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Innovation and competitive advantage in Formula One: an historical-based framework

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SUMMARY

EXECUTIVE SUMMARY

Formula One (also known as Formula 1 or F1) is the highest class of international racing for open-wheel single-seater formula racing cars. F1 originated in the 1950s and its evolution has been driven by a series of technological, business and regulatory innovations. Physically speaking, Formula One drivers must deal with big G forces and massive fatigue during all the 22 weekends in calendar and some races are extremely challenging. A perfect example of this assumption is the fact that a driver can lose between two to four kilos only by completing a race. Concentrating on the technological side, Formula One is an extremely competitive championship, where teams hire the best engineers with the intention of building the fastest car on the grid and win the drivers' and constructors' championships. Therefore, the innovations in Formula One flow at a very fast pace, with new developments deployed by the teams at almost every Grand Prix. To gain even the smallest competitive advantage, working within the limits of the regulations, engineers are required to use fantasy in huge amount and hope that their solution can represent the new benchmark for the sport. This extremely competitive world, in which rules changes, radical or not, happen every season and new innovations appear continuously, is a perfect playground to understand how innovation works.

This dissertation tries to understand exactly this: how innovation works in Formula One, how it has shaped its competitive landscape in more than 70 years of existence and how it is the basis for the F1 of the future.

In doing so I'm going to go back in time to analyse the most influent innovations in the history of the sport. I will understand how these innovations were born and how they have helped the adopting teams, analysing their effect on the car's performances and on the team's situation in the standings. I'll then use the historical part of the dissertation to build a framework of innovation for Formula One, outlining causes, consequences and vectors of innovation in F1 and using historical data and tools such as S-Curves to understand how the radicalness of an innovation in the Circus is measured.

In the last part of my work I will analyse the new 2022 regulations, with a particular attention to the budget cap rule. In particular, I'll put down the whys and the goals of this rule with a broader charts' analysis. At the end, thanks to the help of some charts, I'll see how the consequences the new rules have caused in the F1 competitive landscape, trying at the same time to understand their causes.

CHAPTER ONE

Introduction

Since I was a kid, I had a passion for racing. Formula One was the championship I started to watch first, and still now it's one of my favourites. I don't clearly remember what the first race I watched live was and when I watched it, but I still remember the first complete season of racing that I followed. It was 2007, and still in my head there's the image of Kimi Raikkonen crossing the line of that year's Brazilian Grand Prix and winning the World Championship. One of the activities of my weekend routine during childhood (and, in some sense, now too) was watching the race after having lunched with my family. When I saw the opportunity of writing a dissertation about Formula One, I didn't look back and I took it. So, the first motivation that has driven me in making this work was passion.

Together with this passion, my other motivation that took me in making this work was the F1 environment, which I consider a perfect playground to understand how innovation works and how outsiders can become industry frontrunners by exploiting new technology. In Formula One, differently from the firms' world, performance is not measured in revenues or indicators (ROE, ROI, ROA…) but in on-track results. This makes the Circus an ideal open-sky laboratory to understand better how technologies come and go without having their evolution influenced by a firm's fate or revenues and how they can influence the performances of the innovative and adoptive firms.

Having said this, the aim of the dissertation is to build a framework of innovation for Formula One to understand what radicalness means in Formula One and how teams gain advantages against their competitors. The framework that will come out from this dissertation will be useful not only to Formula One's or for racing teams, but also in very dynamic and high technology industries, such as the tech ones.

To reach the thesis' aim, I'm going to divide this work in three major parts:

- In the first part, I explore the history of the major innovations in Formula One, describing the competitive landscape at the time, how the team "discovered" and adopted the innovation, the insights on the new technology and the consequences of the newness on the adoptive team's performances and on the competitive landscape;
- The second part will be dedicated to the framework, which I will build using the innovations analysed in the first part. In particular, I will outline causes, consequences and vectors of innovation in Formula One, and I will analyse technological radicalness by using laptimes and typical innovation tools such as S-Curves;
- In the third and last part, I will outline the new 2022 rules, explaining their effects on the competitive landscape. In particular, I will analyse the budget cap rule, trying to understand why it was adopted and what effects will have on innovation and competitive landscape in Formula One.

CHAPTER TWO

A short view back to the past: the story of innovation in Formula One

If we want to build a framework to understand and analyse the innovation in the Formula One championship, we need to first understand its path. What I'm going to do in this chapter is to see and explain the most important innovations in motorsport history, explain the advantages for the firm(s) that adopted them and how they changed the balance of performance in the context they were introduced.

2.1: Pre F1 era

The first proper car competition took place in France in 1894 and consisted in a simple 126 kilometres race through the roads that connected Paris to Rouen[1]. In 1906 the first edition of the Targa Florio, the oldest car race in the world that still exists today as a rallying event[2], was held, and in a closed circuit in Le Mans took place the first ever Grand Prix (GP), which was won by a Renault car. The first cars were very simple: the competitors were big firms such as Renault, Fiat, Mercedes Benz and Peugeot, and the racing cars were usually orthodox adaption of road cars. Therefore, racing was just seen as a mere circus in which the main variable for success was the ability of the driver.

However, this changed when motorsport started to become more and more popular. In this period a winning firm could build itself a better status and consequently experience a sales' growth. For all these reasons, a lot of new manufacturers joined motor racing and building a fast car started to become a very important condition to win races. In this scenario, engineers tried their best to find solutions that made their manufacturer's car more competitive than the others. The main focus was on the engine: at that time, the most common thinking was that a car, to be fast, had to be fast on straight line. Consequently, every manufacturer came up with a different solution, everyone hoping that theirs could become the standard for the racing sector. In this mess, first regulations came out, and started to be a very important variable in the process of innovation. The improvements made on the engines helped defeating the remaining prejudices on the internal combustion engine, which became the new standard for mass production, substituting the steam engine.

World War I, although it stopped all competitions, was very important for the development of innovation in racing, thanks to the contribution of the war industry in the development of materials, fuel, carburation, cooling and component design. Some firms, such as Bugatti and Bentley, which weren't as strong as the major manufacturers of the time, started to use these innovations before everyone else. Some of them, like the first aero designs, failed, but the efforts put in other areas paid interests, as both firms reached reasonable success[3] [4]. In 1922 the first ever regulated serie of race, the *Formula Grand Prix*[5], was created. The regulations for the events, which weren't interconnected between them (they weren't part of the same championship), allowed a minimum weight of 800 kilos and a maximum displacement of 3000 cm^3, and were changed the next year (minimum weight of 650 kilos and displacement of 2000 cm^3). This fast change of rules pushed the engineers in finding a way to improve the erogation of the mix air-petrol into the pistons. The best idea came

[1] https://en.wikipedia.org/wiki/Auto_racing
[2] https://en.wikipedia.org/wiki/Targa_Florio
[3] https://it.wikipedia.org/wiki/Bugatti_Tipo_35,_37_e_39
[4] https://en.wikipedia.org/wiki/Bentley_3_Litre, https://en.wikipedia.org/wiki/Bentley_4%C2%BD_Litre, https://en.wikipedia.org/wiki/Bentley_Speed_Six
[5] https://it.wikipedia.org/wiki/Formula_Grand_Prix

from FIAT, that introduced the forced induction[6]. This innovation became the standard and was immediately copied by all the manufacturers. In 1931 the limits on displacement were cancelled. The *Formula Grand Prix* is considered the “father” of Formula One.

Between the wars motorsport grew rapidly: thanks to its increasing popularity, the first permanent circuits to stage races were built. Engine and chassis were still the main fields of development, but engineers started to look for new areas in which they could find some advantages. In 1922 the regulatory authority, the Commission Sportive Internationale (C.S.I.), banned the carry of the spare wheel in the car during the race. Consequently, the main focus of the tyre companies shifted on tyre wear rates, to find new formulas that can help the compounds last for all the duration of a race. During the 20s also started to appear the first bodyworks with an aero logic, although they were designed to produce less drag resistance, a concept which would be obsolete today.

During the 30s motorsport’s balance of performance shifted from France to Italy and Germany. During its first days, motorsport had a very patriotic component: the focus was not on the driver who eventually won the race, but on the winning manufacturer and its nationality. Cars were even painted with different colours to symbolise their country of origin (red, or *Rosso Corsa*, for the Italian manufacturers, green, or *British Racing Green*, for the English cars, blue, or *Blue de France*, for French firms, and white for Germany are some examples). If a manufacturer won an important race, better if in foreign soil, it was a pride for the firms’ country. The dictatorships in Italy and Germany tried to use motorsport’s popularity and patriotism at their advantage, investing in their country’s manufacturers (Alfa Romeo for Italy, Mercedes and Auto Union for Germany) to obtain remarkable success, gain consensus and boost the automotive industry. As a result, Italy and Germany became important hubs of motorsport innovation, and their manufacturers dominated all the seasons of the European Championship, at that time the major competition for racing cars[7]. The German manufacturers also benefitted from the major rules change of 1934, which for the first time regulated the maximum weight, that was set at 750 kilos. The German firms were capable of building lighter cars, which allowed them to place heavier but more powerful, due to their higher displacement, engines than their competitors. In 1938 Mercedes, with Rudolf Caracciola as driver, even broke the world speed record for cars, reaching the speed of 432.7 kilometres per hour (268.9 mph), a record which remained unbeaten for 79 years.

2.2: The 50s: the first years, the Silver Arrows and the engine position

After World War II the motorsport’s world was very variegated and divided. Its centre, Europe, came out from the war in disastrous conditions. There wasn’t time for racing, as all the great part of European cities had to be rebuilt from scratch. In 1946 the Federation Internationale de l’Automobile (F.I.A.), the newly formed regulatory authority, prepared a new set of rules that regulated the cars for the first post war GPs. These regulations allowed two types of engines: the 1.5 litres supercharged and the 4.5 litres unsupercharged. The first race that was disputed under the new regulations was the Turin Grand Prix, which can be defined as the Formula One’s first race. In 1949 the F.I.A. decided to group seven GPs around the globe into one championship to decide who was the best driver in the world: the Formula One World Championship was born. The first race was held in Silverstone and was won by Italian driver Nino Farina, who at the end of the year became the first Formula One World Champion. For the first eight championships the F1 only awarded the drivers’ title. Since 1958 also the constructors had their own championship. The first title was won by Vanwall, an England based constructor.

[6] https://en.wikipedia.org/wiki/Forced_induction
[7] https://en.wikipedia.org/wiki/AIACR_European_Championship

The Italian manufacturers dominated the first seasons, with Alfa Romeo and Ferrari winning the first four championships. But in 1954 the F.I.A. changed the rules, abandoning the 2.0 litres engines that now were used in Formula Two for the most powerful 2.5 litres engine. Manufacturers that used the less powerful engines, like Alfa Romeo, Lancia and some English teams such as Cooper and Vanwall, tried to find gains in other areas, and came up with some creative solutions. Lancia, for example, instead of fitting their new V8 engine into the car, decided to build it as an integral part of the chassis, a solution that will be reused with success by Colin Chapman's Lotus almost a decade later. But the breakthrough was found by a new entrant.

Mercedes, in fact, saw this rules change as an opportunity and, after a fifteen year break from motorsport, decided to build a car to take part in the 1954 World Championship. The result of their efforts was the W196[8], a very innovative car for the time: it was the first Mercedes' racing car without a supercharged engine, the first machine to have a direct injection fuel system, which derived from the aircraft industry, and had two types of bodywork: the normal one, adopted in normal or slow tracks, which was more conventional, and the *Monza Type* bodywork, which was designed to reach a higher speed and was used in fast circuits like Monza and Reims. Thanks to these innovations, which were a unicum in the F1 grid at the time, the W196 dominated in the seasons 1954 and 1955, although made its debut at the fourth race of the 1954 season, winning nine of the twelve races it took part and going on the podium in ten of them. The car also helped Juan Manuel Fangio winning two of his five world titles. The W196 would have raced also in the 1956 season, but after the Tragedy of Le Mans, in which Mercedes' private driver Pierre Levegh and eighty-three spectators lost their life after Levegh's car flew on the crowd due to a contact with Lance Macklin's Aston Martin, the *three-pointed star*'s manufacturer decided to withdraw from Formula One at the end of 1955 season and made no return in motorsport until 1987.

Formula One was starting to have a greater commercial influence. The sport was becoming more and more popular and there was an increase in the efforts for developing cars, which led to building faster and faster machines. Sadly, the Tragedy of Le Mans, the most tragic incident in the history of motorsport, had bad consequences for the sport: the races were forbidden in Switzerland, and some constructors, such as Mercedes, decided to abandon the sport to protect their reputation. In this situation, the big European manufacturers decided not to fund, or diminished, the activities of their racing teams, except for the manufacturers which were born with the specific purpose of racing (Ferrari, Maserati) and sold cars to directly finance their racing activities. These manufacturers became the frontrunners in the F1 grid. In this mess, the centre of the new F1 world became Great Britain, that started to produce talented drivers (Stirling Moss, Peter Collins, Tony Brooks, Mike Hawthorn…) and in which some passionate people started little racing teams or businesses linked to motorsport. The little English racing teams, differently from the established firms, couldn't produce road cars to make racing more sustainable for them and hadn't the resources to produce highly sophisticated components, such as the engine. So, to save as more money as possible and to be competitive, they had to outsource. In doing this they achieved two advantages: the nominated less costs and the opportunity to utilise components from highly specialized firms that were growing near them. In England the racing district was born, in which businesses and teams created a synergy in which the racing team wasn't the producer of its car but was just the terminal that put together the efforts of the businesses around them. The "Constructors" or "Assembler" (assemblatori), as Enzo Ferrari would sarcastically call them, were born.

As I've said before, the constructors didn't had the prestige and resources to compete with the established firms. The Cooper was one of them. Cooper Car Company was founded in 1946 by Charles Cooper and his son John. The team participated in races valid for the Formula One World Championship from its foundation in 1950 to 1969, except for the 1951 season. Cooper hadn't the resources of the bigger teams, and therefore the results were not very good. However, Cooper also produced cars to race in minor Formulas. One of their

[8] https://en.wikipedia.org/wiki/Mercedes-Benz_W196

Formula Three car had an architectural newness for the time: due to economic and technical reasons, they placed their 500cc motorcycle derived engine in the rear of the car, while all the other cars, including F1's most important teams, had their engine placed in the front. When Charles and his son started to think about the new Cooper T43[9], the car that had to compete in the 1957 Formula One World Championship, they took inspiration from that Formula Three experience and decided to place their 2.2 litres (far less than the 2.5 litres of the Ferrari's engine) Climax engine at the rear of the car. Although the rear engine placement was unicum in the F1 grid at that time, it was not completely new: it was tested by Auto Union and raced in the 30s, while in 1956 Bugatti took part at the Monaco Grand Prix with the T251, the first F1 car to mount its engine behind the driver. This architectural innovation had a lot of benefits: thanks to the less space between the engine and the rear tyres, the transmission shaft was shorter, and consequentially the car was lighter and less long, so easier to manoeuvre. The engine placed at the rear also helped making a bodywork which decreased the drag. The car made its debut at the 1957 Monaco Grand Prix and finished 7th with Jack Brabham at the wheel.

When it first raced, the rear engine car was welcomed with scepticism by the F1 great manufacturers: Enzo Ferrari said: "A cart is supposed to be pulled – not pushed – by the oxen". The drivers too weren't great fans of the innovation, arguing that placing the engine in the rear would eliminate the safety advantages that an engine placed in the front assured.

But the situation changed in 1958. In the Argentinian Grand Prix of that year a Cooper T43 driven by Stirling Moss became the first ever rear engine car to win a Grand Prix valid for the World Championship, leading a whole field of Ferrari and Maserati, all equipped with most powerful engines placed in the front of the car. The car won also the very next race, the Monaco Grand Prix, with Maurice Trintignant at the wheel. The next year Jack Brabham became the first ever driver to win the World Championship with a rear engine car. He did it, of course, with a Cooper T43. The Australian driver repeated himself again the next year with a Cooper, and the English team won the constructor's championship in 1959 and 1960. Rear engine cars became the new standard: Ferrari and the other established firms were forced to change the placement of the engine in their future racing cars. After Brabham clinched the title in 1959 every F1 cars that won the constructor's title or helped its driver winning the driver's title had its engine placed in the rear. Cooper became the first ever not automotive firm (so a "Constructor") to win both the driver's and constructor's championships in Formula One. Although after 1960 they started a decline which led them to withdraw from Formula One at the end of the 1969 season, Cooper changed Formula One forever and paved the way to more constructors in the years that followed.

