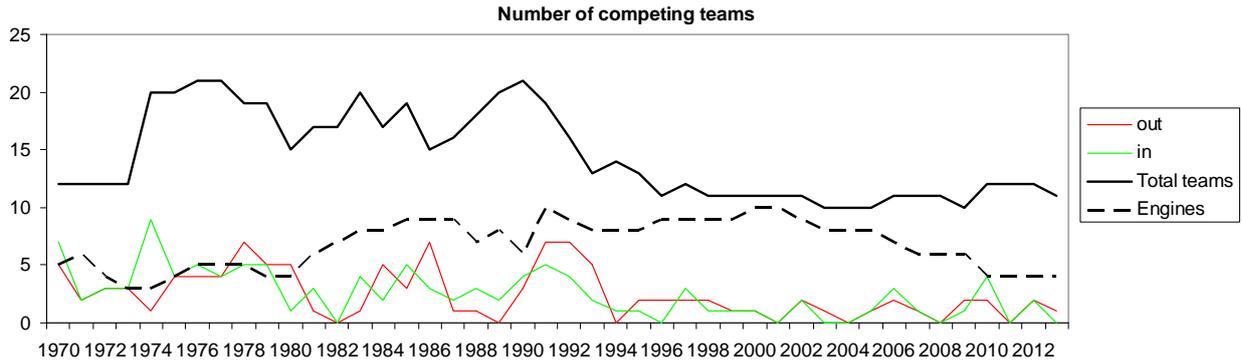


Figure 9 Number of teams in Formula 1 1970 – 2013 (source: statsf1.com)

Whereas performance in qualifying is solely down to the design and performance of car and driver performance in a single lap, race competition involves a number of additional factors such as race strategy and reliability. This is more so the case in the last two decades where drivers communicate throughout the race with the team. The use of race simulators has also made possible the real time race strategy design and implementation (Bekker and Lotz, 2009). This in combination with the reintroduction of pit stops after 1994 brought team race strategy in the foreground. At the same time the computational capabilities of the teams both for design and race strategy simulation and analysis grew exponentially and most importantly they became available to all teams. Thus it can be claimed that race results are an indicator of team rather than driver performance more so now than in the past. Car and race simulation became even more important as extensive winter track testing was restricted down to three four day sessions for 2014 and in season testing to four two day sessions. This cut the advantage that top teams had for extensive testing throughout the year and resulted in the gradual reduction in the performance between the top six finishes from 1988 to 2013 as shown in Figure 10.

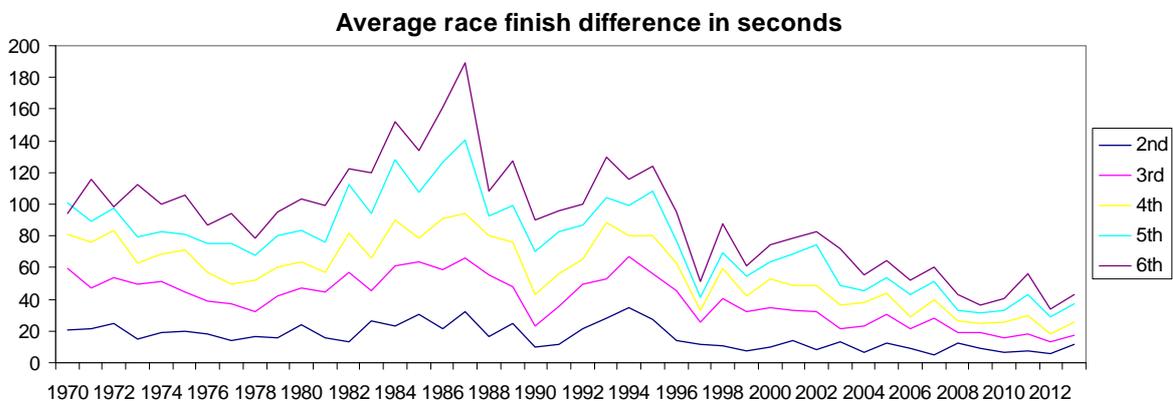


Figure 10 Average race finishing difference from winner 1970-2013 (source: chicane1.com)

