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From Concept to Victory: Examining the Impact of Innovation on Formula One Success

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EXECUTIVE SUMMARY:

Formula One, also known as F1, represents the pinnacle of international open-wheel single-seater formula racing. Emerging in the 1950s, its evolution has been primarily fueled by a range of technological advancements, business strategies, and regulatory changes. From a physical standpoint, F1 drivers endure intense G forces and substantial fatigue over the course of the 22 race weekends in the calendar, with some races posing extreme challenges. This high-stress environment is exemplified by the fact that a driver can shed anywhere from two to four kilograms simply by finishing a race. Turning the focus to its technological aspects, F1 is a fiercely competitive arena. Teams recruit top-tier engineers to construct the quickest vehicle on the track in a bid to secure the drivers' and constructors' championships. As such, the pace of innovation in F1 is swift, with teams introducing new developments at nearly every Grand Prix. In a quest for even the tiniest edge, engineers are tasked to tap into vast reserves of creativity, aiming to create solutions that set new standards for the sport. This intensely competitive domain, where rules can change season by season and innovation is constant, provides an ideal backdrop for examining the process of innovation.

The objective of this thesis is to delve into this very process: the operation of innovation in F1, its role in shaping the competition over its seven-decade history, and its potential to define the future of F1.

To achieve this, I will journey back in time to explore the most pivotal innovations in the sport's history. I aim to understand the birth of these innovations and their impact on the teams that embraced them, studying their influence on car performance and team rankings. Drawing on this historical exploration, I plan to construct a model for F1 innovation, highlighting its triggers, effects, and pathways, and employing tools and historical data to evaluate the degree of radicalness of an innovation in this arena.

In the final portion of my study, I will analyze the new 2022 regulations, paying special attention to the budget cap rule. I will outline the reasons and objectives behind this rule, supported by comprehensive chart analyses. In conclusion, I will leverage these charts to evaluate the impact of the new regulations on the F1 competitive landscape, simultaneously attempting to comprehend their underlying causes.

CHAPTER 1: Introduction

From my early childhood, I've been captivated by racing, with Formula One seizing my interest above all others. The 2012 Brazilian Grand Prix saw an exhilarating final battle for the title between Sebastian Vettel (Red Bull) and Fernando Alonso (Ferrari). After a rough start and a collision, Vettel, from last place, patiently climbed up the ranks. Despite an intense race with multiple lead changes, the victory went to Jenson Button (McLaren), with Vettel finishing P6, enough to secure his third consecutive world title. The race also marked the final Grand Prix for Lewis Hamilton with McLaren and Michael Schumacher with Mercedes. It became a staple of my childhood weekends, and still is to some extent, to indulge in a race following a family lunch. When presented with the opportunity to pen a thesis on Formula One, I jumped at the chance without a second thought. Thus, my first driving force behind this work was sheer passion.

Alongside this passion, another motivating factor was the dynamic and competitive environment of F1. To me, it serves as the perfect stage for examining the mechanics of innovation and how outsiders can rise to prominence through the clever use of new technology. Unlike traditional businesses, success in Formula One isn't gauged by revenue or standard metrics (ROE, ROI, ROA, etc.), but rather by on-track results. This unique aspect makes the F1 circuit an optimal real-world laboratory to observe the ebb and flow of technology, uninfluenced by the financial fate of a company, and to comprehend how these innovations can affect the performance of both the innovating and adopting entities.

With this in mind, the goal of this thesis is to create an innovation framework specifically for Formula One. This would clarify what constitutes radicalness in this context and how teams can leverage it for competitive advantage. The resulting framework is expected to hold value not only for Formula One teams or those in the racing industry, but also for fast-paced, tech-driven sectors where innovation is key.

To achieve the objectives of this thesis, I will structure my work into three primary sections:

- The initial segment delves into the history of significant innovations in Formula One, recounting the competitive environment of their time, the process through which teams "discovered" and embraced these innovations, detailed insights on the emerging technology, and the impact of these novel developments on the performance of the adopting teams and the competitive landscape.
- The second section is dedicated to constructing the framework, which will be based on the innovations examined in the first part. Specifically, I will highlight the triggers, impacts, and pathways of innovation in Formula One, and assess technological radicalness utilizing lap times and standard innovation tools.
- The final segment will focus on the new 2022 regulations, elaborating on their influence on the competitive landscape. Of special interest will be an analysis of the budget cap rule, with an aim to comprehend its rationale for implementation and the potential effects it will have on innovation and the competitive scenario in Formula One.

CHAPTER 2: A Brief Retrospective: Tracing the Trail of Innovation in Formula One

In order to construct a framework that facilitates the understanding and analysis of innovation within the Formula One championship, it is essential to first comprehend its trajectory. In this chapter, I will delve into and elucidate the most significant innovations in the history of motorsport, expound on the benefits they offered to the adopting entities, and assess their impact on the performance equilibrium within the context they were incorporated.

2.1: Before the beginning of the F1 era

The first car competition took place in France in 1894, it consisted in a very basic 126 kilometers race from Paris to Rouen[1]. In 1906 the first edition of the Targa Florio, the oldest race car in the world that still exists today as a unifying event[2], was held, and in the closed circuit in Le Mans took place the first ever Grand Prix (called: GP), that was won by a Renault car. The first competition vehicles, fielded by major firms like Renault, Fiat, Mercedes Benz, and Peugeot, were straightforward adaptations of road vehicles. Racing was perceived as a spectacle, with success largely determined by the driver's abilities.

This perception underwent a transformation as motorsport's popularity surged. Winning teams began to enjoy enhanced status and increased sales, attracting more manufacturers into racing. The quest to build faster cars became critical, prompting engineers to brainstorm ideas that would give their vehicles a competitive advantage, primarily focusing on the engine to boost straight-line speed. Regulatory rules started to emerge, profoundly influencing the innovation process.

Despite a pause during World War I, motorsport innovation advanced, aided by developments in materials, fuel, carburation, cooling, and component design from war industry efforts. Companies like Bugatti and Bentley, although not as dominant as some of the bigger manufacturers, were quick to adopt these innovations. 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, allowed a minimum weight of 800 kilos and a maximum displacement of 3000 cm3, and were changed the next year (minimum weight of 650 kilos and displacement of 2000 cm3). This fast change of rules pushed the engineers in finding a way to improve the erogation of the mix air-petrol into the pistons.

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[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_4%C2%BD_Litre, https://en.wikipedia.org/wiki/Bentley_3_Litre, https://en.wikipedia.org/wiki/Bentley_Speed_Six,

[5] https://it.wikipedia.org/wiki/Formula_Grand_Prix

Fiat introduced the concept of forced induction[6], which became the standard and was quickly adopted by all manufacturers. The Formula Grand Prix is seen as the precursor of Formula One. The popularity of motorsport proliferated between the wars, leading to the construction of the first permanent racing circuits. Engineers continued to innovate, exploring new areas for potential advantages.