2.3 The 60s: the cigars and Colin Chapman's Lotus

During the second half of the 50s motorsport suffered a high number of casualties. Many drivers lost their life during GPs due to crashes. Fatal crashes had always been part of motorsport, but after the Tragedy of Le Mans the number of deaths increased, even in Formula One. To stop this trend, at the end of the 1960 season F.I.A. decided to change some regulations in the name of safety, including decreasing the maximum engine displacement at 1.5 litres. Over alimentation was banned, a minimum weight of 450 kilos was introduced and F1 teams were obliged to use fuel with no more than a hundred octanes[10]. As a result, the cars abandoned their big and not aerodynamic shape for a slimmer and shorter one. For this reason, the cars of the 60s are usually remembered as "cigars". The rules were not changed until 1966 season, and during these five years only one fatal crash occurred at the 1961 Italian Grand Prix[11], in which Ferrari's driver and

[9] https://en.wikipedia.org/wiki/Cooper_T43
[10] https://it.wikipedia.org/wiki/Campionato_mondiale_di_Formula_1_1961
[11] https://en.wikipedia.org/wiki/1961_Italian_Grand_Prix

championship contender Wolfgang von Trips and fourteen spectators lost their life. This crash is remembered as the deadliest one in Formula One history.

When the new rules were introduced in 1961, the most prepared team was Ferrari, which had all the facilities to build and develop its car without any external dependency. The constructors, in contrast, depended on multiple suppliers that, although highly specialized, produced standard elements and, since they had many racing teams as their clients, were sometimes late with the developments. For example, after the regulation change of 1961 almost every English constructor stopped developing its own engine and adopted the commercially available Coventry Climax, which had less power than the Ferrari one. Therefore, because all the cars looked almost the same, the teams started looking for advantages in different areas than the engine, making the 60s one of the most fertile decades for racing innovation.

One of the main characters of this decade was Lotus. Founded in 1958 by Colin Chapman, a former driver and RAF member, will be remembered as one of the most innovative F1 firms, thanks to the fantasy of its founder. Chapman's first breakthrough came in 1962 with the Lotus 25[12]. In that time, F1 cars were built with a tubular chassis, around which the bodywork was then developed. Chapman's idea for the Lotus 25 was to introduce the so called monocoque chassis, a concept in which chassis and bodywork where an all-in-one part with the machine. The monocoque was made putting together some sheets of aluminium and had a lot of advantages: the car was lighter (it weighted half as much as its predecessor, the Lotus 21) while at the same time a lot stiffer, and so safer. The monocoque was also cheaper than a classic tubular chassis, so Chapman saved money, which went into the car's development. The Lotus 25 was a huge success: it took part at 42 GPs in its four years of activity, winning 25 of them and helping Jim Clark winning his two titles in 1963 and in 1965, although during the 1965 season was replaced by the new Lotus 33, which was an incremental improvement of its predecessor. The 25, as the Cooper T43 did, marked another important change in the build-up phase of an F1 car, as all the firms now had to build their cars with a monocoque chassis if they wanted to be competitive.

The 1.5 litres cars were starting to become very highly developed, but due to their low displacement, they were considered too easy to drive. In 1966 the F.I.A. decided to double the displacement of the engines from 1.5 to 3.0 litres. The new engines were able, after having reached the peak of the development, to produce more than 500 bhp (brake horsepower), a level that Formula One had never touched before. The higher power meant higher speed, which meant more dangers, which meant more fatal crashes. Also, the new regulations for the engines meant that firms had to switch their production, an action that produced transition costs that were higher for firms which hadn't experience on more powerful engines. Due to the transition costs Coventry Climax, which supplied the engine to almost every English constructor on the grid, decided not to produce a 3.0 litres engine and consequentially withdrew from F1 in 1969, after a failed attempt to build a powerful engine for the Shannon team. The constructors were in a difficult situation and had to decide between abandoning the competition or finding another engine at more costs.

For the 1966 season Chapman signed a contract with English manufacturer BRM, but for the following year he decided to commission an engine for his team. Ford, that at the time was in a fierce fight with Ferrari due to their failed attempt of buying the Maranello based team, funded the project with 100.000 £, and Cosworth was Chapman's choice for the engine's build-up. The result of this joint venture was the Cosworth DFV[13], a V8 3.0 litres engine which was powerful, light (thanks to its architecture), simple and, after some races, reliable. Thanks to these characteristics, the Ford Cosworth DFV easily won the battle of the engines against Repco, BRM, Weslake and Maserati (Ferrari didn't sell their own engine at the time) and became the new standard for the F1. Lotus had the exclusive right to use the engine, but after 1967 they agreed to sell it to other teams too, making the DFV the first choice for constructors and new entrants in F1, also for its cheap

[12] https://en.wikipedia.org/wiki/Lotus_25
[13] https://en.wikipedia.org/wiki/Cosworth_DFV

cost (7.500 £ per engine, which adjusted to the inflation today would correspond to 90.000 £), and the "official" hereditary of the Coventry Climax engine. Thanks to the DFV, Ford re-entered from the investments made in 1967 before the start of the new decade, while Cosworth acquired important economies of scale and experience and Lotus, but also other constructors, gained the on-track's dividends. The Ford Cosworth DFV raced in Formula One continuously from 1967 to 1983, entering in a total of 262 GPs, with a palmares of 155 wins, 12 drivers' championships and 10 constructors' titles, making it the winningest engine of all time.

Chapman's genius didn't stop there: at the end of the decade Lotus was the first team in F1 to build wings on their cars, introducing the concept of downforce in F1. Chapman was probably influenced by the years of service in the RAF after his degree. Downforce is a concept which is the base for Formula One cars of today. The Lotus 49[14] was the first car with aerofoil wings, and during its sporting career, it won two titles in 1968 with Graham Hill and in 1970[15] with Jochen Rindt, although he died during the qualifying session that year's Italian GP. The car that followed its legacy, the Lotus 72[16], was one of the most innovative cars in the history of Formula One. Built with solution new for the time, such as side mounted radiators, which were positioned at the front of the car in that time, inboard brakes and an overhead air intake for the engine (the "airbox"), its shape was designed with the purpose of "cutting the air". Thanks to this approach the car was 20 kilometres per hour faster than the Lotus 49 in straight-line speed, although both cars were mounting the same Cosworth DFV engine. The Lotus 72 went on winning 3 constructor's title and 2 driver's title, entering in 75 GPs and winning 20 of them, becoming one of the winningest F1 cars that ever raced in the category.

2.4 The 70s: the wing, kit and fan cars

If the 60s were a golden age for innovation in Formula One, in the 70s the progresses arrived at their peak. In this decade, and in the first years of the 80s, the number of solutions that were tested and implemented reached a level never touched again. The 70s were dominated by the Ford Cosworth DFV engine, of which I have spoken before. Its power, simplicity, reliability and low cost made the entry barriers in Formula One for anyone very low, as long as they could afford a competitive engine and an old chassis. Therefore, there was the boom of the so called "kit cars". The tyre war between the suppliers was fierce, and in the 70s produced an important innovation: in 1971 Goodyear produced the first set of slick tyres, which had a completely smooth tread. Differently from the grooved tyres, which were the standard at the time, the slicks had more contact with the track, and consequentially more grip. Soon Firestone and Dunlop, the other two F1 suppliers, had to make the switch too. During this decade, Formula One started to become more commercial, continuing a trend that started in the 60s. Sponsors started to have a bigger importance: as long as they were the most important voice of revenues for F1 teams, they had a big power on them. Sponsors could even dictate the colours and the shape of the livery. In this period there were also big improvements in driver's safety, especially pushed by three-time world champion Jackie Stewart, who himself risked his life due to an accident: fireproof suits, integral helmets and safety belts were implemented and revealed themselves crucial in saving the life of Niki Lauda after his crash at the 1976 German Grand Prix, although the number of casualties remained high.

The introduction of aerofoil wings in Formula One and the consequent entrance of the concept of downforce in the championship were an important milestone for the category, but wings had a cost: since they made the car bigger, they were a drag generator. Therefore, more wings means less straight-line speed. All the teams started to look for the payoff between these two characteristics, and some teams came up with some peculiar solutions. The most creative ones were the constructors, that were pushed by the fact that the DFV

[14] https://en.wikipedia.org/wiki/Lotus_49
[15] In the 1970 season, Jochen Rindt raced with the Lotus 49 in three GPs: South Africa, Monaco and Belgium. In his championship winning campaign, Rindt won the Monaco Grand Prix with the 49.
[16] https://en.wikipedia.org/wiki/Lotus_72

was the standard for them and had no space for improvement on the engine. These teams experimented a lot during this period and brought to the track some of the most unorthodox solutions in the history of Formula One. Some of them didn't work as expected, like the Tyrrell P34[17], known as the "six-wheeler". The P34, instead of having two wheels at the front and two at the rear, had two more wheels at the front of the car. The goal of this solution was to have less drag thanks to the lower front of the car and the less space occupied by the two front tyres, which were smaller and covered by the front wing. Consequentially, the car's front was smaller, which helped the car in having a better entrance in turns. Tyrrell's front tyres had a diameter of 10 inches instead of the 13 inches which were the standard at the time. Therefore, a great effort was required to make the little tyres capable of keeping up against the big forces that an F1 car must suffer. Goodyear, interested in using this innovation to gain ground in the tyre war against Firestone and Dunlop, decided to contribute, creating a smaller but stronger tyre, while Koni designed the suspensions. Although a promising start, with podiums, the third place in the constructor's championship of 1976 and even a win at the Sweden GP of that year with Jody Scheckter, with his teammate Patrick Depailler who finished in second position, the car had big overheating problems at the front tyres. In addition, Goodyear decided to abandon the project early, due to the difficulties of creating the type of tyre the P34 needed, leaving the team without any development regarding the wheels. After some desperate upgrades and the creation of a "B" version, the project was abandoned at the end of 1977.

The search for downforce was a must for the F1 teams of the 70s, and Lotus was struggling. After the glorious 72 car won the constructor's title in the 1973 season, for the 1974 season Colin Chapman and his group of engineers revealed the new Lotus 76, which in Chapman's head had to be a breakthrough, but failed miserably, and after just 7 races was substituted with an updated version of the 72, which raced in 1974 and 1975. For 1976 there was the need of a new car, and the result was the Lotus 77[18]. The car had some interesting solutions, such as the suspension system, which was realized to adapt to every track, no matter the height or road surface. The system worked perfectly, but the problem was that, potentially, the suspensions could have been set in infinite ways, and the Lotus' inexperience on this new system often meant that the team did not achieve the ideal setting. Although the system was not used in all its potential, it could be easily seen as the precursor of the active suspensions in Formula One, which I'll explain later. Apart from this, the car lacked steering precision and hadn't a good straight-line speed. Mario Andretti, Lotus' driver at the time, called this car "*a dog*", although he won the 1976 Japanese Grand Prix. Altogether, the 77 wasn't a successful car, and floated in the midfield for most of its racing life. For 1977 Chapman asked his senior engineer, Tony Ruud, to put together a team to build a winning car, starting from a 27-page script that Chapman himself wrote about the studies he made on an airfoil that revealed itself a breakthrough in terms of downforce. The result of Ruud team's work was the Lotus 78[19], a revolutionary car. The 78 was the first F1 car that used the Bernoulli principle that accelerating airflow causes a reduction in pressure. Ruud and Peter Wright, one of the members of Ruud's team, had previously worked together at a similar project in 1970, when they were working for BRM, but a lack of testing facilities, materials and methods and the manufacturer's misfortunes made the project sink. Before starting the project, Wright recovered some material of that BRM experience. The team started testing the solution at the wind tunnel of the Imperial College in London, which had a "moving ground" that enabled detailed study of the aerodynamic effects of a body close to the ground, an innovative feature for the time and ideal for considering the performance of a Formula One car. While testing one of the models, Wright casually had remarkable results. He later discovered that, as the rolling floor's speed increased, the shaped underbody was being drawn closer the ground, producing downforce. So, Wright attached two pieces of cardboard at the model car's lateral sides, and the level of resulted downforce was "phenomenal". He discovered that shaping the underside of the

[17] https://en.wikipedia.org/wiki/Tyrrell_P34
[18] https://en.wikipedia.org/wiki/Lotus_77
[19] https://en.wikipedia.org/wiki/Lotus_78

sidepods as inverted aerofoils created significant underpressure that "sucked" the car down, forcing the tyres harder onto the track, and therefore creating a significant amount of downforce. This phenomenon will be known in Formula One as "ground effect". Ground effect had the big advantage of being a low drag solution, so the improvements in cornering speed had no effect on the straight-line speed that, because of the decreased air resistance, in theory was even higher. After the first tests were done the car had two major problems: the first was a not ideal balancing, that led to the installation of a large rear wing, which created drag. To compensate, Ford provided a more powerful version of the DFV, which would prove unreliable. The second problem was with the lateral wings called "skirts". When he first designed them, Wright decided to use brushes at the base of each skirt, to diminish the level of attrition, but this solution revealed itself insufficient. After some tests with other materials, he then opted for moveable rubber, which resulted very effective. Although the ground effect was very effective, the 78 did not show all its potential, even if it won 7 races, two of them in the 1978 season, and became a laboratory for its successor, the 79[20], an improved version of its predecessor, that dominated the 1978 World Championship. That year's world champion, Mario Andretti, said that the car was able to "paint the road". The Lotus 78 and 79 will be the main character of that time in F1 and opened the era of the so called "wing cars" in F1.

Seeing all the advantages of the ground effect on Lotus, the other teams tried to copy the idea and build their wing car. The Brabham team could not copy Lotus at all because of the size of their V12 Alfa Romeo engine, a lot bigger than the DFV which was the standard among all the other constructors. The engineers had to find another way to close the gap from Lotus, and they took inspiration from the 1970 Chaparral 2J[21]. This car not only had the skirts that inspired Lotus, but also two fans at the rear of the car, driven by an independent two stroke engine, which created downforce by drawing large amounts of air under the chassis. The idea was tested, with negative results, by Tyrrell months earlier, but Gordon Murray, Brabham's head of engineering, decided to attempt. To make the situation trickier, the rules severely forbidden any type of moving device which had an aerodynamic effect on the car but allowed it if its first purpose was different. Murray played on this breach, saying that the fan was for "cooling purpose". The first results were staggering: when the car was fired up in the 1978 Swedish Grand Prix, the downforce was so big the car touched the ground while not moving. The BT46[22], Brabham's car, dominated that Grand Prix, after whom the fan was banned for security reasons, following the protests of the other teams. The era of the fan cars was blocked before it started, but the wing cars continued their existence until 1982. At the end of that year, after years of disputes, they were banned because the G-forces were becoming too high and too dangerous for the drivers.

Among the ground effect another innovation revealed crucial for the next ten years. Renault was one of the pioneers of racing. A state-owned French manufacturer, one of the biggest car producers In Europe, Renault never created a proper racing department. This changed in 1976, when the French manufacturer decided to create a structure with the goal of competing in Formula One the next year. In 1977 Renault participated in its first championship races with the RS01[23], which presented itself with a turbocharged engine, the first Formula One car equipped with that type of power unit. Differently from the normal aspirated engines that all teams used at the time, the Renault power unit was equipped with at least one turbocharger, which used the energy produced by the exhaust gases to force more air into the engine, producing more power. The technology was used with success in the American racing series, in which were introduced in the 1970, and by Renault itself, that with a turbocharged engine arrived second at the Le Mans 24 Hours of 1977 and went on to win the race a year later. Renault wanted to transfer their know how on this technology in Formula One too, but their first year did not go as planned: the RS01 proved cumbersome and overweight and was not competitive. The engine itself was chronically unreliable: the car collected 19 retirements in 26 starts

[20] https://en.wikipedia.org/wiki/Lotus_79
[21] https://en.wikipedia.org/wiki/Chaparral_Cars#2J
[22] https://en.wikipedia.org/wiki/Brabham_BT46
[23] https://en.wikipedia.org/wiki/Renault_RS01

during its racing life, stats which awarded the RS01 the nickname "*The yellow teapot*", because of the smoke that came out from the rear of the car when it blew up, something that happened often in that period. At the end of its racing life the RS01 started to collect the first results, with a fourth place at the 1978 Watkins Glen GP and a pole position at the South African GP a year later. Its successor, the RS10[24], went on to win the 1979 French Grand Prix at Dijon, becoming the first turbocharged engine to win an F1 Grand Prix. That race proved the effectiveness of the turbo engines and, after the reliability problems were solved, the turbo overcame the naturally aspirated engines in performance, effectively marking the end of the Ford Cosworth DFV era, which won its last race in 1983 at Detroit with Michele Alboreto.

2.5 The 80s: The turbo era

The 80s are remembered as the years of the turbo era. As I said earlier, this type of engine was introduced in Formula One in 1977 by Renault and during the first years they proved hugely unreliable. However, after some years of development, Renault started to have results and more teams moved from normally aspirated engines to turbo engines. The main reason of these moves was in the massive power that turbo engines had: during the decade these power units arrived to produce 1000 bhp and in some circumstances (qualifying laps) the power could reach 1200 bhp, a level never again reached in Formula One and two times higher than the power of the normally aspirated Cosworth DFV, which explains why the turbo engines ended the era of the DFV, that year by year started to become obsolete and, after winning its last championship in 1982 and its last Grand Prix a year later, was never again used by the established teams. Due to their massive power, the turbo engines also created a big concern inside the F.I.A., which worried about the driver's safety. During the decade, the governing body tried to put a limit on the development of the turbos with rules that restricted the freedom of the teams. But, since the constructors had found solutions to maintain the power high, the F.I.A. decided to ban the turbo engines at the end of 1988 season, which was dominated by the McLaren MP4/4 pushed by a Honda turbo engine, a car that won 15 out of the 16 races in the 1988 calendar.