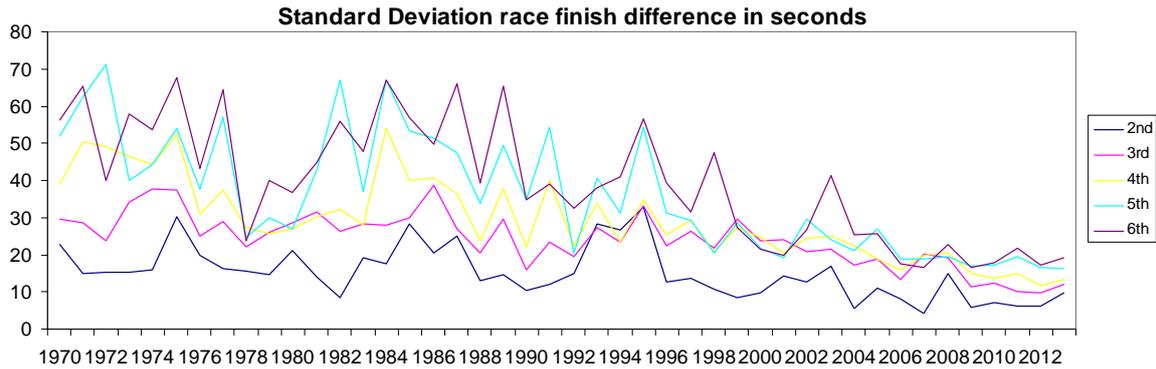


Figure 11 Standard deviation of top 6 finishing difference 1970-2013(source: chicane1.com)

The introduction of computer technology and sensors in every aspect of F1 apart from distorting competition, had another interesting effect. It enabled teams to record a lot of data during the race weekend and analyse them (an F1 car has more than 100 onboard sensors, Reuters.com, 2013). The end result is that despite the increase in the number of races per season, continuous regulation changes and the ever present need for pushing technology to its edge, average retirements per season steadily decreased while their standard deviations have remained relatively stable. Race retirement data also illustrate the gap that begins to open in terms of reliability between top 4 or top 6 and middle field teams.

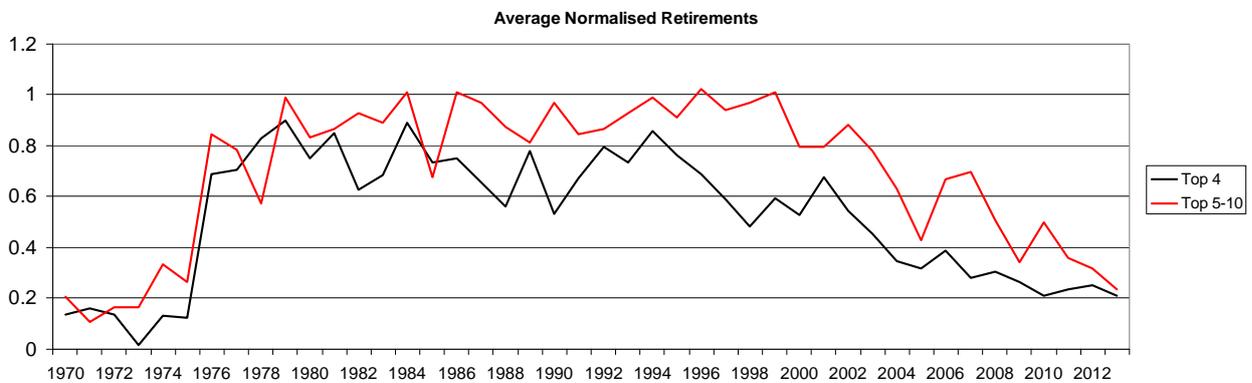


Figure 12 Average race retirements 1970-2013 (source:Wikipedia.org)

### 6. F1 competition intensity

Competition intensity in F1 is important because it attracts large audiences and this in turn makes the sport attractive to sponsorship with which teams develop further their cars. Competition intensity as perceived by F1 audience has two components: team and driver competition and championship results with the driver’s championship receiving more attention in the media each season.

Figure 13 shows the distance in points scored from the constructors champion team normalised by points scoring system and number of races per season. This can be used as a proxy for competition intensity. It is obvious that seasons where the championship is won or lost in few points, alternate with seasons where one team usually ends up dominating the season. This is a result of technology, regulation and organisational evolution of F1 teams. It is evident in the case of 2000–2004 and 1988-1991 seasons where Ferrari and McLaren respectively continuously won the constructors championship. It was a different story in each season. Other teams managed to raise their competitiveness following regulation changes. For example 1988 and 2002 seasons were followed by seasons that were much closer in points.