In the 1920s, the first aerodynamic bodyworks emerged, primarily designed to reduce drag resistance. Development primarily focused on engine and chassis, but engineers also began exploring other areas to gain an edge. In 1922, the Commission Sportive Internationale (C.S.I.), the regulatory body, prohibited cars from carrying spare wheels during races. As a result, tyre companies shifted their primary focus to improving tyre durability, seeking new formulations that would enable tyres to last the entire duration of a race. Additionally, the 1920s saw the emergence of the first aerodynamically designed bodyworks. While they were initially created to reduce drag resistance, this concept would be considered outdated in today's context.

The 1930s saw the motorsport performance balance shifting from France to Italy and Germany. Motorsport was imbued with patriotic sentiment, with the spotlight on the winning manufacturer and its nationality but not on the performance of the driver. Cars were painted with different colors in order to symbolize their country of origin, red for Ferrari, the Italian manufacturers; blue for the French team, green for the English cars and white for Germany. The dictatorships in Italy and Germany capitalized on this nationalistic fervor, investing in their country's manufacturers (Mercedes for Germany and Alfa Romeo for Italy) to achieve significant success, gain popular approval, and stimulate the automotive industry. As a result, Italy and Germany emerged as hubs of motorsport innovation, dominating every seasons the major competition for racing cars[7], the European Championship. The 1934 regulation change, which introduced a maximum weight limit, benefited German manufacturers who could build lighter, yet more powerful cars. In 1938, Mercedes, driven by Rudolf Caracciola, set a world speed record for cars of 432.7 km/h, a record that remained unbeaten over 80 years.
This public road speed record was broken on the 4th November 2017, by a Koenigsegg Agera RS driven by Niklas Lilja (max speed of 457.49 km/h).

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

After the Second World War, the motorsport's industry was considered as being a very controversial world. It wasn't a time for racing because most of the European cities needed to be rebuild from scratch. But in 1946, the Federation International de l'Automobile (FIA), prepared new set of rules that will regulate the cars (and the manufacturers) in order to offer to the public, the first post-war GPs. Two engines were allowed: the 4.5 liters atmospheric and the 1.5 liters supercharged[8]. In 1949 the FIA decided to create the Formula One World Championship, which was a group of seven GPs spread over the globe. The first race was held in

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

England at Silverstone and was won by the Italian driver Nino Farina (the latter became the first ever Formula One World Champion). The Italian manufacturers dominated the first seasons with Alfa Romeo and Ferrari winning the first four championships. In 1954, the FIA. revised the regulations, transitioning from the 2.0-liter engines, which were then utilized in Formula Two, to the more powerful 2.5-liter engines. Manufacturers, such as Alfa Romeo, Lancia, and certain British teams like Cooper and Vanwall, that relied on the less potent engines sought performance enhancements in other areas, leading to a wave of innovative solutions. For instance, Lancia opted not to simply install their new V8 engine into the car, but rather to incorporate it directly into the chassis. This strategy would later be successfully employed by Colin Chapman's Lotus nearly a decade afterwards. However, the most significant breakthrough came from a newcomer to the scene.

In reality, Mercedes regarded this change in the rules as a chance and opted to construct a vehicle to compete in the 1954 World Championship after taking a fifteen-year break from the sport. The end result of their labors was the W196[9], a very innovative car for its time. It was the first Mercedes racing car without a supercharged engine, the first machine to have a direct injection fuel system, which was inspired by the aircraft industry, and it had two types of bodywork: the normal one, used in normal or slow tracks and more conventional, and the Monza Type bodywork, designed to reach a higher speed and used in fast circuits like Monza and Reims. These groundbreaking innovations, which were unparalleled on the F1 grid at the time, allowed the W196 to dominate the 1954 and 1955 seasons. Despite making its debut only in the fourth race of the 1954 season, the W196 won nine out of the twelve races it participated in, making it to the podium ten times. It also played a key role in Juan Manuel Fangio securing two of his five world titles. The W196 was expected to race in the 1956 season as well. However, in the wake of the Le Mans Tragedy, where Mercedes' private driver Pierre Levegh and eighty-three spectators tragically lost their lives, the Mercedes manufacturer decided to withdraw from Formula One at the end of the 1955 season. They did not make a return to motorsport until 1987.

As Formula One began to wield significant commercial influence, the sport's popularity grew alongside an intensification of car development efforts, leading to increasingly faster vehicles. Unfortunately, the Le Mans Tragedy, the darkest episode in motorsport history, cast a long shadow over the sport. Races were banned in Switzerland, and some manufacturers like Mercedes withdrew from the sport to protect their reputation. During this tumultuous time, most major European manufacturers either ceased or reduced funding to their racing teams. The exceptions were those manufacturers like Ferrari and Maserati, who were initially established for racing and funded their activities through direct car sales. These manufacturers emerged as the leaders on the F1 grid. In the midst of this upheaval, Great Britain became the new epicenter of the F1 world. It began to produce talented drivers such as Stirling Moss, Peter Collins, Tony Brooks, and Mike Hawthorn, and motorsport enthusiasts started small racing teams or businesses associated with the sport.

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

Unlike established firms, these small British racing teams did not manufacture road cars to support their racing activities and lacked the resources to produce sophisticated components like engines. To stay competitive and save money, they had to outsource, which resulted in two significant benefits: decreased costs and access to components from specialized firms growing in their vicinity. This led to the birth of the racing district in England, where businesses and teams collaborated to create a synergy where the racing team was no longer the producer of its car, but rather the entity that consolidated the efforts of the surrounding businesses. Thus, the era of the "Constructors", as Enzo Ferrari would sarcastically refer to them, was born.

The Cooper Car Company, founded in 1946 by Charles Cooper and his son John, didn't possess the resources or prestige of the larger, established firms. They participated in the Formula One World Championship from 1950 to 1969, excluding 1951. Despite limited resources, they introduced a game-changing innovation: placing the engine at the back of the car for economic and technical reasons. This design was initially implemented in their Formula Three cars and later inspired the creation of the Cooper T43 for the 1957 Formula One World Championship. The rear engine placement, although unique in the F1 grid at the time, wasn't entirely new and offered numerous benefits, including a lighter, shorter, and more maneuverable car, as well as reduced drag. Despite initial skepticism from major manufacturers and drivers, the rear engine design proved its worth in 1958 when a Cooper T43[10], driven by Stirling Moss, won the Argentinian Grand Prix. The following year, Jack Brabham became the first driver to win the World Championship with a rear-engine car, repeating the success in the next year. This led to rear-engine cars becoming the new standard in F1, forcing even established firms like Ferrari to adapt. Cooper, a non-automotive firm or "Constructor", was the first to win both the driver's and constructor's championships in Formula One. Although they experienced a decline after 1960 and withdrew from F1 at the end of 1969, their innovations left an indelible mark on the sport and paved the way for more constructors in the subsequent years.