Speaking of McLaren, the team was founded in 1963 by Bruce McLaren, a New Zealand driver, and made its debut in Formula One in 1966. During the 70s the Woking-based team won its first constructors' title in 1974 and helped Emerson Fittipaldi that same year and James Hunt in 1976 clinching the drivers' title. However, after 1976 Mclaren started to decline and lost positions in the roster, finishing the 1980 season in ninth place, still now their worst performance in the World Championship. In that year Ron Dennis, a racing entrepreneur, merged his Formula 2 team, the Project Four, with the team McLaren, creating the McLaren Racing. When started to look for an engineer, he decided to pick John Barnard, that during his career had previously worked with McLaren: in 1972 he designed, with Gordon Coppuck, the McLaren M23[25], the car that won the 1974 constructors' title and that helped Fittipaldi and Hunt in their respective winning championship campaigns. At the time of his return to Woking, Barnard had created himself a reputation in USA, working with Chaparral and designing for them the Chaparral 2K, the first Indycar machine which used ground effect. This means that, when he came back at McLaren, Barnard was known as a "revolutionary designer". When started to design the new car, Barnard identified carbon fibre as the material with which building the monocoque. At the time, all the F1 cars on the grid had monocoque built in aluminium, a trend started in 1962, when the monocoque became the standard for F1 chassis, and the designers used carbon fibre as a reinforcement for weak parts of the car. The material, due to its resistance and lightness, was used intensively in the aerospace industry to build spaceships or airplanes. Barnard had also another reason to use carbon fibre: in his intentions the car's chassis had to be as close as possible to the track to optimize ground effect, but this would have made the aluminium flex too much, so he needed a stiffer material. The problem at the time was that he couldn't find any firm in the UK capable and willing to build such chassis because of its complexity.

[24] https://en.wikipedia.org/wiki/Renault_RS10
[25] https://en.wikipedia.org/wiki/McLaren_M23

Barnard later used one of his contacts in America that helped him in reaching a firm willing to build the monocoque. The McLaren MP4/1[26], this is the name of the car, became the first ever F1 car whose monocoque was built entirely in carbon fibre, although the Lotus 88, which later was banned, was presented earlier. In 1981 (it would later race in 1982 and 1983 too) the car, driven by John Watson, won the British Grand Prix, the first win for McLaren since the 1977 season, proving the good level of performance reached by the English team thanks to the new material. Later in the season, at the Italian Grand Prix, Watson had a massive crash in which the car split in half, but thanks to the chassis' stiffness the driver came out from the accident completely unharmed, proving the level of safety reached by the car. The material proved so effective that the McLaren example was soon copied, and now the carbon fibre is used as the main material in building racing cars' chassis. Carbon fibre had an important role also in the field of drivers' security: since its introduction in the racing world in 1981, only four drivers have lost their life in Formula One cars built with a carbon fibre chassis, thanks also to the help of the "survival cell", which was introduced in 1982. The MP4/1, although the carbon fibre's effectiveness, never won a World Championship, but its successor, the MP4/2[27], a John Barnard's creation too, which raced from 1984 to 1986, won all the drivers' titles of the seasons it took part, together with two constructors' titles, also thanks to the switch from the Cosworth DFV to the more powerful Porsche turbo engine.

The carbon fibre was not the only Barnard's breakthrough of the decade. In 1987 he left McLaren to join Ferrari, where he started to work on the 1989 project. That year's project was quite important for Ferrari: 1988 was in fact the last year in which the turbo engines were allowed, since the next year F.I.A. only allowed normally aspirated engines, and Ferrari started to work early on the project in order to have more time to develop it. Barnard was one of the first engineers to understand the importance of slimmer cars in the new era. The major problem Barnard faced in designing the new F1 car was with the gearbox. At the time, in fact, the drivers had to change gears manually with a gearstick, a system still used in today's commercial cars. In particular, the gearstick's presence caused the monocoque to be less aerodynamic efficient, a problem which Barnard had to face a lot of times in his career. That time, he decided to find a way to completely remove the gearstick. The English designer thought about designing a hydraulic gear change system which could be operated by pushing a button on the wheel. He then decided to use two paddles at the rear of the steering wheel instead of the buttons on it. The system was the semiautomatic gearbox, and had many advantages: first, the driver had full control of the car and hadn't to move his right hand to use the gearstick. The system also did not allow the driver to accidentally downshift during a straight and did not allow a downshift if the engine revs were too high, effectively reducing the damages on the engine. It also didn't use the gearstick, allowing Barnard to create a more aerodynamic monocoque. Although the advantages of the semiautomatic gearbox were big, Barnard had to fight with Ferrari's internal politics to get the system adopted. At the time, the former McLaren engineer was not working in Maranello, Ferrari's headquarter, but from his hometown in the United Kingdom. This allowed some rebels, such as Harvey Postlethwhite and Jean-Claude Migeot, to work on a parallel project which had a higher nose and a manual gearbox. When Barnard's system proved to be the best one, the rebels were sent to other teams and the semiautomatic gearbox was the chosen design by Ferrari for the 1989 season. In that season the Ferraris suffered an important lack in reliability (Gerhard Berger only finished three out of sixteen races that year), but when it crossed the finish line the 640[28], this is the name of the car, arrived always in the first three positions. The system was soon copied by all the teams, and for this became the new standard in F1, substituting the manual gearbox. It is still used in today's F1 cars.

[26] https://en.wikipedia.org/wiki/McLaren_MP4/1
[27] https://it.wikipedia.org/wiki/McLaren_MP4/2
[28] https://en.wikipedia.org/wiki/Ferrari_640

2.6 The 90s: The electronics

The 90s are remembered as the electronic era. In this decade F1 teams adopted solutions such as semiautomatic gearbox, traction control, anti-braking system and active suspensions, innovations that would later appear also in the common cars. These solutions were effectively driver's aids, and consequently the ability required to drive an F1 car diminished. For this reason, the F.I.A. decided to ban all the electronic aids, apart from the semiautomatic gearbox, at the end of the 1993 season. In 1994 the deaths of Roland Ratzenberger and Ayrton Senna at the San Marino Grand Prix of that year posed the attention on the driver's safety. On this side, the F.I.A. imposed stiffer chassis and more severe crash test and tried to slow down the average speed of the cars imposing simpler car and forbidding the slick tyres. During this decade the technological advances caused a sudden and important rise of costs. Therefore, historic constructors such as Tyrrell, Lotus and Jordan had to withdraw from Formula One in this decade or in the next because couldn't keep up with the developments and the costs. Altogether, because of the rising costs, the field passed from nineteen teams in the 1990 season to eleven in the year 1999.

One of the most famous driver's aids of the decade was the active suspensions. This system was not new in Formula One: as I said earlier, in 1976 Lotus had tried a system of suspensions for their 77 car which enabled that part of the car to have possibly infinite settings. The system was manual and was not used in all its potential because a lack of experience often caused the car not to have the ideal setting. In 1981 F1 cars, due to the development on the wing car, reached a high level of downforce, which caused the car to bounce hard at high speeds, a phenomenon called *porpoising.* To solve the problem, Lotus' engineer Peter Wright, which was involved in the development of the 77, came up with a computer controlled hydraulic suspension system, which was so effective it could maintain the car at the right height during the entire lap at a given track. This system, which was effectively the first example of active suspensions in Formula One, was approved by Colin Chapman, but soon after he died in mysterious circumstances. The project was then abandoned, but Lotus retook the project in 1987 with the Lotus 100, which revealed itself a competitive car, especially in slow and bumpy circuits like Detroit and Monaco, where the car won its only two races that year. In that season, the Williams had started to develop its active suspensions system too and used it during the Italian GP of that season, which Nelson Piquet won followed by Ayrton Senna's Lotus. Although the system's great results, both teams dropped the technology once again, but in 1992 Williams introduced a more developed and sophisticated version of the system in the F14B[29] that, together with the addition of electronic systems such as traction control, ABS and semiautomatic gearbox, allowed the team to dominate the 1992 and 1993 season, installing a technical superiority which would last until 1997. The FW14B became known as the *"car coming from another planet"*, and the videos in which the car modifies its height while stopped in the box are still viral today. The electronic aids, and so active suspensions too, were forbidden at the end of 1993, putting an end to the Williams domination, although there are suspects that Benetton was still using them in Michael Schumacher's Benetton 194. The German driver won his first title that season.

After Senna's and Ratzenberger's deaths at Imola in 1994, as I said earlier, the F.I.A. decided to introduce rules that improved drivers' safety. In 1998 took place the most radical regulation change of that decade: slick tyres were banned in favour of grooved tyres, the overall width of the cars was slashed by 12%, the brakes were simplified, the minimum dimension of the survival cell was increased and the headrest's side increased. These rules had the goal to guarantee drivers' safety by slowing the cars down in the corners. The engineers immediately started to look for ways to regain cornering speed. The solutions were various, but one case was severely covered by the media. The McLaren MP4/13[30] was the Woking's team challenger for the 1998 season, winning both constructors' and drivers' titles. The British constructor had started to develop a particular braking system the previous year, which presented itself as a two-pedal system, one for front and one for rear brakes. The rear ones were used inside corners by the drivers to control oversteer, effectively

[29] https://en.wikipedia.org/wiki/Williams_FW14
[30] https://en.wikipedia.org/wiki/McLaren_MP4/13

functioning as a manual traction control. The system was discovered by accident: Darren Heat, a racing magazine photographer, noted in a photo he took at the 1997 Austrian GP that a rear brakes disc was glowing in a corner's point where the car should accelerate. Surprised, he theorized the existence of an extra pedal for rear brakes. At the next Grand Prix at the Nürburgring he exploited both McLaren's retirements to take a photo of the cockpit's pedals section, discovering the extra pedal. McLaren used a more sophisticated system at the start of the 1998 season, lapping the whole field at the first Grand Prix of the year in Australia. Although it was a manual system, and therefore legal, the opponents lobbied together and protested with the F.I.A., a pression which resulted in the ban of the system for the rest of the 1998 season.

2.7 The New Millennium

In 1995 the F.I.A. allowed a maximum displacement for F1 engines at 3.0 litres. After this rule change the field, which at the time used engines with 8, 10 or 12 cylinders, converged to the solution of 10 cylinders-V disposed. The team which gained more advantages from this rule change was Ferrari, which from 1999 to 2004 won six constructors' championships and five drivers' championship with Michael Schumacher, installing a domination which would be replicated by Mercedes a decade and a half later. During this six-years' time a lot of teams tried to reach Ferrari performances. One of the most active teams was Renault. The French manufacturer came back in Formula One as a team in 2002, after a seventeen-years pause, during which worked as engine supplier for many teams including Williams, that won all its 90's titles with a Renault engine. Renault proved itself as one of the most innovative and creative teams in Formula One, a characteristic which, after a major regulation change in 2005, led them to be the frontrunner: in 2005 Renault broke the Ferrari domination winning both the constructors' and the drivers' titles with Fernando Alonso, at the time the youngest ever world champion in F1's history. For the last three GPs of the 2005 season Renault equipped R25 with a mass damper[31]. This element had a weight between nine and fifteen kilos and was fixed with a spring inside the nose. The mass damper was useful to stabilize the car during a passage on a kerb or on a bumpy part of the track, allowing the car to maintain stable the aerodynamic flow and therefore making it more driveable. The mass damper gave Renault an advantage of three tenths of a second per lap on average, which is a lot for a simple element. The R26, Renault's 2006 car, was equipped with the mass damper too, but after some races the F.I.A. ruled it illegal, after it was considered a moveable aerodynamic element. The mass damper's ban did not deprive Renault and Alonso of their second consecutive titles, which were won after a fierce fight with Ferrari and Michael Schumacher respectively.

In 2009 Formula One adopted a big regulation change. F1 cars had become, aerodynamically speaking, very complex. This led to very sensitive machines, which could lose a lot of downforce if not put in the ideal conditions. Also, to maintain competitivity the teams started to spend more and more money, arriving at a point that maintaining an F1 team was not economically sustainable anymore. The 2008 economic crisis did not help, leading Honda, Toyota and BMW to withdraw from Formula One in the next two years. So, the goal of the F.I.A. with these new rules was to have closer races, reaching at the same time an economic stability for the teams. Specifically, there was the return to the slick tyres, a reduction of aerodynamic appendixes and, most importantly, the possibility of using a new system called KERS (Kinetic Energy Recovery System). The KERS had to recover energy from the brakes' heat to redeploy it during a lap. The KERS energy allowed an extra 80 bhp for 6,6 seconds for every lap. A budget cap was also on the table, but after the teams threatened the F.I.A. to form an independent championship the idea was abandoned. The KERS was adopted by Ferrari and McLaren, the two established teams at the time, but was completely snubbed by some teams, including Brawn GP.

31 https://en.wikipedia.org/wiki/Tuned_mass_damper

Brawn GP was a F1 team founded by former Ferrari's technical director Ross Brawn. After leaving the Scuderia at the end of 2006 he came back in 2008 as Honda technical director, after a sabbatical year. His main goal was to build a fast car for 2009, but the economic crisis made the Japanese manufacturer withdraw from Formula One at the end of the 2008 season. The team, including all the infrastructures and the 2009 car's projects, was sold for one pound to Brawn, who renominated it Brawn GP. Brawn was extremely optimistic about the 2009 he prepared for Honda. First, he decided not to use the KERS because it weighted too much and concentrated all the economic and physical efforts on the aerodynamic of the car. Brawn designed a double diffuser to regain the downforce lost due to the rules change, which increased the airflow speed at the bottom of the car, therefore creating more downforce. After the first tests it became clear that Brawn had found a silver bullet for its car, and the established teams protested with the F.I.A., that decided for the regularity of the project. The BGP 001[32], this is the car's name, dominated the first part of the 2009 championship and, after a second part of the season in which a lack of liquidity caused a lack of development, clinched both constructors' and the drivers' title with English driver Jenson Button, creating the most recent fairy tale in the history of Formula One. In 2010 Brawn GP was acquired by Mercedes, that came back in F1 as a team after fifty-five years and whose story I'll tell later.

The KERS proved itself heavy and difficult to collocate but, although was not the right solution at the start of the 2009 season, it proved crucial later: at the Hungarian Grand Prix, in July, Lewis Hamilton's McLaren became the first car equipped with the system to win a Grand Prix, and the system proved crucial when Kimi Raikkonen's Ferrari used it to pass Giancarlo Fisichella's Force India, which wasn't equipped with the system, and won the Belgian Grand Prix. The KERS also paved the way to the adoption of hybrid power units in 2014, a year which saw the start of the dominance of the Mercedes F1 Team.

2.8 The Hybrid Era

The first part of the second decade of the third millennium was dominated by the Red Bull Racing team. The firm, as an energy drink company, was founded in 1984 by Austrian manager Dietrich Mateschitz after a working trip he made in Thailand, when a particular beverage helped him to get rid of the jet lag. After the reasonable success of the energy drink, he decided to unite the firm with his passion for sport by starting to sponsor athletes, including F1 drivers like Gerhard Berger. In 2005 Red Bull acquired the Jaguar Team, changing the name in Red Bull Racing and entering for the first time in F1 as a constructor. The very next year they bought the historical Minardi Team, now renamed Toro Rosso ("Red Bull" in Italian), to give a chance to the young prospects of the Red Bull's drivers academy, the first F1 team to build a structure of this kind. After struggling during the first years, in 2009, thanks to the new regulations, Red Bull became a serious title contender, and in 2010 they won their first constructors' title together with the drivers' title won by Sebastian Vettel, the youngest World Champion ever and a Red Bull's academy alumnus. Vettel was also the first driver to win a race with a Red Bull branded team, reaching the milestone at the 2008 Italian Grand Prix with Toro Rosso. The Vettel-Red Bull duo went on to dominate the years from 2010 and 2013, winning all the championships in that years in a style that remembered the Ferrari-Schumacher duo of the first 2000s.

In 2014, to meet the automotive market's demand for more sustainable engines, F1 realized, at the time, the biggest and most radical technical regulations change in its history. The engines were revolutionised: instead of the obsolete V8 normally aspirated engines, the F.I.A. adopted the V6 hybrid turbocharged power units with a displacement of 1.6 litres. These new very complex power units are composed of six elements:

- The internal combustion engine (ICE), which is a normal V6 aspirated engine;

[32] https://en.wikipedia.org/wiki/Brawn_BGP_001

- A turbocharger (TC), which collect the waste gases, mix them with the air taken by the compressor and pump this mix into the engine and, to give a “boost” of power, or to produce energy, which will then be collected by the MGU-H;
- The MGU-H, that collect engine from the turbo to give it to the energy store, the MGU-K or to redeploy it back to the turbo;
- The MGU-K, the KERS’ hereditary. This component, like the MGU-H, works in both ways: it takes energy from the braking and give it to the energy store and can use the energy from the storage to deploy it to the engine, generating a power boost;
- The energy store (ES), which simply store the energy collected by MGU-H and MGU-K;
- The control electronics (CE), which controls the power exchanges between ES, MGU-H and MGU-K.