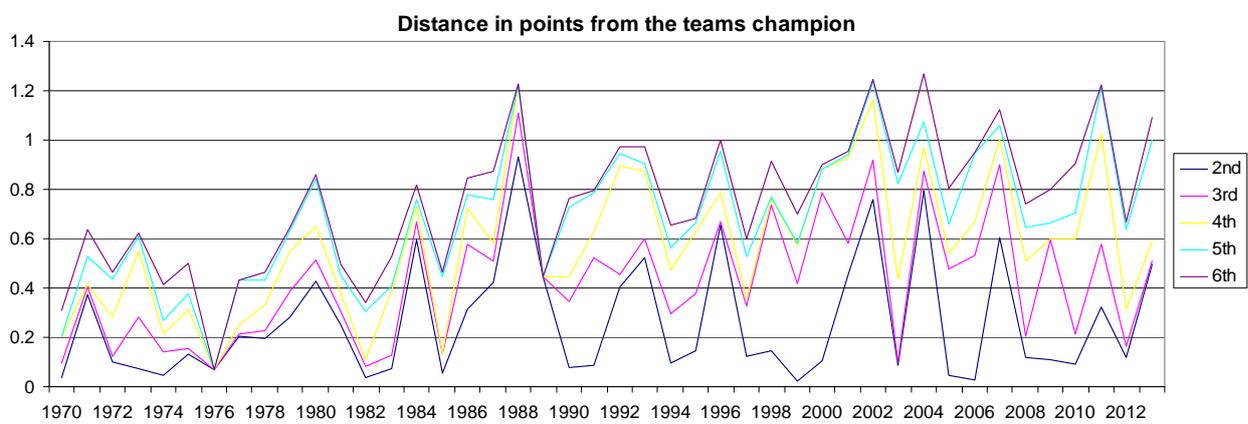


Figure 13 Points distance from teams champion 1970 – 2013 normalised (source: statsf1.com)

Figure 14 shows another indicator for the dominance of a team during the season, measured in absolute number of races a team has led in points standings. Again there is an identifiable pattern where first and second alternate at the top of points standings. For example in 1994 Benetton team was leading in points until the very last races where Williams took the lead. This was also a year where the drivers and constructors championship went to different teams (Figure 15). On most seasons however the winning driver and winning team lead in points for a considerable number of races.

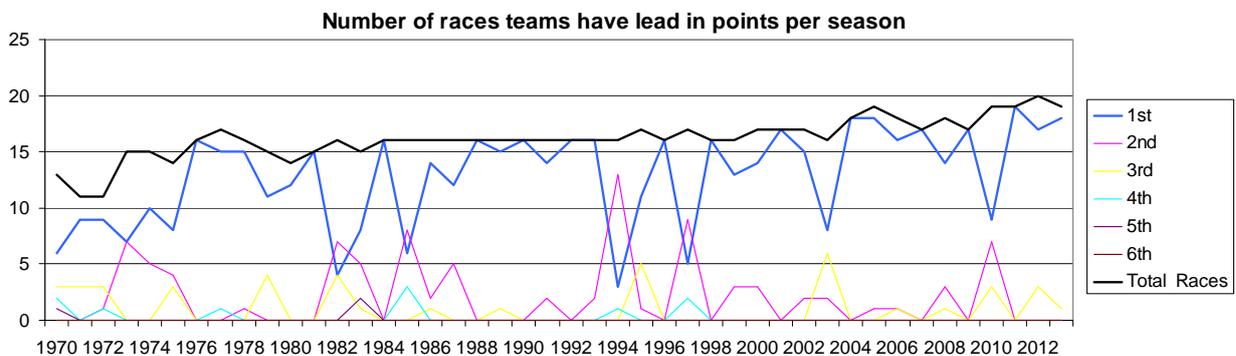


Figure 14 Number of races teams have lead in points 1970 – 2013 (source: statsf1.com)