2.3: The 60s: Colin Chapman's Lotus & cigars

Security in F1 has always been the manufacturers' number one problem. To curb this, the FIA implemented safety-focused regulations at the end of the 1960 season. These included reducing maximum engine displacement to 1.5 liters, banning supercharging, setting a minimum weight of 450 kilos, and limiting fuel to a maximum of a hundred octanes. Consequently, car designs became more streamlined and shorter, earning the nickname "cigars." These rules remained in place until 1966, and during this period, only one fatal crash occurred at the 1961 Italian Grand Prix[11], where Ferrari's driver Wolfgang von Trips and fourteen spectators tragically lost their lives. This incident is remembered as the deadliest in Formula One history. When the new regulations took effect in 1961, Ferrari was the best prepared team, having the capability to build and refine its car internally. On the contrary, the constructors relied on several suppliers who, despite their specializations, produced standardized components and sometimes lagged behind in innovation due to serving multiple racing teams. For instance, following the 1961 regulation change, most English constructors halted their engine development and opted for

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

the readily available Coventry Climax, which was less powerful than Ferrari's engine. As such, with cars appearing nearly identical, teams began exploring advantages in areas other than engines, making the 1960s a period rich in racing innovations.

A key figure of this era was Lotus, established in 1958 by Colin Chapman, an ex-driver and RAF member. Known for its innovative approach under Chapman's leadership, Lotus achieved its first major breakthrough in 1962 with the Lotus 25[12]. At that time, F1 cars were built around a tubular chassis. Chapman, however, introduced the concept of a monocoque chassis for the Lotus 25, a unified structure combining chassis and bodywork. Constructed using aluminium sheets, this monocoque chassis was lighter, stiffer, safer, and cheaper than a traditional tubular chassis, freeing funds for further car development. The Lotus 25 was highly successful, winning 25 of the 42 GPs it competed in over four years and aiding Jim Clark in securing his two titles in 1963 and 1965.

In 1966, the FIA decided to double engine displacement from 1.5 to 3.0 liters. The new engines, at peak development, could deliver over 500 bhp (brake horsepower), an unprecedented power level in Formula One. However, this power increase led to higher speeds, escalating risks, and hence fatal crashes. The change also meant companies had to reorient their production, leading to high transition costs, especially for firms inexperienced with more powerful engines. Consequently, Coventry Climax, the main engine supplier to English constructors, decided to exit F1 in 1969. For the 1966 season, Chapman contracted with BRM, but the following year, he commissioned a bespoke engine for his team. Ford, then in a heated rivalry with Ferrari, funded the project with £100,000, and Cosworth was selected to build the engine. The outcome was the Cosworth DFV, a 3.0-liter V8 engine that was potent, lightweight, simple, and eventually reliable. With these attributes, the Ford Cosworth DFV[13] outperformed rivals like Repco, BRM, Weslake, and Maserati, becoming the new standard for F1. Lotus initially held exclusive rights to the DFV engine, but post-1967, it was sold to other teams, making it a top choice for constructors and new F1 entrants due to its accessibility (£7.500 per engine in 1967 or about £90.000 per engine in 2005). The DFV effectively replaced the Coventry Climax engine. With this, Ford recouped its 1967 investments by the start of the next decade, Cosworth gained economies of scale and valuable experience, and Lotus, along with other constructors, collected on-track benefits. The Ford Cosworth DFV, active in F1 from 1967 to 1983, competed in 262 GPs, achieving 155 wins, 12 driver's championships and 10 constructors' titles, earning its status as the most successful engine ever.

Chapman's ingenuity extended beyond the 1960s, with Lotus pioneering the use of wings on F1 cars, bringing downforce into the sport—a fundamental concept in modern Formula One. His RAF experience likely influenced this innovation. The Lotus 49[14] was the first to sport aerofoil wings and clinched two titles in 1968 and 1970, despite Rindt's tragic death during the 1970[15]

[12] https://en.wikipedia.org/wiki/Lotus_25
[13] https://en.wikipedia.org/wiki/Cosworth_DFV
[14] https://en.wikipedia.org/wiki/Lotus_49
[15] During the 1970 season, Jochen Rindt raced with the Lotus 49 in three GPs: Monaco, Belgium and South Africa. In his championship winning campaign, Rindt won the Monaco Grand Prix with the 49.

Italian GP qualifying. Its successor, the Lotus 72, was a groundbreaking F1 car. It introduced unprecedented features like side-mounted radiators, inboard brakes, and an overhead engine air intake. Its aerodynamic design made it 20 km/h faster than the Lotus 49, despite having the same Cosworth DFV engine. The Lotus 72[16] won three constructor's and two driver's titles, participated in 75 GPs, won 20, and became one of the most victorious F1 cars in history.

2.4: The 70s: It is getting serious…

The 70s marked the zenith of innovation in Formula One, with an unprecedented number of experimental solutions. The decade was dominated by the Ford Cosworth DFV engine, its power, simplicity, and affordability enabling a surge in "kit cars". The fierce tyre war led to Goodyear's introduction of slick tires in 1971, increasing grip and forcing competitors to adapt. Formula One's commercialization grew, with sponsors gaining influence over team revenues and even car liveries. Improvements in driver safety, led by Jackie Stewart, introduced fireproof suits, full helmets, and safety belts[17], which proved life-saving during Niki Lauda's 1976 accident.

However, fatalities remained high. Aerofoil wings and downforce were important advancements, but they increased drag, reducing straight-line speed. Teams sought a balance, leading to unique solutions, especially from constructors who had no room for engine improvement due to the dominance of the DFV. During this period, teams brought some of the most unconventional solutions to Formula One. Notably, Tyrrell P34[18], the "six-wheeler", had four front wheels aimed to reduce drag and enhance turn entry. Despite promising initial results, including a win, the car suffered from overheating problems and tyre development issues, leading to its abandonment in 1977. Lotus, struggling post the successful 72 car, introduced Lotus 76, which was quickly replaced after underperforming. The subsequent Lotus 77[19] had an adaptable suspension system, a precursor to active suspensions, but lacked steering precision and straight-line speed. It underperformed, leading to the creation of Lotus 78 by a team led by Tony Ruud, following Chapman's studies on airfoil and downforce. Lotus 78[20] was revolutionary, the first F1 car to utilize the Bernoulli principle for creating downforce. Initial testing at the Imperial College's wind tunnel with a moving ground showed promising results. On adding lateral cardboards to the model car, the downforce generated was phenomenal.
The shaping of the car's sidepods as inverted aerofoils generated significant downforce through "ground effect", sucking the car onto the track. This improved cornering speed without affecting straight-line speed. Two major issues arose: imbalance, leading to a large rear wing installation causing drag, offset by an unreliable, more powerful Ford DFV engine; and ineffective "skirts", which were improved by using moveable rubber. Despite these issues, the Lotus 78 won seven races and served as a testing ground for its more successful successor, the Lotus 79[21]. Dominating the 1978 World Championship, Mario Andretti, the champion, famously said the car could "paint the road". The Lotus 78 and 79 ushered in the era of "wing cars" in F1.