The new regulations were approved in 2011, giving the team time do develop new solutions for the engine. As I said before, Mercedes re-entered in Formula One as a constructor in 2010 buying Brawn GP and rebranding it as Mercedes GP. The team, which now had Nico Rosberg and Michael Schumacher as drivers, thought that the success reached by Brawn GP the year before was enough to keep them as the frontrunners for the 2010 season. However, the Mercedes team struggled a lot during the first two years of its existence and decided, after the new regulations were announced, to focus massively on the new regulations, although continuing improving their performances during the years 2012 and 2013. A lot of efforts were put on the engine. In 2010, when the regulations had still to be defined, Mercedes produced an in-line four cylinders engine, but had to discard the idea because of the F.I.A.’s decision to adopt a V6 turbo-hybrid engine. After years in the making, Mercedes came up with an engine that was different from its competitors. One architectural solution was the split turbo, an unicum in the F1 grid. The system consisted in the splitting of the turbo and the compressor, which were positioned in different places of the engine. This little innovation was one of the keys that helped Mercedes to dominate the last eight championships, together with a culture that allowed them to find innovative solutions, such as the DAS system in 2020, while still be the frontrunners in the F1 grid. This was also the reason why the Mercedes domination was only scratched after a regulation change in 2017, which only allowed the competitors to near themselves to the Silver Arrows.

CHAPTER THREE

The framework

After understanding the path of innovation in Formula One, it’s time to use it to build a framework that explains how teams, manufacturers and constructors innovate and build a competitive advantage over their opponents.

3.1 What is innovation

Before starting to talk about innovations in Formula One it’s important to understand what innovation is and how can be classified.

Innovation can be defined as the implementation of a newness or a significant improvement regarding a product, a process or a marketing campaign, to make some examples. Schumpeter would later add to this definition the commercialization of the newness to better differentiate innovation from invention.

Innovation can be classified in many ways:

- Direction of newness, which measures how much the innovation changes the users’ habits. In this sense we speak about *continuous innovation,* if the users’ habits are not haltered much or at all by the innovation, or *discontinuous innovation,* if the innovation has an important footprint on the users’ habits;
- An innovation could be also classified as a *component innovation,* if it does not change the overall design of the product, or as an *architectural innovation,* which modifies the product shape as a whole;
- Innovation can also be classified by its magnitude. The magnitude of an innovation indicates its difference from the established technologies. Therefore, an innovation would be *incremental* if involves only small improvements and does not differ a lot from the previous technology. On the other hand, an innovation is *radical* if the technology introduced is completely new not only to the firm itself, but to the world;
- The magnitude of the innovation directly takes us into talking about the effects of the innovation on the existent competences. An innovation is *competence enhancing* if it’s built on the pre-existent set of competences and knowledges. Vice versa, a *competence destroying* innovation makes the pre-existent know how obsolete and requires new skills and methods to be assessed and managed. Usually, the concept of competence enhancing innovation is linked with the incremental innovation, while a radical innovation is often a competence destroying one.

3.2 Innovation in Formula One

Starting from what I’ve said before, we can start to understand what innovation means in Formula One and explain its causes and consequences.

First, we must understand what innovation means in Formula One. Although some newness, such as the monocoque and the electronics’ aids, were implemented in road cars too, and so were commercialized, the innovation’s definition I’ve wrote in the previous paragraph it’s not completely fit for F1. To understand what innovation means for a racing team, we must compare them to normal firms. The goal for a firm is to become competitive in their core market, therefore increasing their revenues that will be later invested in the firm’s activities or used to pay salaries or compensate the shareholders. To reach this goal, firms have to innovate and diversify in one of the four Ps (price, product, placement, promotion, which become five if we add packaging) to build a competitive advantage over their competitors. So, the Schumpeter’s definition is correct if we speak about normal firms.

For F1 teams, though, it's a bit different. The goal for an F1 team is to win races and championships, and to do this they have to build a fast car. Specifically, a car is fast when it can complete a lap in a closed circuit in the least possible time. This definition, although it's absolutely true, does not fit completely in the rules of the championship, because in F1 teams gain points valid for the championship based on their final position during a race, which has a defined number of laps. Therefore, innovation in Formula One can be defined as any type of improvement which allows the car to cover the race distance in a closed circuit in a lower time than it could have done without the innovation. That's why an improvement in one area of performance (grip, drag, acceleration, braking…) it's not an innovation until it gives time advantages to the team that has adopted it. For example, an improvement in straight line speed, if not helped by a better braking, can make the car go slower in a timed lap, therefore making the improvement useless. If the team will reach an improvement in braking too or in another area that helps the car go faster, then the improvement can be called innovation. In the experiments I will do later in this document I will use the pole times as a reference, in order to obtain more realistic and simpler results.

Having understood this, we need to classify the F1 innovations. To do so, I will borrow the classifications done prior in this chapter. In particular, the distinction between incremental and radical seems to fit better our purpose, because it describes better than any other classification how innovation works in F1, although we can also use the other classifications: for example, Cooper brought an architectural innovation when the T43, the first car whose engine was placed in the rear, was unveiled, and so did the Tyrrell team when the P34, the "six-wheeler", was presented.

Using the magnitude of innovation as a reference, we have to adapt the framework we used before to describe innovation in general:

- As I've said before, an incremental innovation regards only small improvements and does not revolutionise a car in its overall. In Formula One, incremental innovations could be a new front wing, a better shaped bodywork or anything that can make the car faster. Today, teams introduce incremental improvements on their cars almost every weekend, with the purpose to improve the performance of their cars or, simpler, to adapt them to a particular circuit;
- Radical innovations are, instead, changes that revolutionise the balance of power in Formula One. These changes have therefore an important improvement in performances and give the team who "invented" o first adopted the improvements a significant advantage over its opponents.

This dissertation will focus on radical innovations, since these types of innovations offer a better example of how innovation work in Formula One and help more in the construction of the framework.

After having classified the innovations in Formula One, the next step is to understand how to measure the radicalness of an innovation in Formula One. As I've said before, an F1 innovation could be described as any type of improvement which helps the car to spend less time to complete a race distance, so the only way to measure the effective radicalness of an F1 innovation is to watch the chronometer. Every innovation will take, therefore, an improvement in laptimes for the innovative team and, after copying it, the whole field. But how big has this improvement to be to acknowledge a radical innovation from an incremental? To understand it better I will use as a reference the pole laps' evolution of the GPs held at the Autodromo Enzo e Dino Ferrari of Imola between 1980 and 2006.

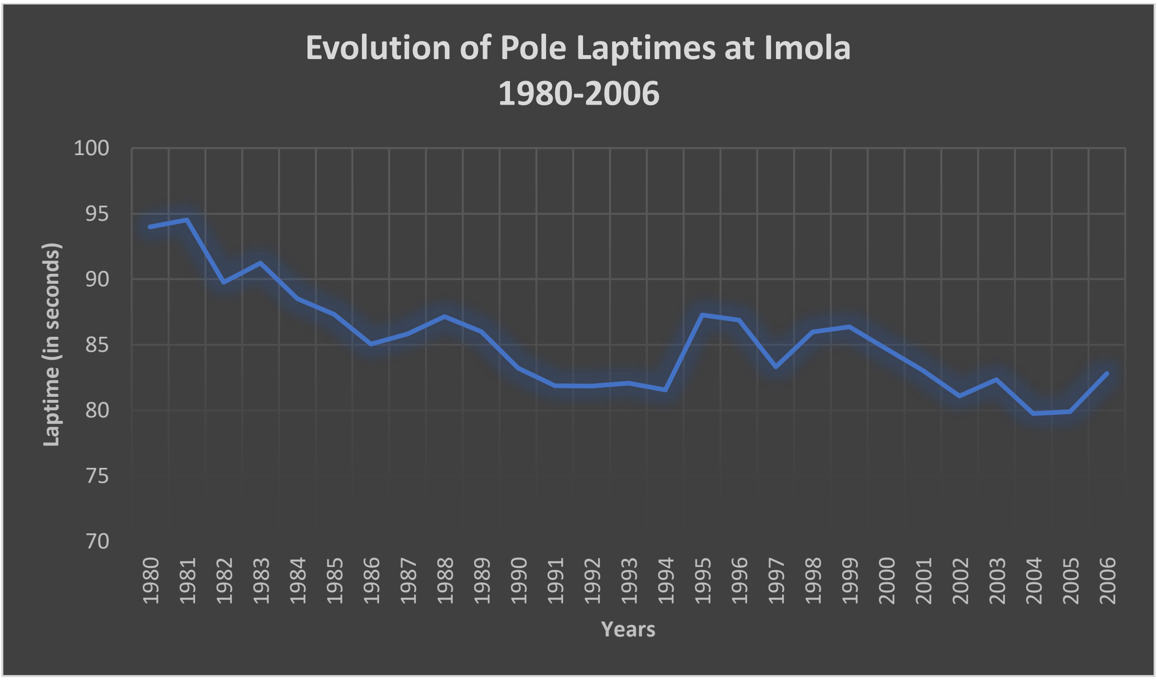

CHART ONE. Data source: [STATSF1]

In this chart we can see how the laptimes around the Santerno's circuit have evolved. In 2005 the qualifying time was composed of the sum of two flying laps so, to make the chart as realistic as possible, I've considered the fastest one of the poleman's two laps as the pole time. A lower point on the chart correspond to a faster time. As we can see, the era in which the laptimes go down faster than in any other era is the period from 1980 and 1989, as you can see also by the charts that follow.

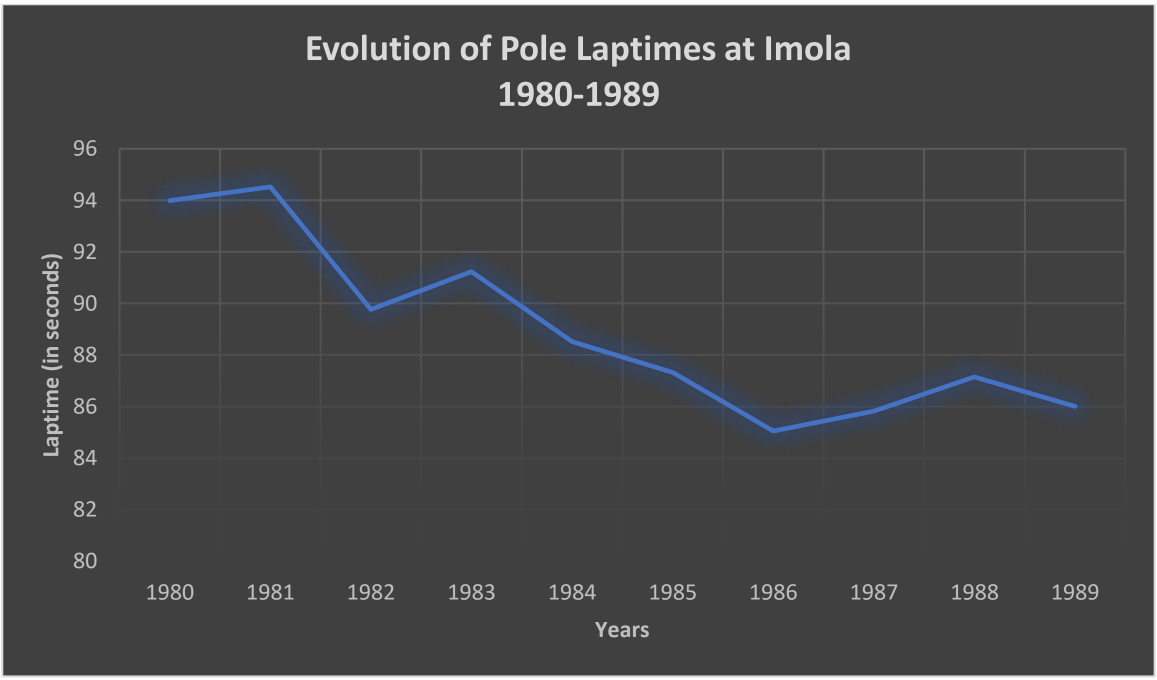

CHART TWO. Data source: [STATSF1]

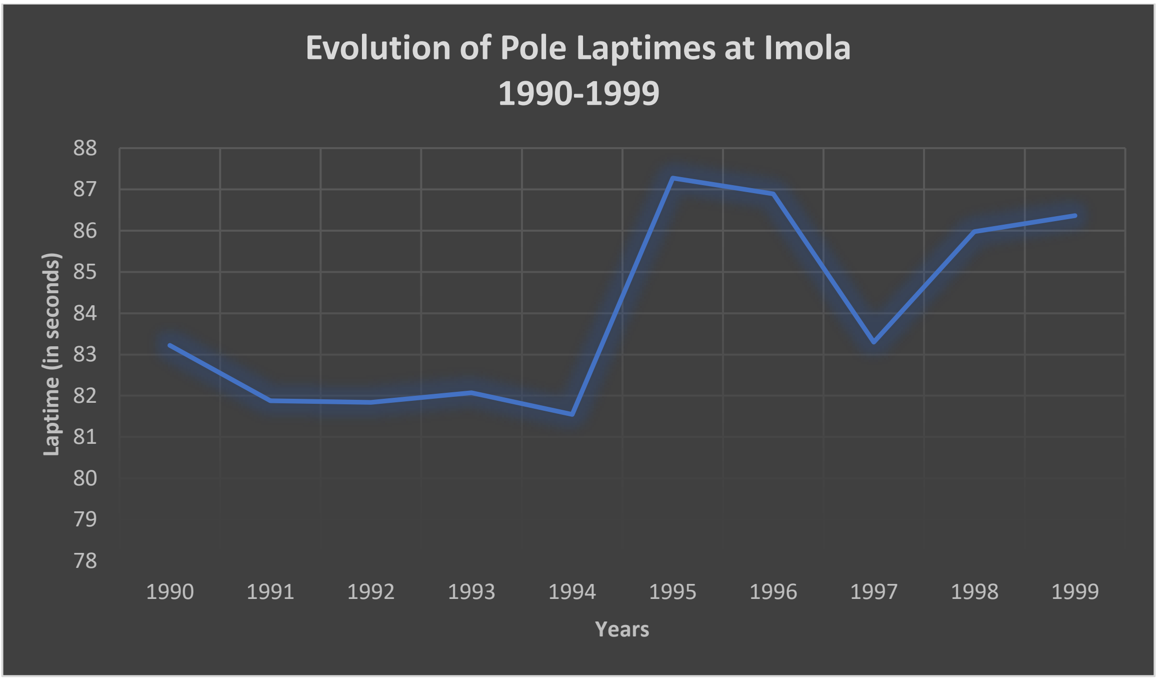

CHART THREE. Data source: [STATSF1]

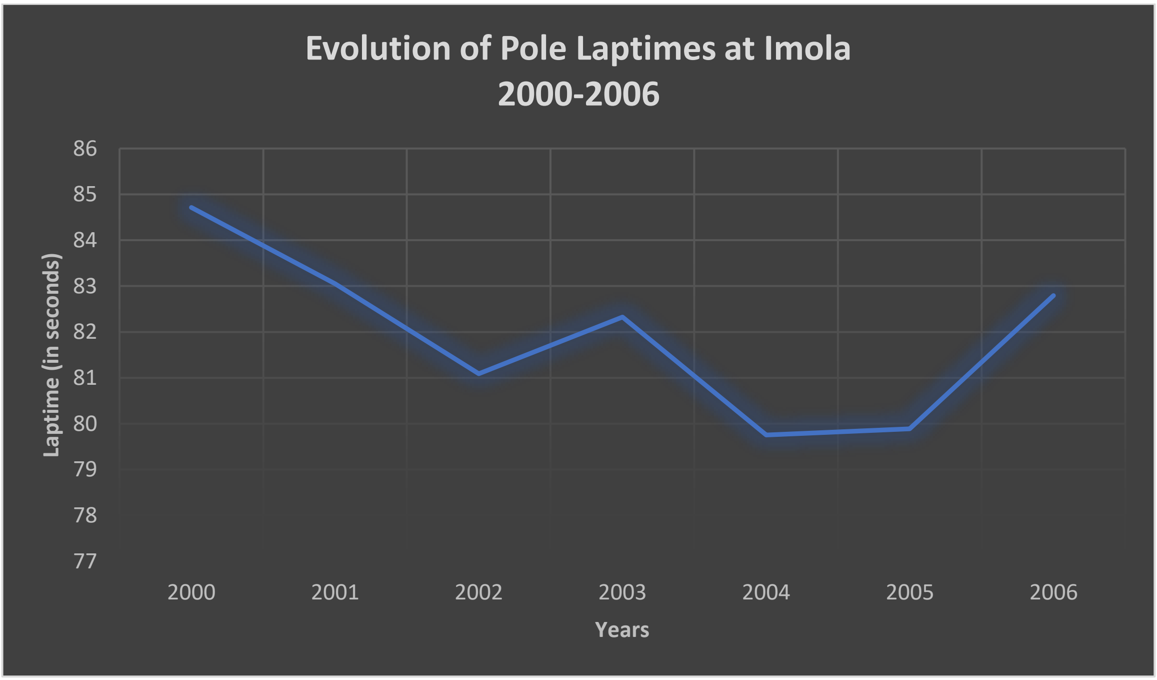

CHART FOUR. Data source: [STATSF1]