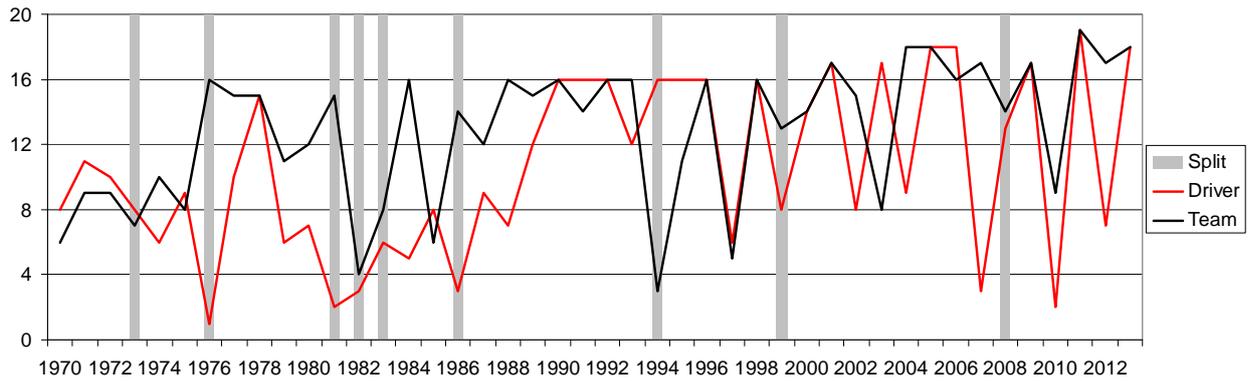


Figure 15 F1 seasons where driver and team championship were won by different teams

Looking at competition intensity for the driver's championship, the distance of the top 6 from the champion in points normalised for number of races and points system, alternates between seasons (Figure 16). Again the 1994 season for example is really close. A noticeable difference is that driver competition was more intense in 1970-1990 than 1990-2013.

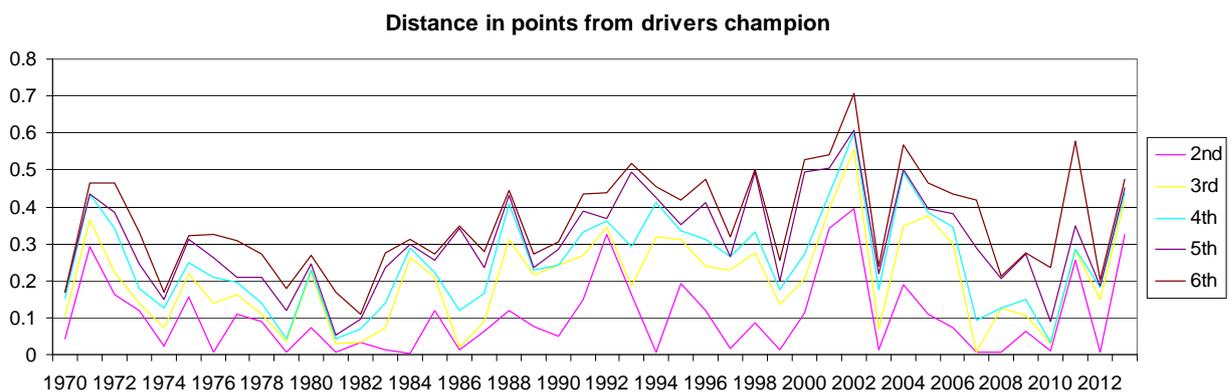


Figure 16 Points distance from drivers champion 1970 – 2013 normalised (source: statsf1.com)

A similar pattern to Figure 16 is evident for races lead in points in the driver's championship (Figure 17). Seasons where the eventual champion lead in most races are followed where the season is split between the top 2 drivers in final standings. The difference with team results is that intensity in terms of drivers appears to be higher in more seasons. The difference in team and driver results is that teams with a relatively good, reliable car with which both drivers score points in each race, can outcompete a faster, winning car that is nonetheless less reliable. This has happened in 9 seasons where the driver's and team championships went to a different team (Figure 15). 6 of these seasons are from 1970 to 1986 while the rest 3 are thinly dispersed in the following 27 seasons indicating that team and driver performance has become more closely related.