[16] https://en.wikipedia.org/wiki/Lotus_72
[17] https://www.formula1-dictionary.net/safety_seat_belts.html
[18] https://en.wikipedia.org/wiki/Tyrrell_P34
[19] https://en.wikipedia.org/wiki/Lotus_77
[20] https://en.wikipedia.org/wiki/Lotus_78
[21] https://en.wikipedia.org/wiki/Lotus_79

Recognizing the ground effect benefits, other teams, including Brabham, attempted to emulate Lotus' wing car design. However, Brabham, limited by their larger Alfa Romeo engine, innovatively used fans to create downforce, a concept inspired by the 1970 Chaparral 2J[22]. Despite initially impressive results at the 1978 Swedish Grand Prix, the fan cars were banned due to safety concerns, ending their era before it began. However, wing cars remained in play until 1982 when they were banned due to increasingly dangerous G-forces. Simultaneously, Renault introduced another significant innovation. In 1977, they debuted in Formula One with the RS01[23], equipped with a turbocharged engine - a first in F1. Turbochargers use exhaust gas energy to force more air into the engine, enhancing power. Despite its success in American racing series and at Le Mans, Renault's first year in F1 was challenging, with the RS01 proving cumbersome and noncompetitive. Despite the initial hurdles and frequent retirements, earning the RS01 the nickname "The Yellow Teapot" due to its tendency to smoke, the car began to show potential towards the end of its career with a fourth place in the 1978 Watkins Glen GP and a pole position in the South African GP. Its successor, the RS10[24], claimed victory in the 1979 French Grand Prix, marking the first win for a turbocharged engine in F1. Once reliability issues were addressed, turbo engines superseded naturally aspirated engines in performance, signaling the end of the Ford Cosworth DFV era, with its final victory in 1983 in Detroit with Michele Alboreto.

2.5: The 80s: The Turbo era

The 1980s are renowned as the turbo era. As mentioned before, Renault introduced this engine to Formula One in 1977. Initially, these engines were tremendously unreliable, but after several years of advancements, Renault began to see success. Consequently, more teams transitioned from naturally aspirated engines to turbo engines. This shift was largely due to the enormous power turbo engines provided. Throughout the decade, these power units generated up to 1000 bhp, sometimes even hitting 1200 bhp during qualifying laps - a record that has not been surpassed in Formula One. This was double the power of the naturally aspirated Cosworth DFV, which gradually became obsolete, marking its last championship win in 1982 and its final Grand Prix victory a year later. No established teams have used it since then. The sheer power of the turbo engines caused the FIA to be concerned about driver safety. Throughout the decade, the governing body attempted to limit turbo development with restrictive regulations. However, as the constructors found ways to maintain high power, the FIA ultimately banned turbo engines after the 1988 season. This season was dominated by the McLaren MP4/4, powered by a Honda turbo engine, a car that won 15 out of the 16 races in 1988.

Turning our attention to McLaren, the team was established in 1963 by Bruce McLaren, a driver from New Zealand, and made its Formula One debut in 1966. In the 1970s, the Woking-based team clinched its first constructors' title in 1974 and aided Emerson Fittipaldi that same year and James Hunt in 1976 in securing the drivers' title. However, post-1976, McLaren's performance declined, with the team finishing the 1980 season in ninth place, marking their worst-ever World Championship performance. In the same year, racing entrepreneur Ron

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[22] https://en.wikipedia.org/wiki/Chaparral_Cars#2J
[23] https://en.wikipedia.org/wiki/Renault_RS01
[24] https://en.wikipedia.org/wiki/Renault_RS10

Dennis merged his Formula 2 team, Project Four, with McLaren, forming McLaren Racing. He chose John Barnard, a former McLaren engineer, who had co-designed the McLaren M23[25], a championship-winning car, in 1972. Barnard, who had since gained a reputation as a "revolutionary designer" in the USA, was brought back to Woking.
Upon his return, Barnard identified carbon fiber as the ideal material for constructing the monocoque. At that time, all F1 cars featured aluminium monocoques, a standard that had been set in 1962, and carbon fiber was only used to reinforce weaker parts of the car. Due to its strength and lightness, carbon fiber was extensively used in the aerospace industry for building spacecraft and airplanes. Barnard had another reason for choosing carbon fiber. He intended for the car's chassis to be as close to the track as possible to optimize ground effect. However, this would have caused the aluminium to flex excessively, hence his need for a stiffer material.

At the time, Barnard was unable to find a UK firm capable and willing to construct such a complex carbon fiber chassis. Through a contact in America, he found a firm to build the monocoque for the McLaren MP4/1[26], the first F1 car with a carbon fiber monocoque. It won the 1981 British Grand Prix, marking McLaren's first victory since 1977. Later that season, a severe crash tested the car's safety, with the driver emerging unharmed thanks to the chassis' strength. The McLaren model was soon emulated, and carbon fiber became the primary material in racing car chassis construction. Despite its effectiveness, the MP4/1 never won a World Championship, but its successor, the MP4/2[27], won all the drivers' titles and two constructors' titles from 1984 to 1986. In 1987, Barnard left McLaren for Ferrari and began work on the 1989 project. Recognizing the importance of slimmer cars in the new era, he faced challenges with the gearbox design. He proposed a hydraulic gear change system operated by paddles at the rear of the steering wheel, removing the gearstick for better aerodynamics. Despite internal resistance at Ferrari, Barnard's semiautomatic gearbox design was chosen for the 1989 season. Although the Ferraris faced reliability issues, the car (the 640[28]) always placed in the top three when it finished races. The semiautomatic gearbox was quickly adopted by all teams and remains the standard in F1 today.