The reasons of this inequality between the charts are various. As I've said in the first chapter, the 80s are remembered as the turbo era, a period in which turbo engines could touch 1200 bhp, a power never more reached by F1. As soon as the turbos' reliability was improved, the performance started to peak. The results in qualifying were also influenced by the fact that in these sessions the engine was pushed to the limit, and only in these occasions could reach the power I mentioned earlier. In that decade another important innovation was the carbon fibre monocoque, which gave a large contribution in designing lighter and stiffer cars that could control the turbo's power. For this reason, carbon fibre must be considered a radical innovation too. The only three seasons in the 80s in which the pole time was slower than the season prior's one were 1983, 1987 and 1988, but these exceptions can be explained: in 1983 the F.I.A. banned the skirts, effectively eliminating the ground effect, an important downforce source, while in 1987 and 1988 the teams gradually abandoned the development of the turbo engines to concentrate their effort on the normally aspirated engines which became mandatory from the 1989 season. At the start of the new millennium there weren't particularly important innovations, but the 90s' chart does not explain very well the situation in that decade. The laptimes are severely influenced by Ayrton Senna's and Roland Ratzenberger's deaths at Imola in 1994, which led to a massive rule change[33] that had the goal of reducing racing speed for the following year. An equally big regulation change was put in place for the 1998 season, where we can see the second spike. Although it can't seem from the chart, the 90s were the era of the electronics and the active suspension, which are considered one of the most radical innovations in F1 history. So why we can't see a very strong peak in performance in these years? The answers are two: the first is that active suspensions were banned two years after their effectiveness was proven in F1, and so teams did not have a lot of interest in developing such technology. The second is that they were used only by one team, Williams, which dominated the years 1992 and 1993, the last ones before driving aids were banned. So, how do we measure the radicalness of an innovation adopted only by one team? By understanding how much advantage the team gained from the innovation.

[33] https://www.f1technical.net/articles/62

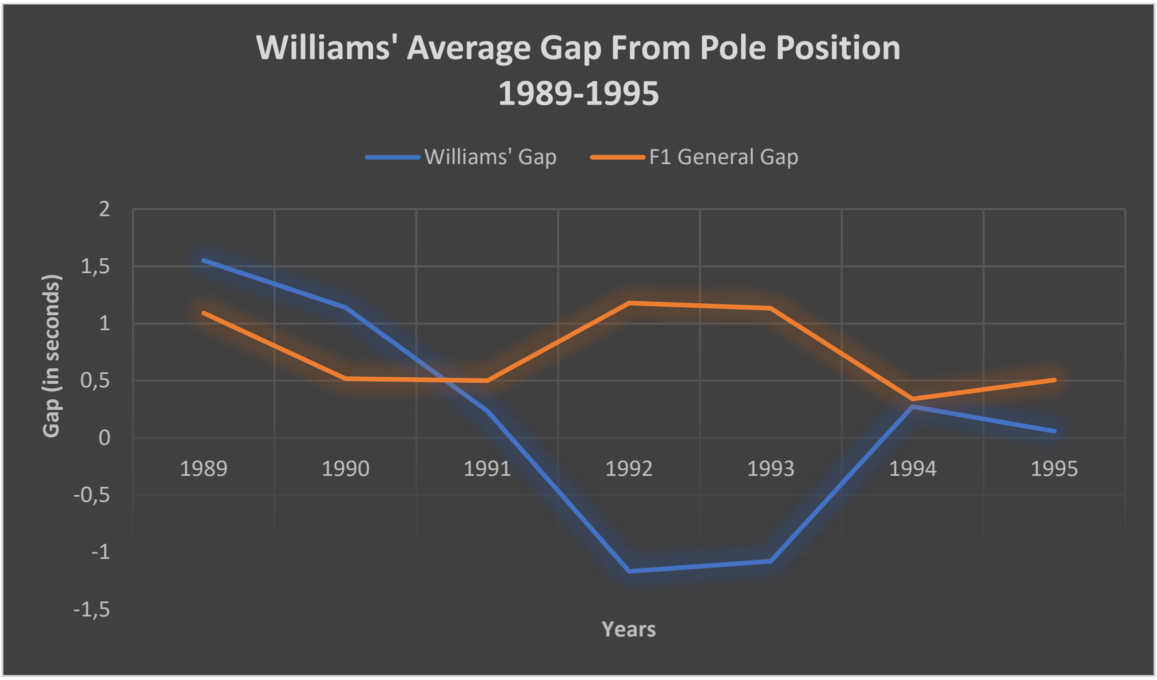

CHART FIVE. Data source: [STATSF1]()

This chart explains well how a radical innovation can change the competitive landscape. In particular, it shows the average gap between the pole position and the first Williams' car in every qualifying session between the 1989 and 1995 seasons. The laptimes are, as the previous charts, expressed in seconds. The times are taken from the qualifying sessions of the seasons' mentioned. When a Williams made the pole position, I've taken as a reference the gap between the pole position and the first different team's car in the standings, and I've considered this number negative. So, to make it clearer, the lower the point on the chart, the faster the Williams' car is. I've also added the F1 general gap of that years, which is the average gap between the first and the second team in qualifying sessions regardless the team's name, as a reference to better understand the competitive landscape in those years.

The results are as follows: in 1989 Williams had a disadvantage, on average, of 1,551 seconds from McLaren, at that time the frontrunners. That gap went down to 0,233 seconds in 1991, a year after Adrian Newey, a young and promising engineer, joined the team. Williams introduced for the first time active suspension in 1992 with the FW14B, an evolution of the FW14 which ran in the previous season. This innovation gave Williams a massive advantage: although the FW14B was just an evolution of the FW14, in 1992 the Williams' average gap from pole position was -1,168 seconds. This means that, in that year, Williams had, on average, an advantage of 1,168 seconds on all the other teams, a net gain from 1991 of 1,4 seconds. This is a lot, considering that all this advantage was gained in one season. Williams continued to have active suspensions on their 1993 car, the FW15C, and that year's advantage remained almost the same as the previous one (1,078 in 1993 against 1,168 in 1992). In 1994 all the driver aids, active suspensions included, were banned, which is the reason why the other teams didn't try to copy the system. As we can see from the chart, Williams lost its competitive advantage that year, but remained one of the major forces of the championship, although the immense empty space left by Ayrton Senna's death at the start of the season.

The same methodologies, both the one-adopter and the all-adopter, can be used to demonstrate the radicalness of another important innovation of the 20th century in Formula One: ground effect. To understand why it is considered a radical innovation I'll do the same work I did for the previous innovations that I've analysed. This time my “test tracks” will be the Hockenheim circuit, in the period between the 1970 and 1981 season, and the Paul Ricard circuit, in the years between 1971 and 1985.

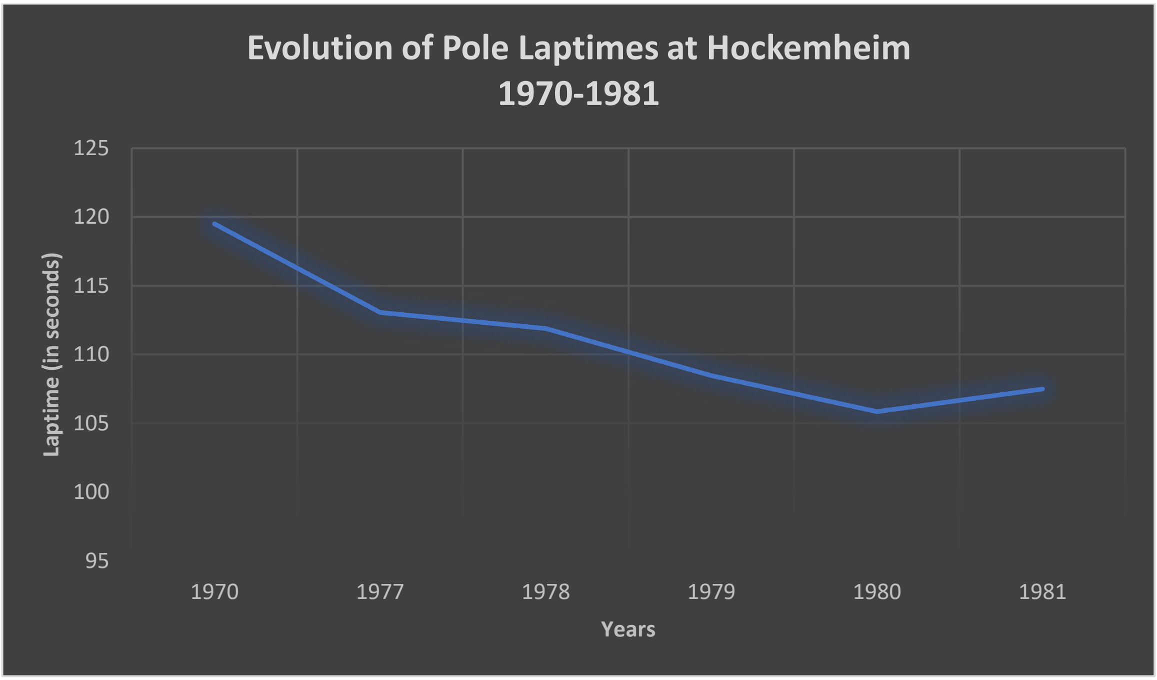

CHART SIX. Data source: **STATSF1**

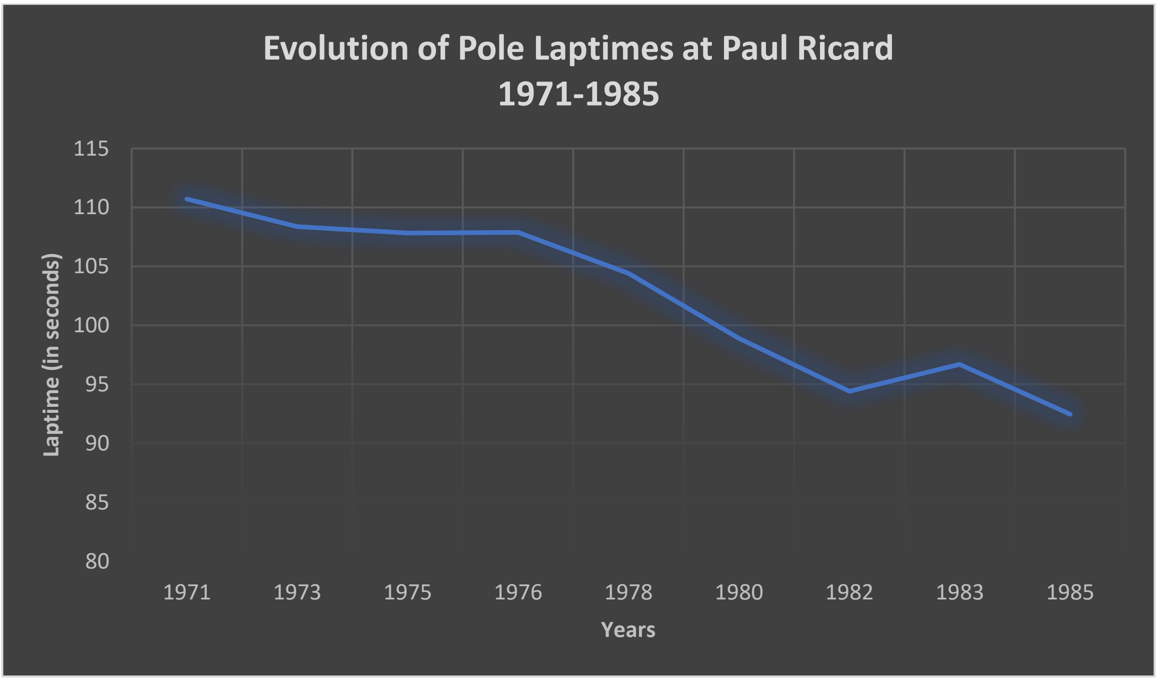

CHART SEVEN. Data source: **STATSF1**

As a reference, we must remember that ground effect was introduced in 1977 with the Lotus 78. In both charts we can see a peak in performance after that year. This peak is more visible in the Paul Ricard's chart, because F1 didn't race at Hockenheim from 1971 to 1976. Still, it's important to underline that, thanks to the ground effect's discovery and its development and, partly, to the introduction of the turbo engines, in the German circuit the time gained between the years 1977 and 1980 is 7,22 seconds, a number higher than the time gained between 1970 and 1977 (6,43 seconds), a longer period, which is impressive. In the Paul Ricard chart this peak is more visible: before 1976 the times seem to be almost slack, but from 1978 we can clearly see a very important peak in performance, which stops after the skirts' ban in 1983 and continues in 1985 thanks to the turbo engines. For this incredible gain in laptimes, ground effect is considered a radical innovation.

Even if I consider the one-adopter method I used for active suspensions, and I adapt it to ground effect, the result remains the same.

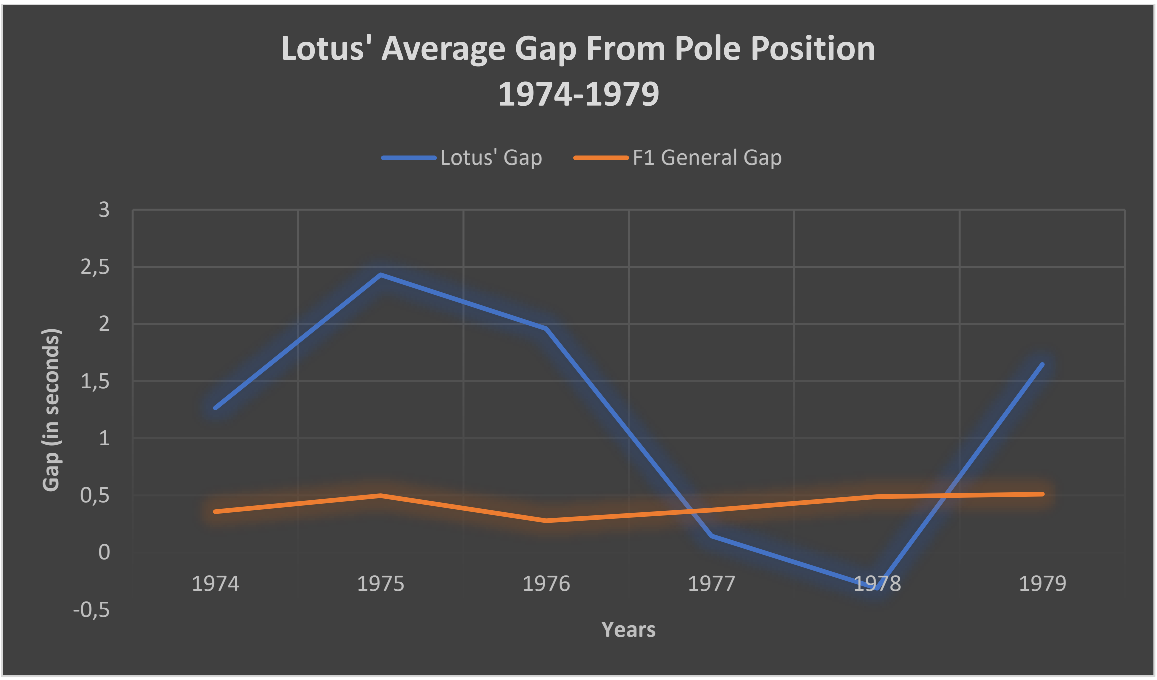

CHART EIGHT. Data source: [STATSF1]

After having won back-to-back constructors' championship in 1972 and 1973 and helped Emerson Fittipaldi secure his first drivers' title in 1972, in 1974, 1975 and 1976 Lotus didn't have the championship they wished. They were far from the top of the class: their average gap from pole position in the three years I've mentioned was 1,884 seconds, more than one and a half second higher than the F1 average (0,367 seconds) in those same years. However, after they came up with the first ground effect car in 1977, their performances improved a lot, and in 1978, after the development of the innovation, their advantage on the other teams was, on average, 0,312 seconds, as you can see from the chart. In 1979 the other team made themselves ground effect cars, and Lotus lost its competitive advantage.