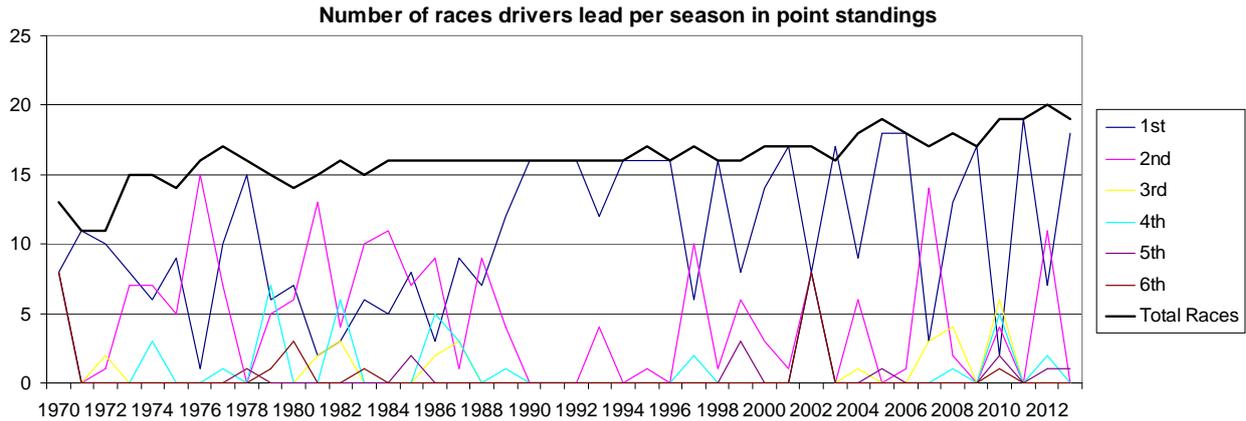


Figure 17 Number of races drivers have lead in points 1970 – 2013 (source: statsf1.com)

The interesting fact is that despite regulation changes, the numerous teams and engine manufacturers that have come and gone and the time span of results considered, there are only 21 F1 teams that have won a race and 9 teams that have won the constructors championship from 1970 to 2013. A handful of teams have dominated the sport both in terms of wins and pole positions (Figure 18). All this suggests that there is some continuity in team performance and there is a possible explanation about this in the path dependent nature of the sport.

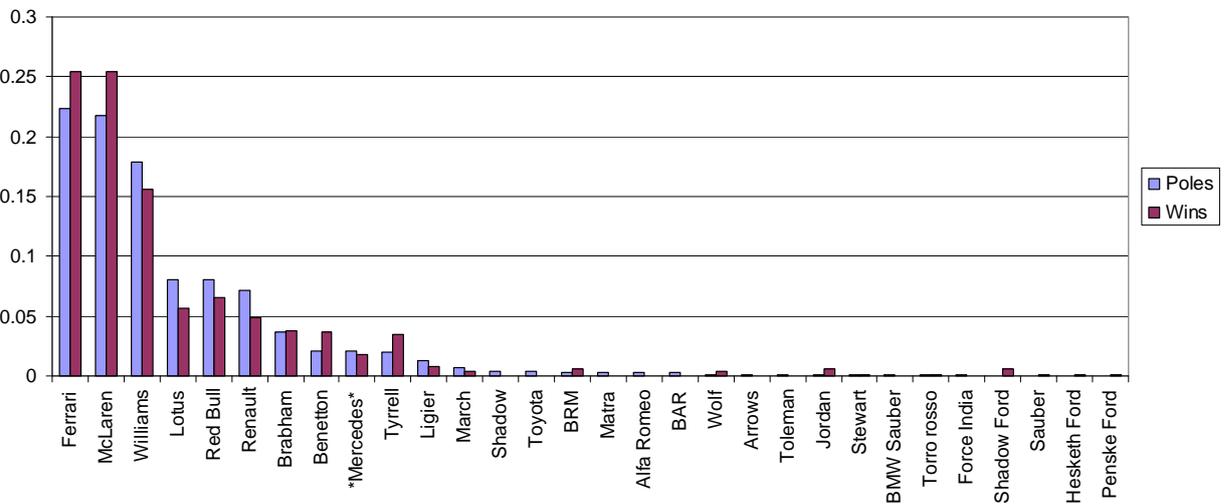


Figure 18 Wins and poles % per team 1970-2013

## 7. Technological path dependency in F1

The concept of technological path dependency comes from the study of industry and technology dynamics (Garud and Karnoe, 2001). It is an accumulation of competences and activities created through sequences of choices between competing technologies that result into a persistent and stable pattern that is independent of other technologies (Fai, 2003; Bergek and Onufrey, 2013). It is driven by self-reinforcing processes that, in the absence of external shocks, lead to an

irreversible state of inflexibility (Vergne and Durand, 2010). In technological path dependency, a path usually leads to a particular technology performance or dominant design.