2.6: The 90s: The technology

The 90s are remembered as the technologic/electronic era. Throughout this decade, F1 teams incorporated advancements such as the semiautomatic gearbox, traction control, anti-braking systems, and active suspensions, which later found their way into everyday vehicles. As these were essentially driving aids, the skill needed to drive an F1 car decreased, leading the FIA to ban all electronic aids except the semiautomatic gearbox in 1993. The deaths of Roland Ratzenberger and Ayrton Senna in 1994 led to a focus on driver safety, with stricter chassis and crash test regulations. As a result of technological advancements, costs skyrocketed, causing historic constructors like Tyrrell, Lotus and Jordan to withdraw from Formula One. One notable driver aid was active suspensions. After Lotus' initial unsuccessful attempt in 1976, Peter Wright

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

of Lotus developed a computer-controlled hydraulic suspension system in 1981 to combat high-speed bouncing caused by increased downforce. This system was effectively the first instance of active suspensions in Formula One. The system was reintroduced by Lotus in 1987 and then by Williams in 1992, contributing to their dominance in the 1992 and 1993 seasons. Post the 1994 Imola accidents, FIA introduced rules to enhance driver safety. The most significant change in 1998 involved banning slick tires, reducing car width, simplifying brakes, and increasing the minimum dimension of the survival cell and side headrests. These measures aimed to slow down cars in corners to ensure safety. However, engineers immediately sought ways to regain cornering speed, leading to various solutions, including McLaren's development of a distinct braking system for the 1998 season. The bests cars at that time were the FW14B[29] and the MP4/13[30]. Rear brakes were manually used by drivers to manage oversteer inside corners, acting as a form of manual traction control. This system was unintentionally discovered when Darren Heat, a racing magazine photographer, noticed a glowing rear brake disc in a corner where acceleration was expected during the 1997 Austrian GP. This led him to hypothesize about an extra pedal for rear brakes, which he later confirmed through photographs at the subsequent Nürburgring Grand Prix. In 1998, McLaren introduced an advanced version of this system, leading the Australian Grand Prix. Despite being a manual system and thus legal, it was banned for the rest of the 1998 season due to pressure from opposing teams and protests to the FIA.

2.7: The new era:

In 1995, the FIA limited F1 engine displacement to 3.0 liters, prompting most teams, notably Ferrari, to favor 10-cylinder engines. Ferrari, led by Michael Schumacher, dominated from 1999 to 2004, winning numerous championships. Renault returned as a team in 2002 and, following a major regulation change in 2005, disrupted Ferrari's dominance by winning both constructors' and drivers' titles with Fernando Alonso. Renault's edge was partially due to the mass damper[31], a device that improved stability and aerodynamics, providing a significant lap time advantage. However, the FIA banned this device in 2006, deeming it a movable aerodynamic element. In 2009, F1 underwent significant regulation changes aimed at simplifying aerodynamics and reducing costs. This included the introduction of the Kinetic Energy Recovery System (KERS), which recycled braking energy, giving an additional power boost each lap. While embraced by teams like Ferrari and McLaren, others like Brawn GP ignored it. Brawn GP[32], led by ex-Ferrari technical director Ross Brawn, acquired Honda's F1 assets in 2008, focusing on aerodynamics instead of KERS. Brawn's double diffuser design proved highly successful, with the team winning both constructors' and drivers' titles in 2009. Brawn GP was then bought by Mercedes in 2010. Despite early difficulties, KERS eventually became a vital component, instrumental in victories for Lewis Hamilton's McLaren and Kimi Raikkonen's Ferrari. KERS also paved the way for hybrid power units, ushering in the era of Mercedes F1 Team dominance from 2014 onwards.

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29 https://en.wikipedia.org/wiki/Williams_FW14
30 https://en.wikipedia.org/wiki/McLaren_MP4/13
31 https://en.wikipedia.org/wiki/Tuned_mass_damper
32 https://en.wikipedia.org/wiki/Brawn_BGP_001

The Red Bull Racing team dominated the early 2010s in Formula One. The team originated from an energy drink company founded in 1984 by Austrian Dietrich Mateschitz, who developed a passion for sports sponsorship. In 2005, Red Bull entered F1 as a constructor by acquiring the Jaguar Team, and later the Minardi Team, renaming it Toro Rosso. This provided a platform for young drivers from Red Bull's academy. With the 2009 regulations change, Red Bull became a strong competitor, winning both constructors' and drivers' titles in 2010 with Sebastian Vettel, a product of their academy. Vettel also became the youngest World Champion and was the first to win a race with a Red Bull team. The Vettel-Red Bull partnership dominated 2010 to 2013, mirroring the earlier Ferrari-Schumacher success. In 2014, F1 introduced the most significant technical regulation change in its history to meet demands for more sustainable engines. The traditional V8 engines were replaced with 1.6-liter V6 hybrid turbocharged power units, which consist of six components.

- The **energy store** (ES), is the energy storage collected by both MGU-K and MGU-H.
- **MGU-H**: is connected to the turbocharger of the engine and converts heat energy from the exhaust gases into electrical energy. This energy can then either be used directly by the MGU-K or stored in the Energy Recovery System’s (ERS) battery for later use.
- **MGU-K**: is connected to the drivetrain of the car and works in two ways. Under braking, it operates as a generator, converting some of the kinetic energy lost during braking into electrical energy. This energy is then stored in the car's ERS battery. When driver needs extra power, the MGU-K operates as a motor drawing energy from the battery and providing boost of power to the drivetrain. This boost is equivalent to around 160hp and can be deployed for approximatively 33 seconds per lap.
- A **turbocharger** (TC), is a device that captures exhaust gases, combines them with air from the compressor, and then feeds this mixture into the engine. This process provides a “boost” of power. The TC generates energy, which is collected to the MGU-H.
- The **control electronics** (CE), controls the power exchanges between ES, MGH-K and MGU-H.
- The **internal combustion engine** (ICE), six-cylinder engines (V6), constructed in a V-configuration at 90 degrees, with a 1.6-litre displacement.

Approved in 2011, the new F1 regulations provided teams ample time to devise fresh engine solutions. After Mercedes' re-entry into F1 as a constructor in 2010, following the acquisition of Brawn GP, it expected the previous success to continue. However, despite the driving talents of Nico Rosberg and Michael Schumacher, the team faced significant struggles in the first two years. Upon announcement of the new regulations, Mercedes shifted their focus significantly towards this, while also enhancing their performance in 2012 and 2013. The engine became their primary area of attention. In 2010, they developed a four-cylinder in-line engine, but with the FIA's decision to adopt a V6 turbo-hybrid, they had to rethink their strategy. Mercedes eventually designed an engine distinct from its rivals, introducing the unique split turbo system. This involved placing the turbo and compressor in different parts of the engine, a small innovation that contributed significantly to their dominance in the subsequent eight championships. This culture of innovation, exemplified by the 2020 DAS system, helped Mercedes maintain their top position on the F1 grid. Even a regulation change in 2017 only slightly reduced their lead, allowing competitors to get closer to the Silver Arrows.

CHAPTER 3: What's inside?

After having seen the trajectory of innovation in Formula One, we can now apply this knowledge to establish a framework. This framework will illustrate how teams, manufacturers, and constructors foster innovation and construct a competitive advantage against their rivals.

3.1: What is innovation

Before dealing with innovations in Formula 1, it's vital to define innovation and its classifications. Innovation refers to the process of creating, developing, and implementing a new product, process, or service with the aim of improving efficiency, effectiveness, or competitive advantage. It's about finding new or improved ways of doing things that can have a positive impact on various aspects of society, from business and technology to social practices and environmental sustainability. Schumpeter expanded this definition to include the commercialization of these new concepts, distinguishing innovation from invention.