So, to conclude this paragraph, we can say that in Formula One there are both radical and incremental innovations, and that the radicalness of an innovation is measured:

- If only one team adopts the innovation, by the advantage gained by the team thanks to the innovation;

- If more than one team or the whole field adopt the innovation, by the peak in the general laptimes caused by the innovation.

3.3 S-Curves and radicalness in Formula One

When talking about innovation, it's impossible to ignore S-Curves. S-Curves are an important innovation tool which shows the evolution and the development of a particular technology, both in the performance and the adopting fields. S-Curves, when overlapped, can also be utilised to understand when and how dominant technology switches happen, which is the main reason I'll use them in my work: to understand what happens when new technologies in Formula One rise and how their radicalness influence the innovation's path in the championship.

To do so, I will use the S-Curves both for performance and adoption of the technology. While adoption rate is very easy to calculate, since counting the teams that adopted a particular technology is not a work which requires a lot of effort, the performance rate can be calculated in various ways, also regarding the type of component interested in the innovation. For example, an engine's performance can be measured seeing its power or reliability, while an aerodynamic development's effectiveness can be calculated by the speed gained in turns, a number which, in my position, is difficult to find. So, to simplify and to have a unique and objective unit of measure for every innovation's performance, I'll use the technology's "curriculum". Specifically, I will use the number of victories made by an innovation to build my S-Curves of performance, considering their tall as my dataset.

The first innovation I'm going to talk about is turbo engines. But first I must make an introduction. Since the first F1 championship was held in 1950, the rules have always allowed teams to use over alimented engines, if we don't count the period between 1961 and 1965 during which were banned, as far as they had a lower displacement, decided by the regulatory authority, than the normally aspirated ones. Yet, until the 80s, no World Championship winning team, except for Alfa Romeo in 1950, used an over alimented engine. Because of the difference on displacement, considered too high by the engineers, the over alimented engines were used only in the first part of the 50s, and for this the battle was over long before the introduction of the Cosworth DFV, a cheap yet powerful engine that all the constructors that didn't have the facilities to build their own engine adopted, in 1967. Normally aspirated remained the standard until 1977, when Renault entered in Formula One with a turbo compressed engine. We can see both engines' performance evolution and S-Curves in the chart below.

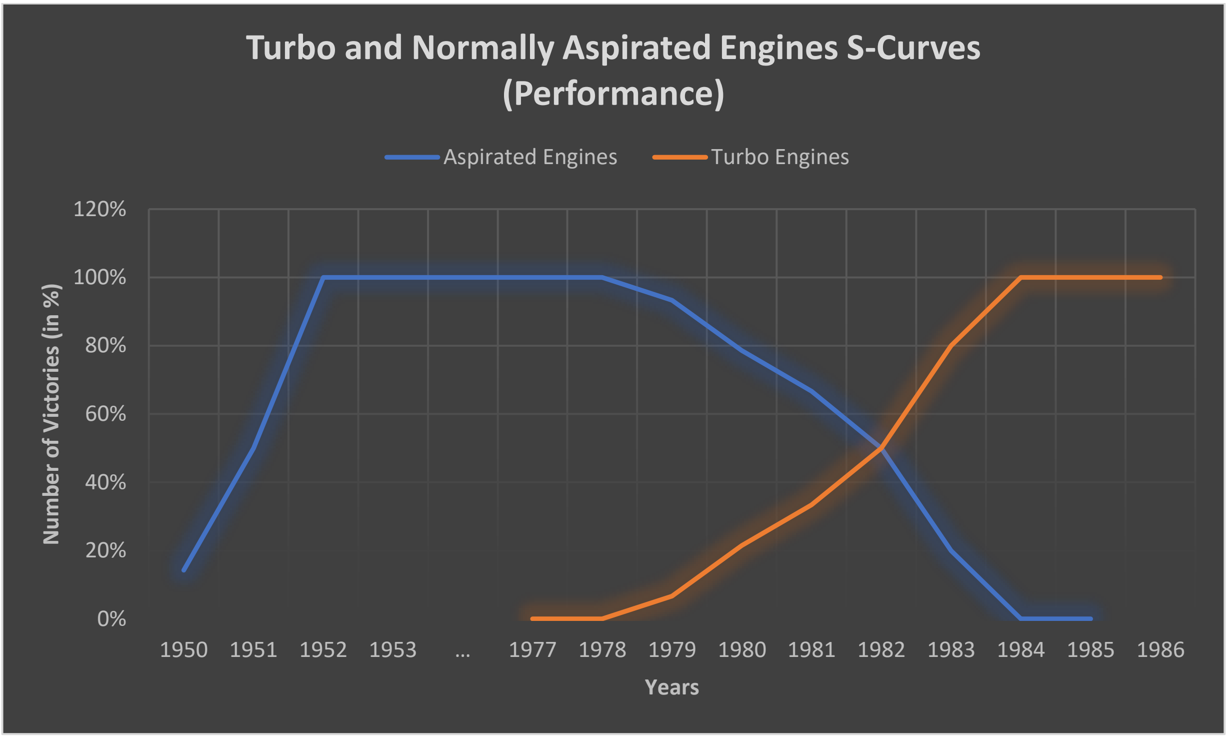

CHART NINE. Data source: STATSF1

After two seasons in which the Renault team experienced chronical reliability problems (they finished only 6 races out of 26 starts), in 1979 things started to change, with the Renault team winning their first Grand Prix at Dijon. The next seasons Renault won three Grand Prix, while in 1981 a turbo engine was adopted by Ferrari too. The victories' tool reached the parity the very next season, and by the following year turbo engines overtook in competitivity the normally aspirated engines. This growth in performance follows a similar path in the adoption S-Curves.

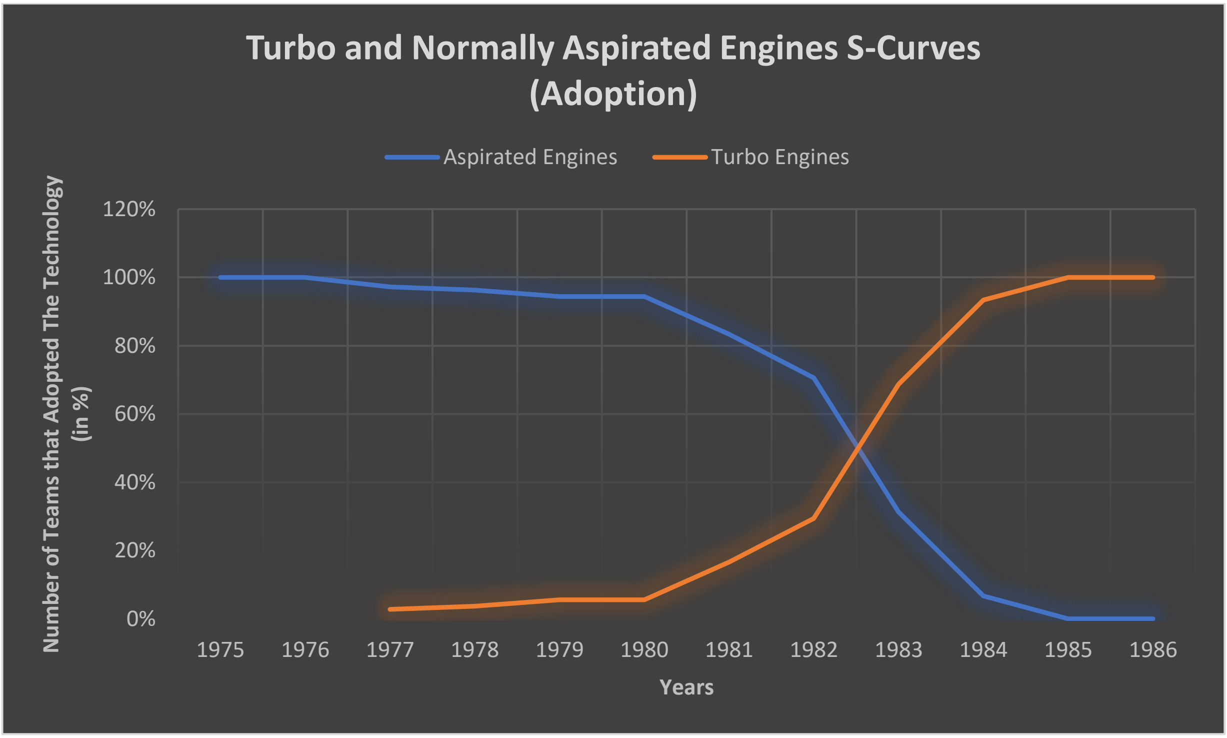

CHART TEN. Data source: STATSF1

Like in the performance S-Curves, the technological switch happens between 1982 and 1983, and in 1985, every team on the grid had their car equipped with a turbo engine. In both charts I've added, with a grey line, the total number of teams and races respectively in every season I've analysed, to give you a better perspective of the competitive landscape. The path followed by both the S-Curves is typical of the radical innovations: slow at the start, then a sudden acceleration and the substitution of the established technology. Also, we can see how the teams behave in presence of a radical innovation: when the innovation is introduced, the great majority of the teams continues to adopt the existing technology, while the innovative team or teams develop the new technology. When the new technology starts to pay dividends and its performances threat the established technology more teams adopt the innovation, just like in the firms' world. This process continues until the old technology becomes obsolete and the innovation establishes itself as the dominant technology. To demonstrate that the turbo engines are not an isolated exception, I'm going to show you the S-Curves of the rear-engine car, a little yet very disruptive innovation.

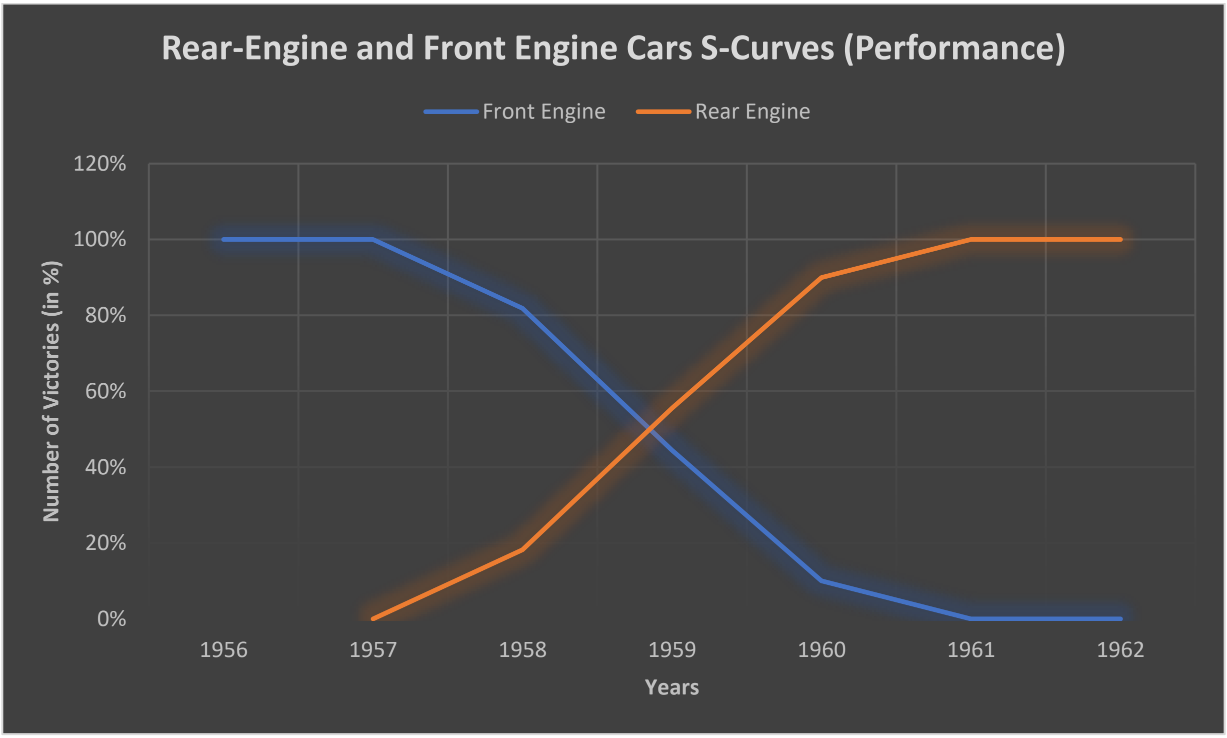

CHART ELEVEN. Data source: **STATSF1**

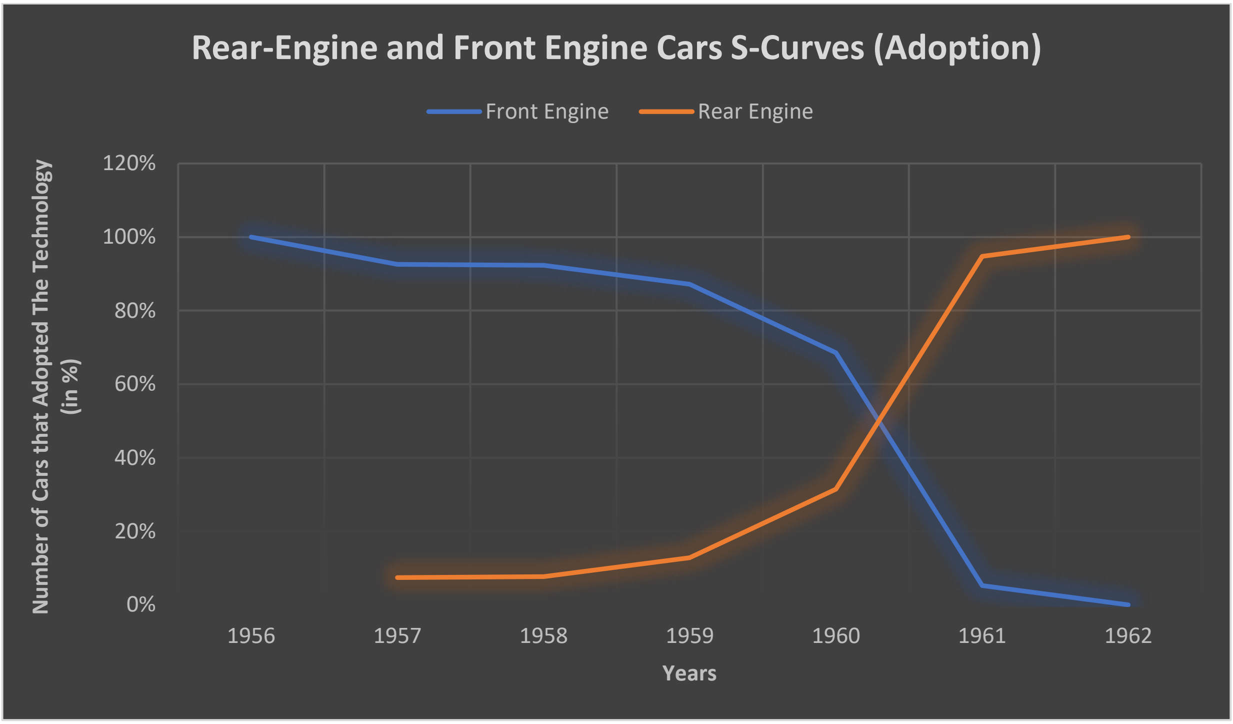

CHART TWELVE. Data source: STATSF1

As you can see, the rear engine cars' S-Curves offers us the same result as the turbo engines' ones. Cooper, with the T43, was the first to introduce a car with its engine positioned in the rear or in a position different from the front of the car in 1957. After a first promising season, they won the first two GPs of the 1958 World Championship and went on to win both titles in the next two years. The first teams to build a rear-engine car apart from Cooper were English teams such as Lotus, BRM and Connaught, thanks to the "district" advantage. Only at the end of the 1960 season an established team such as Ferrari decided to build a car with an engine placed in the rear, leading them to win both titles the next season.

To conclude this section, we have seen that:

- A radical innovation's S-Curves will start slow, then will accelerate and substitute the established technology, before reaching its maturity;
- The non-innovative teams will prefer to continue with the existential technology, and later, when the new technology has proven its competitiveness, move towards the innovation.

3.4 Causes of Innovation in Formula One

An innovation or a technological newness is always caused by something. External changes, serendipity and environmental competitiveness are some of the main causes of innovation. In the second chapter we've seen the path and history of innovation in Formula One and how new technologies have born and developed. Following the innovation's path mentioned, the main causes of innovation in Formula One are two:

- Regulation changes;
- Catching-up situations.

3.4.1 Regulation Changes

Talking about regulation changes, in Formula One these are caused by three major concerns:

- Safety;
- Lack of performance;
- Lack of entertainment.

Safety is the major concern that Formula One's ruling authority has when building a new set of rules. Sometimes new regulations are built exclusively in the name of a major safety for driver. The first major rules change made in the name of safety happened in 1961, when the maximum displacement of the engines was lowered at 1.5 litres from the 2.5 of the previous seasons. Other important regulation changes took place in 1995, after Senna's and Ratzenberger's deaths at Imola the year before, and in 1998. Rules changes made for safety reasons have the effect of slowing the car down, and usually don't cause a great shake up of the grid, although can happen that, if the radicalness' level of the new regulations is big, an outsider can emerge and establish itself as the new frontrunner. This is what happened in 1998, when McLaren dominated the season after finishing fourth in the 1997 World Championship.