The main features of path dependency are (Bergek and Onufrey, 2013): persistence and self-reinforcing mechanisms. The drivers of technological trajectories which in the path dependency literature are commonly referred to as self-reinforcing mechanisms, are a key aspect of path dependency (Vergne and Durand, 2010; Dobusch and Schussler, 2013). The main features of path dependency apply in the case of F1 which is a high tech, fast paced cluster within the broad racing sector. There is persistence in the attainment of racing success, securing team resources, developing technology through R&D to its absolute limit. Eventual success is reinforced as winning teams are in a position to acquire more sponsorship money which will enable it to continue developing the car and continue to win in successive seasons.

The record of past success, the patterns of problem-solving activities, and accumulated competencies constrain the activities of F1 teams and the directions where further improvements in performance can be searched for (Nelson and Winter, 1985; Dosi, 1982; Patel and Pavitt, 1997). Inevitably these improvements are likely to be close to areas of existing expertise i.e. in adjacent areas of the solution space (Teece et al., 1997). Given the nature of F1 competition it is obvious that race car performance rests on the engine and the aerodynamics of the car. It is thus possible to speak about multiple paths: engine, aerodynamics and organisational paths that interact (Bergek and Onufrey, 2013).

The existence of multiple paths also implies that they can be linked to each other and evolve together through learning and recombination of knowledge and other elements between paths (Hakansson and Waluszewski, 2002). This is illustrated in how F1 engine design is linked and influences the design of the aerodynamics of the car through its mere size and the requirement for cooling side pods. For example the use of V10 engines by all teams from mid 1990s onwards, lead to a convergence in the design of the engine cooling sidepods of the cars. Engine size also determines the aerodynamics of the rear end of the car. Lotus in designing its revolutionary ground effect car in 1978, was able to take advantage of the more compact Ford V8 while Ferrari faced the space constraints of its flat V12. The subsequent dominance of this combination with Williams in 1980-81 is testament to the suitability of the design.

Technological paths in F1 are an outcome of competition, in which one of the initially available alternatives (ground effect and compact engines) wins and becomes increasingly irreversible over time (David, 1985). Consequently, a state of lock-in is a possible outcome of path dependency in the absence of external shocks (regulation change that banned ground effect in 1983) (Vergne and Durand, 2010). Even though, path dependency constrains F1 designers and engineers, they are still creative and able to influence the course of technological improvement, change the directions of paths or generate new paths (Araujo and Harrison, 2002; Antonelli, 2009; Garud et al., 2010). A good example is McLaren MP4/4 where the arrangement of all the components of the car under the cover was optimised to improve aerodynamics. Given the ban on turbos, engineers looked for diverse technical solutions elsewhere for example by designing semiautomatic gearboxes, introduced by Ferrari in 1989, and active suspensions introduced by Williams, which outclassed competition in 1992 and 1993 seasons. While engineers had a specific way of problem solving, the example of semiautomotive gearboxes and active suspensions show that engineers also had the requisite absorptive capacity (Cohen and Levinthal, 1990) to evaluate alternative trajectories in response to changing demands and opportunities offered by computer technologies (Araujo and Harrison, 2002).

In the early stages of technology development, several potential paths may appear plausible and possible and this has been the case with F1 as well, every time the solution space for engineers has changed substantially subject to regulation change. However, what has happened in the process is that usually one or two paths remain and the rest gradually disappear (David, 1985; Arthur, 1994). A technological lock in then appears as in the case of ground effect in the late 1970s and turbos in the 1980s. This is usually broken in F1 either by the onset of new technological ideas that introduce new technological trajectories, or by regulation change that banned ground effect in 1983 and turbos in 1989 (F1technical, 2014).

The existence of path dependence in the expertise and the record of success, problem solving and dynamic capabilities of F1 teams in responding to relentless competition shows in the overall rankings of wins and pole positions for 1970-2013. Despite the tremendous changes in technology, engines, regulation, the turnover in teams that competed over the years in F1, in other words waves of creative destruction that could render their capability to compete obsolete (Tushman and Anderson, 1986), there is evidence that it is not that easy to disrupt the capacity of established teams to compete throughout 1970-2013 (Figures 19). The same pattern has been analysed in the automotive and gas turbine industries (Bergek et al., 2013).