Innovation can be categorized in several ways:

- By the degree of change it brings to user behavior. If it doesn't significantly alter user habits, it's a continuous innovation, whereas if it impacts user habits substantially, it's discontinuous.
- By its effect on the overall product design. Component innovations don't change the entire product design, while architectural innovations transform the whole product shape.
- By its magnitude, indicating its deviation from existing technologies. Incremental innovation involves minor improvements and doesn't differ greatly from the prior technology, while radical innovation introduces an entirely new technology, not only to the firm but to the world.
- By its impact on existing competences. Competence enhancing innovation builds on pre-existing skills and knowledge, whereas competence destroying innovation makes previous know-how obsolete and necessitates new skills and methods for evaluation and management. Typically, incremental innovation is competence enhancing, while radical innovation is often competence destroying.

3.2: Innovation in Formula 1

From what have been said before, we can start to understand what means innovation in F1 and explain its causes and consequences.

Innovation in F1 has unique implications compared to traditional businesses. For an F1 team, the primary goal is to win races and championships by building a faster car. Therefore, innovation in F1 is any enhancement that allows the car to complete the race distance in less time than it could have without the innovation. It's important to note that performance improvements in one area (such as speed or grip) aren't considered innovations unless they offer a time advantage. We can classify F1 innovations similar to how we classify general innovations. The distinction between incremental and radical is particularly useful:

- Incremental innovations in F1 are minor enhancements that don't drastically alter the car's overall design, like a new front wing or a better-shaped bodywork. Teams introduce such improvements almost every weekend to enhance their car's performance or to adapt to a specific circuit.
- Radical innovations, on the other hand, are transformative changes that significantly shift the power dynamics in F1. These innovations offer a significant performance boost and give the pioneering team a substantial advantage over its competitors.

As radical innovations are a better example of how innovation work in Formula 1, we are going to have a focus on them in order to construct a more accurate framework.

Understanding how to quantify the radicalness of innovation in Formula One involves examining its impact on race time. As previously stated, a true innovation in F1 is any improvement that reduces the time it takes for a car to complete a race. Therefore, the degree of radicalness can be measured by the resulting lap time improvement. The more time an innovation shaves off, the more radical it is considered. The key question then becomes: how significant does this time reduction need to be to distinguish between a radical and an incremental innovation? To shed light on this, we can analyze the evolution of pole lap times at the Monaco Grand Prix from 1986 to 2010 as a reference.
If I chose the Monaco Grand Prix as a reference, it is because to be competitive/fast, you need a car that has excellent aerodynamic support. This is the most technical street circuit according to Marc Webber, Heïkki Kovalainen and a few others.

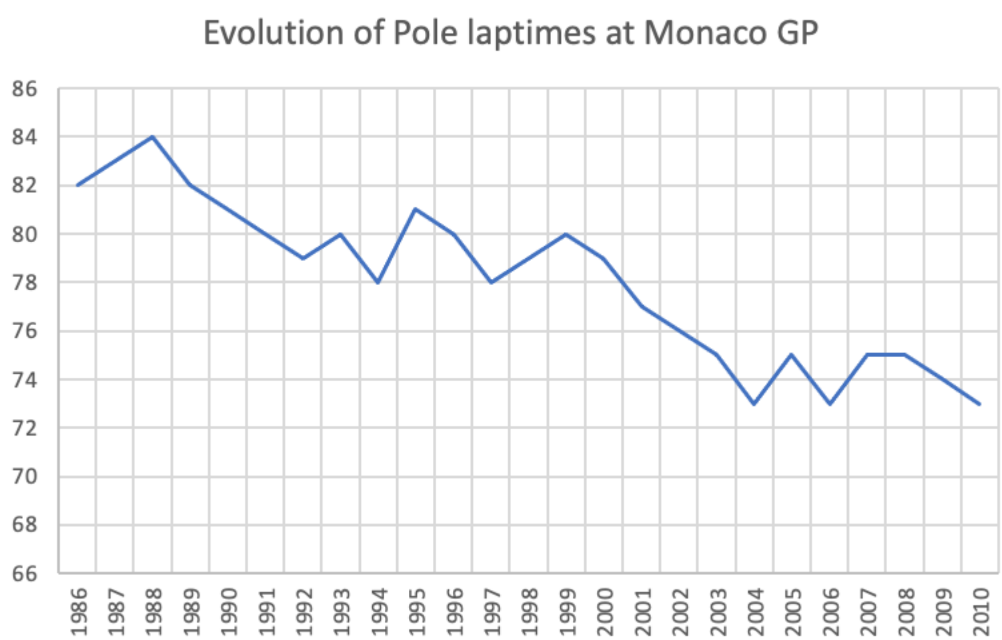

Chart 1. Data source: https://www.statsf1.com/it/circuit-monaco.aspx

In this chart we can see how the lap-times around the Monaco circuit have changed. In 2005 the qualifying time was composed of the sum of the two flying laps so, to make the chart the most realistic as possible, I decided to consider the fastest of the two laps from the poleman.

The lower point on the chart correspond to a faster time. As we can see, this era is the period from 2004 to 2010.