A lack of performance is another cause of regulation changes. Formula One is considered the most technological advanced, the most challenging and the faster motorsport championship in the world. So, when the level of the cars is not considered at the level of the championship the regulatory authority has to intervene to change the rules. This happened in 1966, when the engine displacement was doubled from 1.5 to 3.0 litres, and in 2017. These type of rules changes have the opposite effects of the safety ones: they cause an improvement of cars performance and have great odds of causing a grid shake up.

In Formula One can happen that a particular team is a frontrunner for a long time, a tendency that is happening more and more often in the Circus. This usually cause boring races and predictable championship. To stop this, the authority answers with a series of rules whit the goal of eroding the frontrunner's advantage. This happened in 2005, when the no tyre-changing rule ended the Ferrari domination, and in 1994, when driver aids were banned together with the active suspensions system because were lowering the importance of the driver and were the reason why Williams dominated the 1992 and 1993 seasons. Recently, rules changes for lack of entertainment were also put in place when the cars were becoming too aerodynamically complex and, consequently, more difficult to control when chasing themselves. Rules changes of 2009 and 2022 went in this direction. Effects of these type of regulation changes on car's speed can vary but, as we have seen, have a huge role in shaking up the championship's balance of performance.

3.4.2 Catching-Up Situations

A catching up situation in Formula One occurs every time a team has a disadvantage against the frontrunner team and, at the same time, is willing to close this gap by eliminating the disadvantage or compensating it with a major advantage in another part of the car. During this time the disadvantaged firm can come up with interesting and not conventional solutions that shake up the order in the F1's grid. One of the examples of a successful catching up situations can be seen in 1978 with the Lotus 79. As I've said before, Lotus, after having lost its competitivity, was trying to find a breakthrough to recover positions in the standings. The result of the efforts were the Lotus 78 and its successor, the Lotus 79, the first two Formula One cars to use ground effect. A catching up situation can also be not successful, which is what happened to Tyrrell in the mid-70s when they presented the first six-wheel car in F1 history. The car, although good performances, was not able to achieve the goals Tyrrell had and, after mountains of difficulties, the project was quitted. Catching up situations respect the theory that innovation comes from little and flexible firms although that from the most established ones, but in Formula One there are also examples of teams that, although their high position in the standings, had continued to innovate.

3.5 Vectors of Innovation: Ambidexterity, Firm's Culture and the Importance of People

The explanation of why the established firms continue to innovate regardless of their high position in the standings is ambidexterity, which is the firm's pursuit of both the exploitation, in which they use the current resources and capabilities in an efficient way, and exploration, that means a search for new technologies and theories that could be used in Formula One. One of the most recent examples of ambidexterity in Formula One is Mercedes which, although their domination, continues to search for new and innovative solutions to gain tenths on the opposition. The DAS system is an example of that. A firm's culture plays a significant role in F1 innovation. In this field, we can divide Formula One teams in two main categories: innovators, which are the main characters of innovation in F1 and of its path, and imitators, that prefer to count on pre-existent technology and decide to adopt an innovation only when its competitivity is proved. A member of the first group it's Lotus and, if I see the bigger picture, a big part of the English constructors from the 1960s to the 90s, while a typical example of a follower could be a big manufacturer such as Ferrari, although in their history they also had the opportunity to innovate, being the pioneers of semiautomatic gearbox in Formula One. The newness was possible thanks to the mind of John Barnard, an innovative engineer which in his career designed some of the most innovative racing cars. Barnard is the ideal link to the other important topic of this paragraph: people. The success or the decline of Formula One teams depends on the quality of its human resources: drivers, mechanics, engineers, managers. To understand better the concept, I'll make the example of Lotus, our favourite team for experiments. Lotus' founder and chairman Colin Chapman was one of the most influential personalities in the history of the sport. Thanks to his continuously will to explore new solutions, his team is remembered as the most innovative firm the Circus has ever known and at the same time one of the winningest teams of the sport. When the turbo engines started to overcome in performances the normally aspirated engines Lotus started its decline, but the "coup de grace" was Chapman's death, which still today is an unsolved mystery. The Lotus' situation is better described in the chart below.

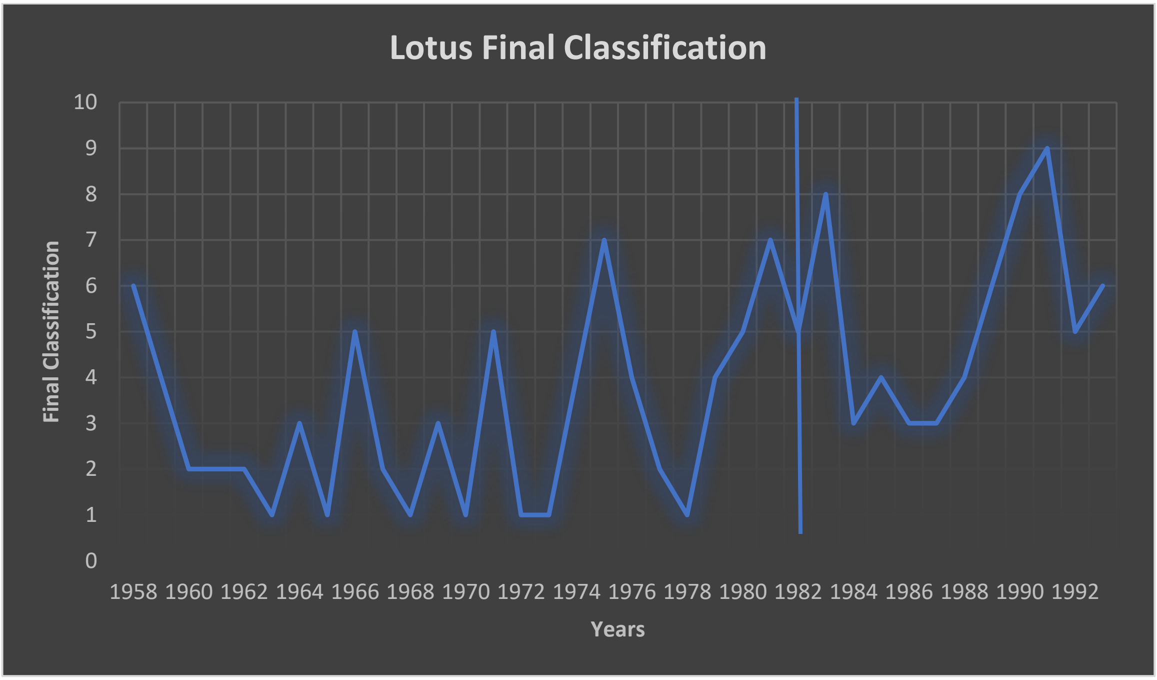

CHART THIRTEEN. Data source: [STATSF1]

As you can see, the Lotus declining was well underway after 1978, but after Chapman's death in 1982 (marked with a line), the team really starts to struggle, with only three third places in the standings thanks to the coming of the turbo engines and the presence of Ayrton Senna in the team. To better understand how Lotus declined after Chapman's death, the average final position of the English team in the constructors' championship before 1982 was 3,16, a number which increased to 5,36 in the seasons between 1983 and 1993, after the founder's passing.

3.6 Consequences of Innovation in Formula One

If the innovation is not successful, it's simply quitted by the innovative team and not used by the other teams. If, on the other side, the newness shows its competitiveness, there are two paths that can be followed:

- Follow up;
- Ban.

In the first case, the opponents start to work on their solutions to contrast the innovation. They could copy the newness or find new ways to recover ground, implementing new innovations themselves. It's the case of the wing cars, the turbo engines, carbon fibre and of the cars with the engine on the rear. These technologies are known for their simplicity, a characteristic that helped the other teams to find new solutions or to innovate.

In the second case the teams, not happy for the advantage gained by one of their competitors, can ask the F.I.A. to rule the innovation illegal. The F.I.A. has the final decision on banning it, a thing that happened with the Brabham fan car, or rule it legal. F.I.A. can itself, in the name of safety, rule an innovation illegal, a decision taken in the 80s with turbos and wing cars in order to contrast the enormous speed reached by the machines of that period.

3.7 Conclusions

In this chapter I have discussed a sort of framework of innovation in Formula One. To sum up, we have understood that:

- Innovations in Formula One, although can be classified in more ways, can be defined as incremental or radical;
- The radicalness of a Formula One innovation is given by the time gained by the innovative team. If the innovation is adopted by more teams, the radicalness of the innovation is given by how faster the overall championship's speed is;
- The main causes of innovation on Formula One are two: regulation changes and catching up situations;
- The consequences of innovation are the follow up by the competitors or the ban of the innovation by the ruling authority.

CHAPTER FOUR

The new F1: budget cap and new regulations

As we've seen in the last chapter, regulation changes are one of the main causes of innovation in Formula One. We have also seen that the more radical a regulation change is, higher the odds of a change in the establishment position are. So, it's important to understand how new regulations can change the competitive landscape in Formula One and how teams approach the new rules. In this chapter I'll take as a case study the 2022 regulation change to analyse why F1 decided to change rules, how teams have approached the new sport code, and how the competitive landscape has changed after the new regulations were implemented.

4.1 The 2022 rules and purpose

In 2017 F.I.A. adopted one of the major rules changes in its history. At that time the cars were considered too easy to drive, too slow and too "ugly". To resolve these problems F1 decided to put on a radical change: cars were larger and had a completely renewed bodywork with more aerodynamic elements and tires became bigger. As a result, the 2017 cars were, on average, 2.6 seconds faster than the previous year's cars and had a much better look. However, as the years passed and the development went on, cars became more and more complex aerodynamically speaking. Due to this, at the end of 2021, following the data provided by Formula One, a car could lose between 35 and 46% of its downforce while chasing another car. This loss of downforce meant that drivers had more difficulties in driving their car while chasing one of their opponents and therefore the chasing conductors had less probability to overtake. This led to more boring races, sometimes decided by strategy and pitstops.

So, to try to make races more spectacular and improving the overtakes number F1 put in place one of the most radical regulations change ever seen in the history of the sport. Firstly, the car's bodywork was "cleaned" of the majority the aerodynamic appendixes and the front and rear wing were simplified. To compensate the loss of downforce, F.I.A. allowed for the first time since 1982 Venturi channels at the floor of the car, effectively reintroducing ground effect in Formula One. These changes helped, if I follow Formula One as a data source, to reduce the loss of downforce in chasing situations between 4 and 18%. Also, the tyres were increased in size (from 13 to 18 inches) and now had a low profile, with more space dedicated to the rims. In order to make the championship more sustainable and to reach the goal of net-zero emissions in 2030, Formula One also started to research the formula for its sustainable fuel: from 2022 the fuel of every car on the grid has to be composed with 10% of ethanol. However, one of the most important innovations was put in place a year earlier, not on the technical field but on the financial one.

4.2 The Budget Cap

In 2021, for the first time in its history, Formula One adopted a budget cap to limit team's spending over development and other areas that create a competitive advantage. The Cost and Performance Cap, which will only cover some expenses that give an advantage to teams, such as R&D and manufacturing, was set for 2021 at 145 million dollars. For 2022 the number was lowered at 140 million and will be lowered again at 135 million in 2023. Then will remain at this number until 2026, when will be revised. A first attempt to introduce a budget cap was made for the 2010 season in order to tackle the effects of the 2008 global financial crisis, but this created a dispute[34] between F.I.A. and F.O.T.A. (Formula One Teams Association) that almost made the 2010 season to sink. More than ten years later, the budget cap was a necessity for Formula One championship.

Specifically, after the rules change in 2014, which led to the use of hybrid engines, the cost of competing in Formula One became higher and higher. Over the years, this has created an important problem regarding the so-called positive feedback loops in the championship. A positive feedback loop is a system in which the outcome of an effect fuels the effect itself. In this way, the consequences "cause the causes" of their self, and therefore grow as long as they verify. To better understand this concept, I'll make the example of a fire. Let's suppose that you put a match in a pile of wood. The consequence of this action will be the start of a fire. To aliment itself, the fire needs heat. When it finds it, the fire grows. This growth generates more heat, which causes more fire, which causes more heat, which means a bigger fire, which generates more heat and so on. In Formula One the goal of every team is success, and to be successful a team needs good drivers, good engineers, liquidity, and good partnerships. If a team has all these components, it's likely to have success. The firm's success means that the successful team will attract the best drivers and engineers and the opportunities of winning and personal growth that it offers, the best sponsors and higher prizes will pump more money into the team and better partners will propose themselves. All these ingredients will cause more success, which will then enhance the components I said before. A positive feedback loop works also in the other way: if a team will have less success, it could lose its best drivers and engineers to a more successful team, the prizes and the sponsorship agreements won't be that ludicrous and the partnerships won't have the quality of the best team's ones, leading to even less success. Positive feedback loops have always existed in Formula One, but how they have grown in the last decade is beyond the standards.

[34] https://en.wikipedia.org/wiki/FIA%E2%80%93FOTA_dispute

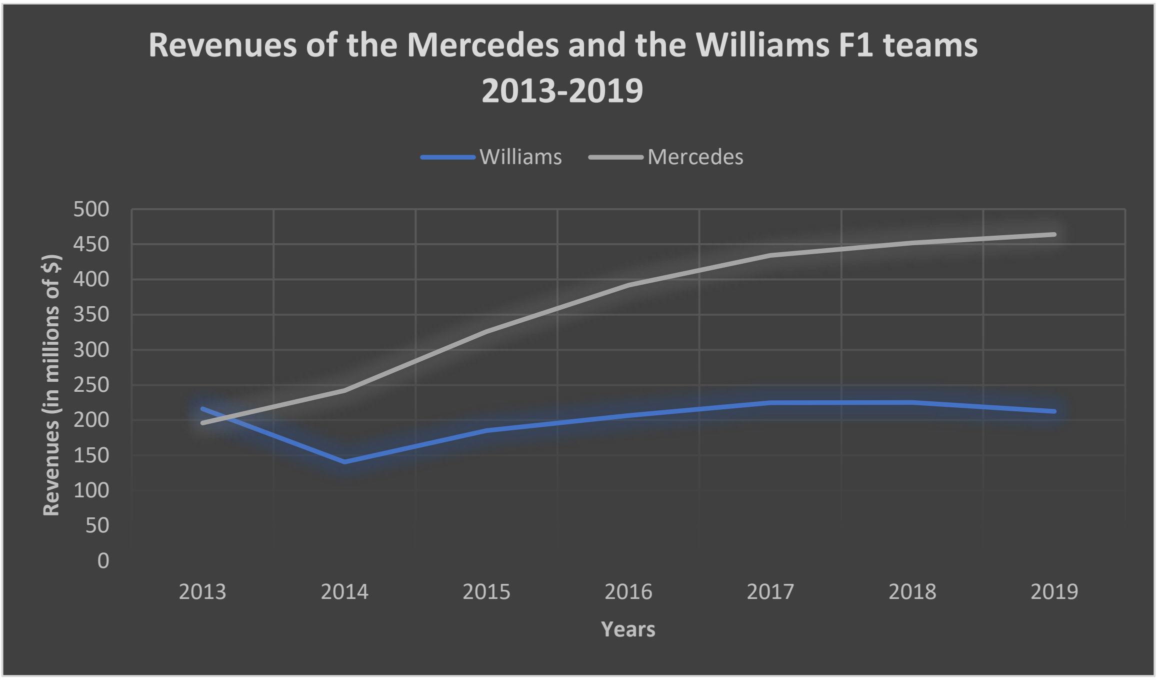

CHART FOURTEEN. Data source: **Williams Grand Prix Holdings PLC and Mercedes Benz Grand Prix LTD documents**[35]

This chart perfectly shows the problem F1 has had to face during these years. In particular, you can see the comparison between the revenues' evolution of Mercedes, the frontrunner during this period, and Williams, the last team in the 2019 standings. While the Mercedes' revenues skyrocketed during their period of domination, the Williams ones, although the team finished in the top-three during the years 2014 and 2015, are almost stacked. This massive difference in revenues reflects itself on the budgets available for every team.