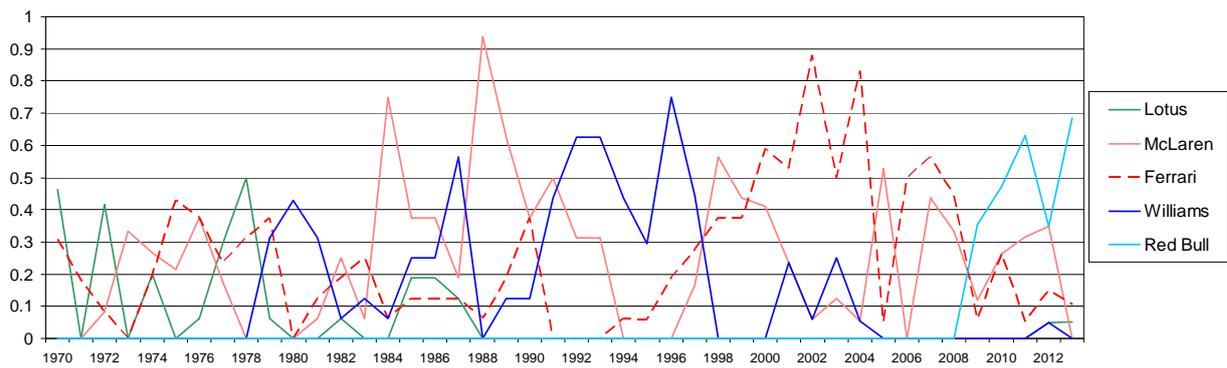


Figure 19 Percentage of team wins per season

Hence a commonly held assumption that usually incumbents in an industry suffer from inertia and core rigidities owing to the technology they use does not apply (Leonard Barton, 1992). The concepts of competence-destroying innovation (Tushman and Anderson, 1986), architectural innovation (Henderson and Clark, 1990) and disruptive innovation (Christensen and Rosenbloom, 1995) are used to describe how the success of incumbents is challenged.

What is a plausible explanation for the domination of just a handful of F1 teams the concept of creative accumulation (Bergek et al., 2013) a process of generating new knowledge which builds on existing knowledge rather than replacing it. Creative accumulation cannot be described as competence-enhancing in the Tushman and Anderson (1986) sense, since it forces incumbents to go beyond their existing knowledge base and search for new competences. In creative accumulation, the existing knowledge base can be seen as a basis for expanding the available choices of firms, rather than a source of inertia (King and Tucci, 2002). To sum up, creative accumulation requires firms to handle a triple challenge of simultaneously (a) fine-tuning and evolving existing technologies at a rapid pace, (b) acquiring and developing new technologies and resources and (c) integrating novel and existing knowledge into superior products and solutions (Bergek et al., 2013). To meet this challenge, they have to engage in technology search and extended experimentation as a basis for building in-house knowledge and absorptive capabilities (Cohen and Levinthal, 1990).

Indeed with the numerous testing that teams subject their cars to they have knowledge of what works and what doesn't within a specific solution space. F1 teams were able to engage in this process of creative accumulation because the entry threshold for F1 has been considerably raised. Most of the dominant teams with the exception of Red Bull were established in the 1970s or even earlier. It is the accumulation aspect that raises the barriers to successful entry for

newcomers. At the same time the process of relentless creativity in taking advantage of regulation loopholes poses a severe risk also for incumbent firms and may lead to their performance demise. For example the coanda effect exhausts in 2012 season were an idea to use engine exhaust to improve aerodynamic downforce of the car. While some teams were successful Williams has suffered a dismal couple of seasons (F1technical, 2013).

The existence of more competing teams than engines means that while engine manufacturers try to accommodate the specific requirements of each team the development of the engine has to follow its own course. Table 1 shows the engine manufacturers that supplied McLaren and Williams, the most successful privately owned teams. A change in the engine supplier implies that teams have to have the required absorptive capacity (Cohen and Levinthal, 1990) to learn about the new engine, adjust the design and aerodynamics of the car to accommodate its dimensions and most importantly see that its power is delivered smoothly, fits driver style and does not lead the car into over steer or under steer. When a new engine agreement is made, it takes more than a year to actually be completely integrated to car development, just like when a new driver gets in a new team needs to learn about all the procedures and specifications relating to the car.