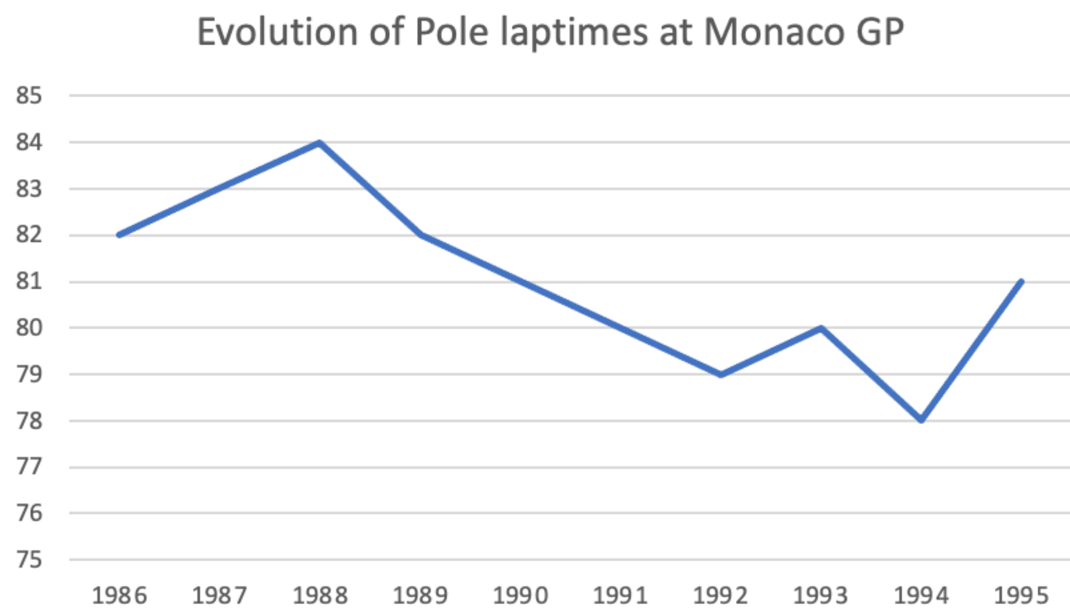

Chart 2. Data source: https://www.statsf1.com/it/circuit-monaco.aspx

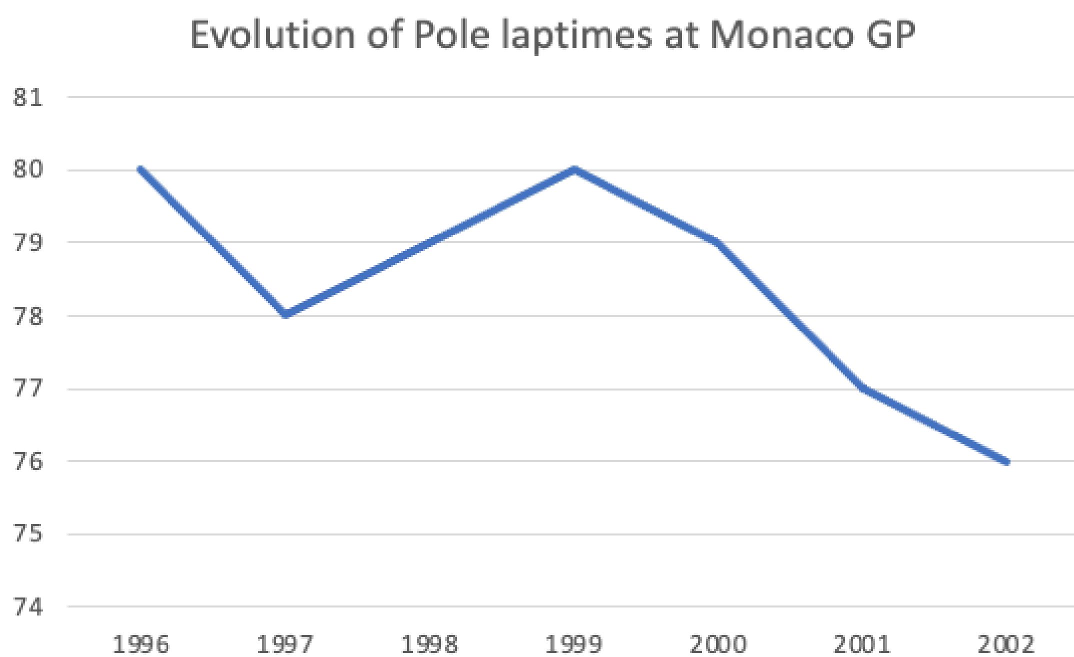

Chart 3. Data source: https://www.statsf1.com/it/circuit-monaco.aspx

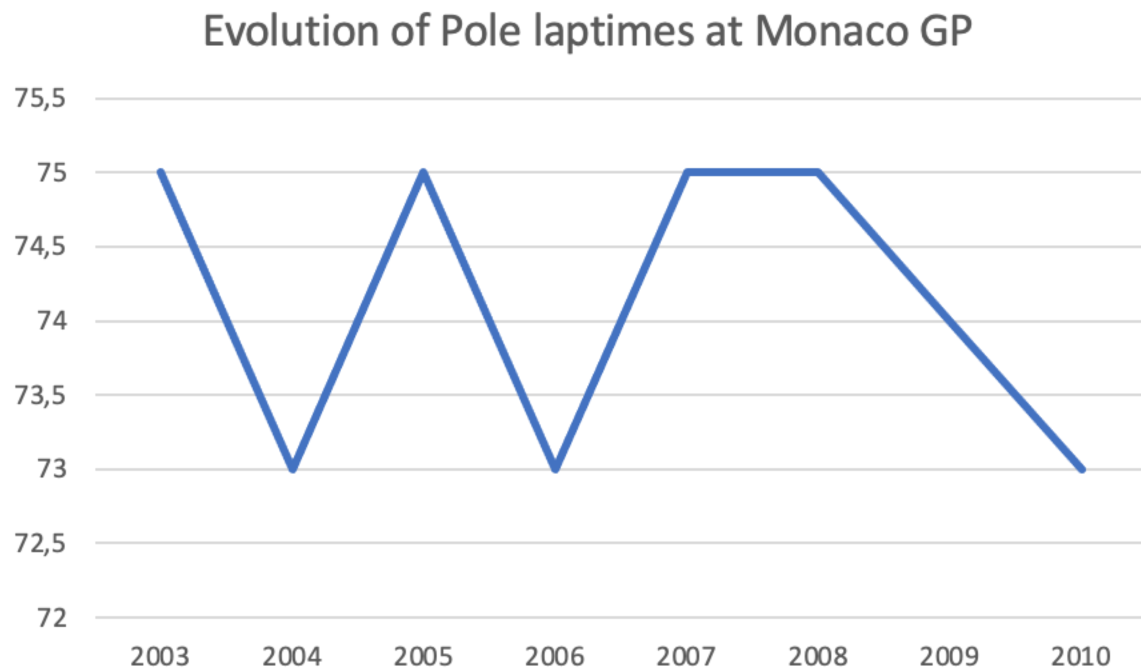

Chart 4. Data source: https://www.statsf1.com/it/circuit-monaco.aspx

The disparity between these charts stems from a variety of factors. The 80s were characterized by the 'turbo era' when turbo engines could reach up to 1200 bhp, a record yet to be surpassed in F1. As the reliability of turbos improved, peak performance followed suit. This was especially evident in qualifying sessions when engines were pushed to their limits. The carbon fiber monocoque was another critical innovation in this decade, enabling lighter and stiffer car designs that could harness turbo power effectively. Hence, it is also deemed a radical innovation. The slower pole times in 1987 and 1988 can be attributed to specific regulatory changes and shifting development focuses. The new millennium saw fewer significant innovations. However, the 90s' lap times were heavily influenced by the sweeping rule changes following Ayrton Senna's and Roland Ratzenberger's deaths in 1994, aimed at reducing racing speed. A similar major regulation change occurred in 1998. Even though electronic aids and active suspension are considered some of F1's most radical innovations, they aren't reflected as significant performance peaks. This is partly because active suspensions were banned soon after their effectiveness was proven, and only one team, Williams, utilized them, dominating the 1992 and 1993 seasons. Therefore, the radicalness of an innovation used by a single team can be measured by the advantage that team gains from it.