[35] Both teams' data are reported in pounds in their financial statement. The adaptation in dollars is made following the rate of change reported at the end of every year (ex. for 2013 I've used the GBP/USD change at 31/12/2013, for 2014 the change rate at 31/12/2014…). The rates of change are taken from Investing.com

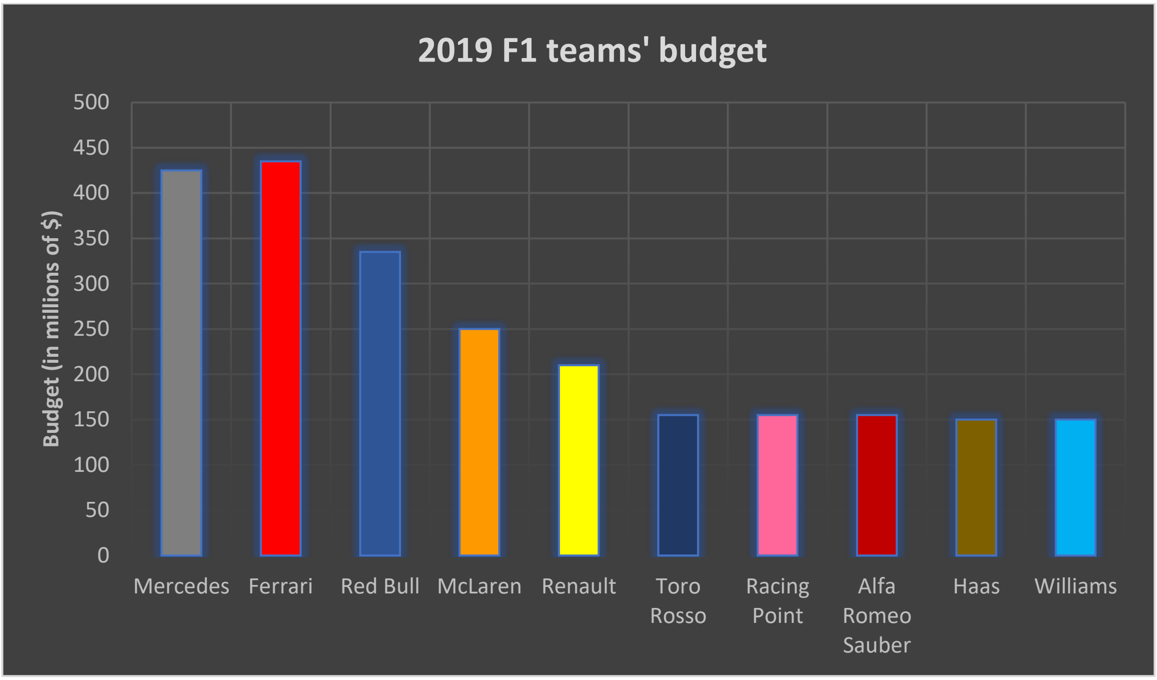

CHART FIFTEEN. Data Source: [racefans.net]

The chart describes well how the balance of competition in Formula One is heavily pending in favour of the wealthiest teams. From this chart we see how the top three teams (Mercedes, Ferrari, Red Bull) spend far more than the other ones. One data is particularly shocking: in 2019 Mercedes, Ferrari and Red Bull, combined, have spent almost the same amount of money of the seventh other teams combined. As I've said before, money is one of the success variables and part of the positive feedback loop that we've seen before. But how much does money count in Formula One? Well, in the 2019 season Mercedes, Red Bull and Ferrari won all the races[36] and made the great majority of the podiums[37]. The only teams outside the top-three that scored at least a podium during the 2019 season were Toro Rosso (two podiums) and McLaren (one podium), and both teams achieved the results in chaotic races. If we see the bigger picture, taking as a reference the seasons between 2014 and 2021, the results are as follows.

[36] https://www.statsf1.com/it/2019/stats-victoire.aspx
[37] https://www.statsf1.com/it/2019/stats-podium.aspx

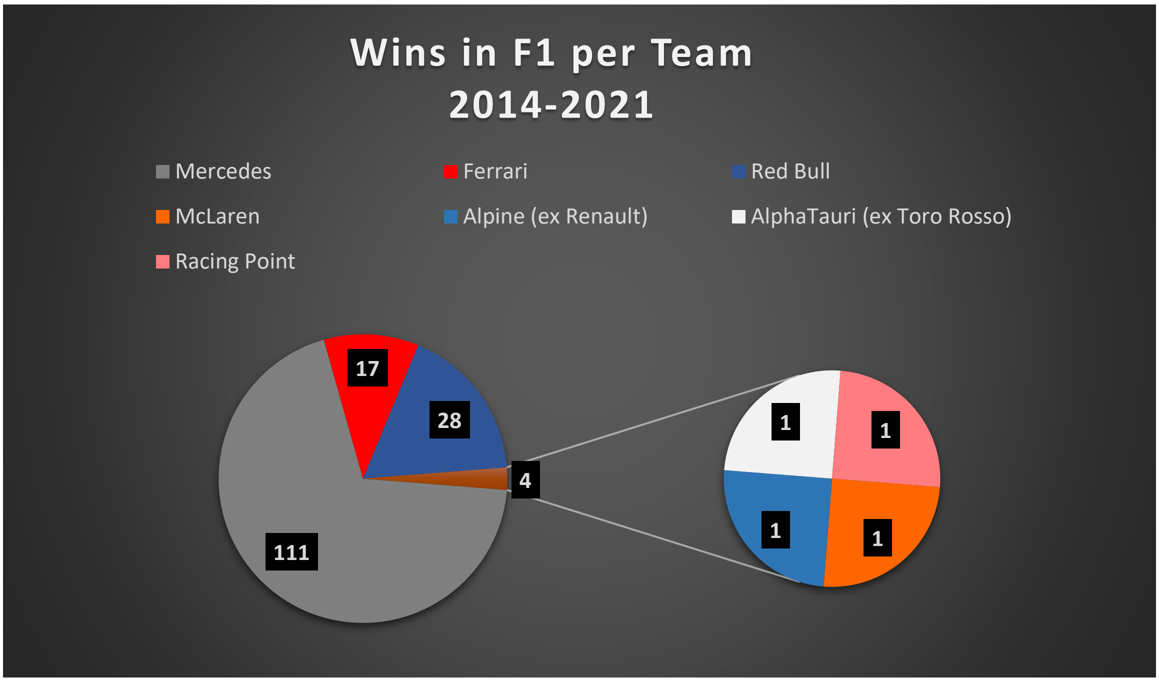

CHART SIXTEEN. Data source: STATSF1

The top three teams (Mercedes, Ferrari and Red Bull) have won 156 races out of the 160 disputed, which means more than 97% of the races were won by these three teams. The other teams who won at least a race during this period were McLaren, Alpine (former Renault team), AlphaTauri (former Toro Rosso team) and Racing Point. All these four teams' wins happened in the last two seasons, and a great part of these races were chaotical and not linear.

In the last decade, especially with the impressive escalation of costs, Formula One has become much more a club of the wealthiest. The competitive elevator, which allows outsiders or less wealthy teams to dream about winning a championship one day, does not exist anymore. Right now, three teams have a major advantage over the rest of the field, both technical and financial. If the race is linear, one of the three between Red Bull, Ferrari and Mercedes will win, leaving the others with almost zero chances of even getting a podium. Also, having more economic possibilities, these teams have more possibilities to exploit new and innovative solutions, effectively lowering the possibilities of radical innovation's discovery in the lower-table teams. With a competitive landscape like this, is difficult for everyone to dream about creating an F1 team and win races and championships. The budget cap was introduced for this reason: to create a fairer championship, where the little teams such as Haas or Alfa Romeo can at least start with the same financial possibility of the frontrunners. We'll see in the next years if the budget cap will have the desired effects.

4.3 How the New 2022 Regulations Have Changed the Competitive Landscape

In the third chapter, I've written that the more radical a regulation change is, the more probability of a grid shake up there. We've seen also some examples that confirms this assumption earlier in the work, such as the Brawn GP 2009 case. To see if this theory can be applied to the 2022 case, I'm going to compare these three seasons with their previous ones to see if and how the not established teams have gained positions and points over the established ones. To give you a better perspective, the teams are ordered in the position they finished in the season prior of the cased ones: for the Brawn GP case, teams are ordered based on their final position in the 2008 season. Regarding the 2022 season, since at the time I'm writing the Circus has just completed its 13th Grand Prix of the season in Hungary, teams will be ordered based on their position in the standings at the end of the 2021 Netherlands Grand Prix, the 13th Grand Prix of the 2021 season.

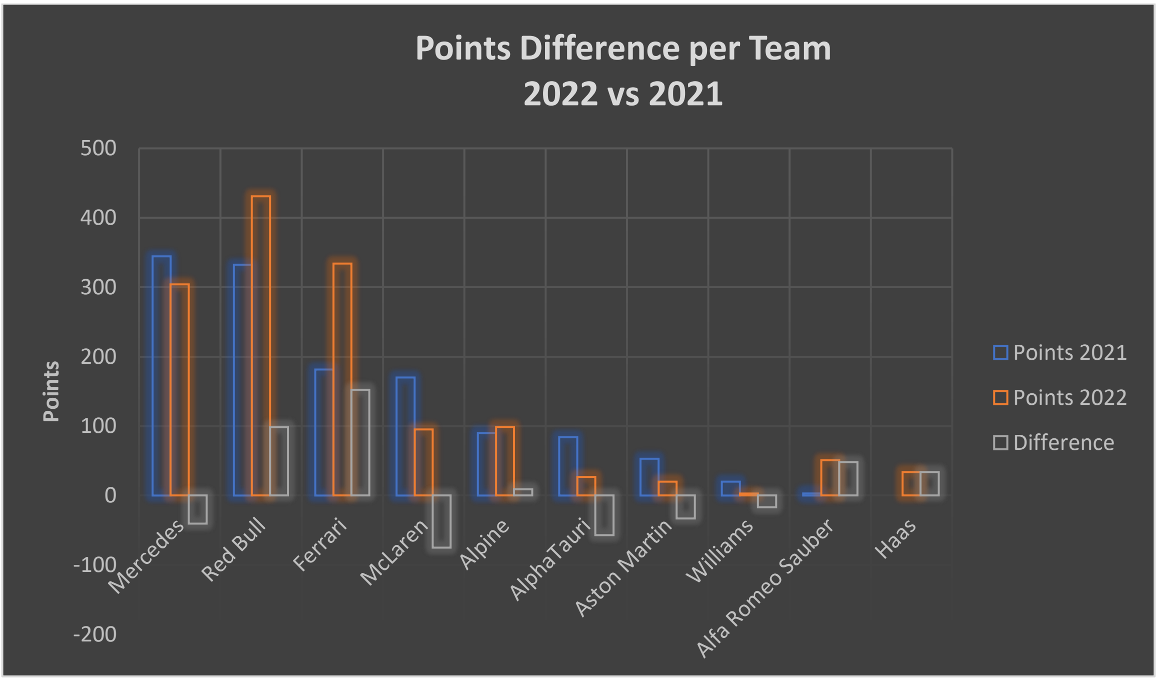

CHART SEVENTEEN. Data source: STATSF1[38]

[38] **Points' system:** 1st: 25pts, 2nd: 18 pts, 3rd: 15 pts, 4th: 12 pts, 5th: 10pts, 6th: 8 pts, 7th: 6pts, 8th: 4 pts, 9th: 2 pts, 10th: 1 pt. An additional point is awarded for fastest lap in the race.

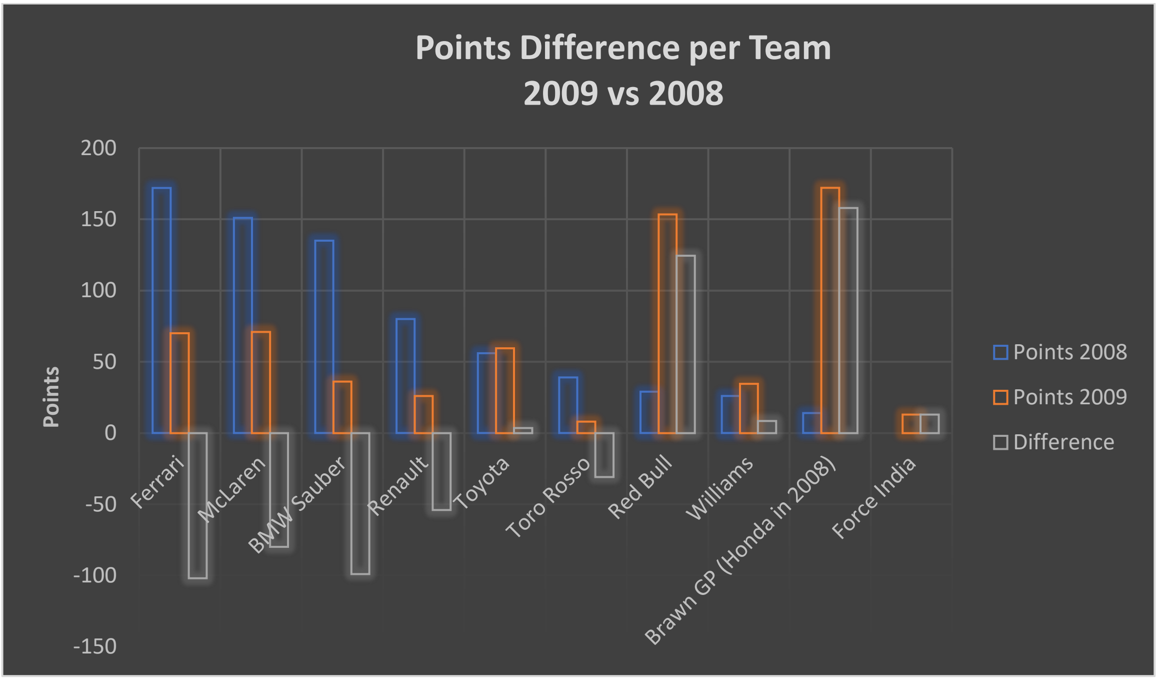

CHART EIGHTEEN. Data source: STATSF1[39]

As we can see from the comparison between the two charts, the grid shake up and the nearing of teams that a lot of people and the F1 organizations were hoping for the 2022 season didn't happen. Now I must pose a question: if the 2022 rules change was at least as radical as the 2009 one, why we can't see a more radical change in the higher plans of the standings? The answer is not easy to understand. For sure the disparity of liquidity in Formula One has had a great influence on the 2022 budget definitions of every team. The 2008 and 2021 seasons were also quite similar, with two teams (Ferrari and McLaren in 2008, Mercedes and Red Bull in 2021) fighting each other for both the drivers' and the constructors' championships until the final race, but while in 2009 both McLaren and Ferrari started poorly the season and partly recovered later due to development, in 2022 both Mercedes and Red Bull didn't pay a high price: the *Silver Arrows,* although a season which at the moment is under the expectations, have probably the most unconventional car of the grid, while the Austrian team has even improved its 2021 score and is the favourite in the battle for both titles. We can conclude that, during these years, teams have started exploiting their ambidexterity, successfully seeking competitivity both in the short and the long term.

[39] **Points' system:** 1st: 10pts, 2nd: 8 pts, 3rd: 6pts, 4th: 5 pts, 5th: 4pts, 6th: 3pts, 7th: 2 pts, 8th: 1 pt.

CONCLUSIONS

Formula One is an ideal playground to study how innovation works and how technological and establishment changes happen. As I've written in my work, the Circus' history is full of teams that have scaled the standings thanks to cheeky, intelligent and genius innovations, establishing themselves as frontrunners.

However, something has changed recently. The costs of maintaining an F1 team have skyrocketed during the last decade in an unprecedented way. The difference in earnings and budget between the very top of the table and the low-standings teams is becoming larger and larger every year. Due to this, the competitive elevator, which once allowed little teams to fight for the top positions, has stopped: bigger teams use the surplus of their budget to exploit a vast range of solutions for their cars, a possibility that littler teams don't have. As a result, in the last decade the established teams (which right now are Mercedes, Ferrari and Red Bull) have formed a sort of "oligopoly" in which they divide victories, podiums and World Championships between themselves.

Formula One and its teams' financial sustainability problems are also facing an important technological challenge. The environmental issue has made the normally aspirated engines obsolete and the need of a new and more sustainable engines. This led in 2014 to the adoption of the hybrid-turbocharged power units, which are adopted now and probably will be adopted in the next future. These power units are a technological miracle: they can reach a thermal efficiency of 50%, while normal engines score a 25% average on the same field, but are very complex and expensive, which makes this solution unsuitable for normal road engines.

Both the issues are an enormous entry barrier for little constructors and even for big manufacturers, and constitutes an existential threat to Formula One itself, which is starting to tackle the problems.

Regarding the financial field, as we've seen in the last chapter, F1 has introduced the budget cap, which aims to create a fairer competition at least financially.

On the engine argument, F1 is planning new engine rules for 2026 with the goal of creating more sustainable and less complex power units. The total electric engines, which until 2039 are an exclusivity of Formula E, an all-electric championship, are not an option, so Formula One is trying to create a new 100% non-fossil fuel to power the engines, which from 2026 will still be hybrid but won't have the MGU-H and so will be cheaper and, maybe, able to help big manufacturers in developing new engines for their road cars, a fact which is attracting important manufacturers such as Audi and Porsche in entering in the championship. Regarding sustainability, Formula One has started a campaign to reach net zero carbon dioxide emissions by 2030, an ambitious objective.

Formula One is fighting two battles, a financial one and a technological one, which will shape its future and will probably determine if the Circus will continue its existence.

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