|           |                     | Williams  |                   |
|-----------|---------------------|-----------|-------------------|
|           |                     | 1970-1982 | Ford Cosworth DFV |
| McLaren   |                     | 1983-1987 | Honda RA          |
|           |                     | 1988      | Judd CV           |
| 1970-1982 | Ford Cosworth DFV   | 1989-1999 | Renault RS        |
| 1983-1987 | TAG TTE PO1         | 2000-2005 | BMW               |
| 1988-1992 | Honda RA            | 2006      | Cosworth CA2006   |
| 1993      | Ford HBE 7          | 2007-2009 | Toyota RVX-07     |
| 1994      | Peugeot A6          | 2010-2011 | Cosworth          |
| 1995-2013 | Mercedes FO 110 V10 | 2012-2013 | Renault RS        |

Table 1 Engines that have powered McLaren and Williams 1970-2013 (source: allf1.info)

Drawing on the discussion of the previous sections there are certain concepts at the firm level that are crucial: firm resources, dynamic capabilities, absorptive capacity and the solution space available, that are essential in the success of the team as F1 moves forward at the system level. A qualitative picture of what this involves is shown in Figure 20. This is a two level causal loops diagram. The top part shows F1 as a system where dynamics are driven by innovation. Data presented in the previous sections make the case for innovation raising cost threshold for teams, and raising the reliability and performance levels that teams have to achieve in order to compete successfully and thus raising the cost threshold as well. This has an immediate impact in the



A further more subtle evolution in the nature of competition has taken place during the past four decades. The driver was initially the star of the team, but nowadays it is just a team member that stands in the spotlight much more than anyone else within the team. Team race strategy is a standard component of grand prix, either to secure tactical advantages in the race or even to avoid detrimental competition between the drivers of the same team (Bekker and Lotz, 2009).

Finally, an aspect of team competition is that teams develop the car throughout the season and at some point they have to focus on next year's car and commit some resources to developing both cars. It follows that those teams that have a chance to win the championship have to continue with their present car development to the very end. Teams that are out of the championship race can decide at an earlier stage to focus on developing next season's car. This may put championship contenders at a disadvantage if regulation changes are going to be as far sweeping and radical as the ones for 2014. Based on the causal loop diagram a possible scenario for 2014 is that Red Bull will be less competitive at least in the first half of the season because they pursued dominance in the latter half of the 2013 in order to win the championship. Ferrari and McLaren were not able or did not follow the pace of Red Bull that had a 9 win sweep and thus may be in a better position at least in the first half of the season. Early results from Jerez and Bahrain in 2014 seem to confirm this.

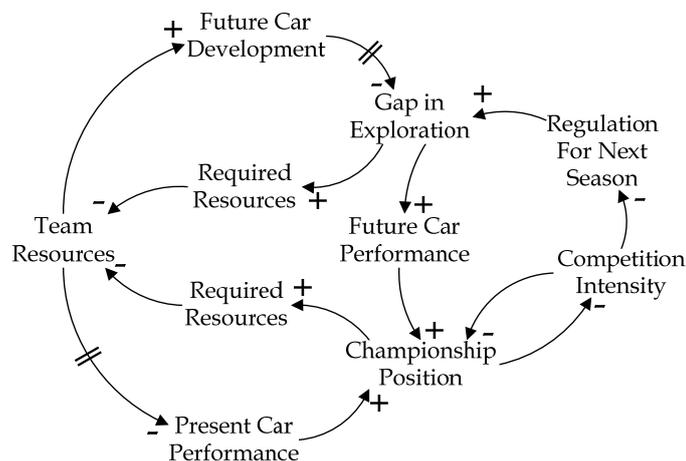


Figure 21 The tension between exploration-exploitation in car development

## 8. Conclusion and Further Research Steps

Formula 1 competition is a fascinating case of technology development and organisational evolution. The 2014 season is highly anticipated as for the first time in several years sweeping regulation changes have taken place whose effect is hard to ascertain other than by following the competition as it unfolds. Thus this paper being work in progress will benefit from information

on how the season evolves, documenting the reaction of teams on problems, reliability issues, successes and failures and seeing whether and how the qualitative picture developed plays out in 2014.

While a comprehensive picture of how competition has developed from 1970 to 2013 has been established through race and qualifying results, this needs to be complemented with an equally comprehensive picture on the evolution of F1 regulation both for engines and cars. This will provide a more complete picture on the way that regulation and events like accidents punctuated the history of the sport, from which to start and understand better the coevolution between technology, car performance and regulation. The work is thus aiming to incorporate the 2014 season results in its analysis and final conclusion.

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