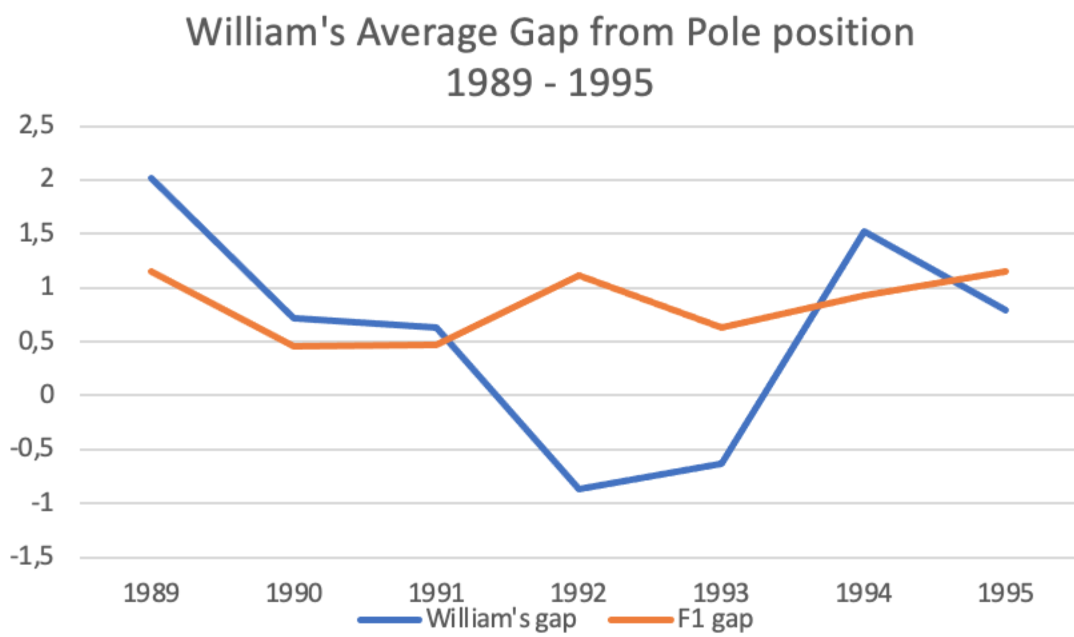

Chart 5. Data source: https://www.statsf1.com/it/circuit-monaco.aspx

This chart effectively demonstrates the transformative power of radical innovation in reshaping the competitive landscape. Specifically, it represents the average time difference between the pole position and the first Williams car in every qualifying session from 1989 to 1995. When Williams secured pole, the gap was calculated between pole position and the fastest car of a different team, and this number was considered negative. Simply put, a lower point on the chart signifies a quicker Williams car. I've also included the F1 general gap for those years, an average time difference between the first and second teams in qualifying sessions, to provide a reference for those years' competitive dynamics.

In 1989, Williams, on average, lagged behind McLaren, the frontrunners, by 2.024 seconds. This gap shrank to 0.629 seconds in 1991, a year after the arrival of talented engineer Adrian Newey. In 1992, Williams introduced active suspension with the FW14B, an evolution of the previous season's FW14. This innovation granted Williams a significant advantage, with the average gap from pole position at -1.113 seconds in 1992. This meant that Williams had an average advantage of 1.113 seconds over all other teams, a net gain of 1.7 seconds from 1991. This significant advantage was obtained in just one season. However, with the banning of all driver aids, including active suspensions, in 1994, Williams lost this edge. Despite this, Williams remained a strong competitor, notwithstanding the profound impact of Ayrton Senna's death that season.

The same methodologies, both the one-adopter and the all-adopter, can be used to assess the ground effect's radicalness, another crucial 20th-century Formula One innovation. To discern why it's considered a radical innovation, I'll use the same process I employed for prior innovations. I'll use data from the Interlagos circuit (1973-1980) and the Buenos Aires circuit (1974-1981) as test tracks.

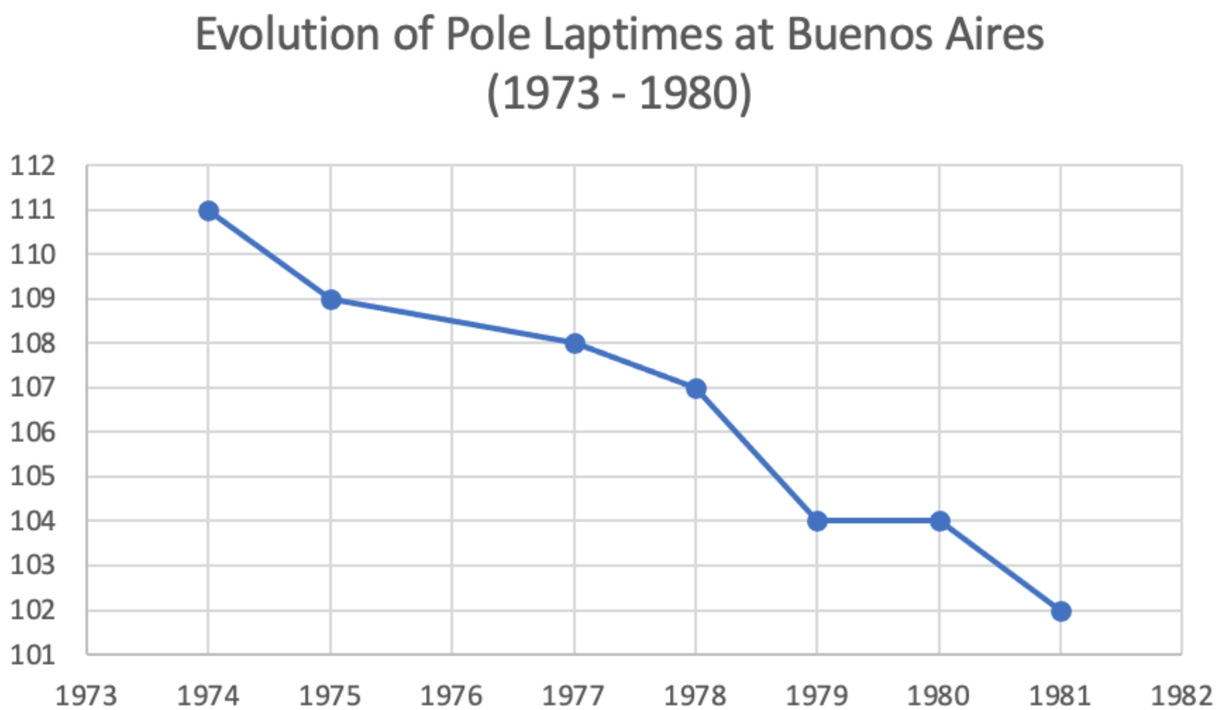

Chart 6. Data source: https://www.statsf1.com/it/circuit-buenos-aires.aspx

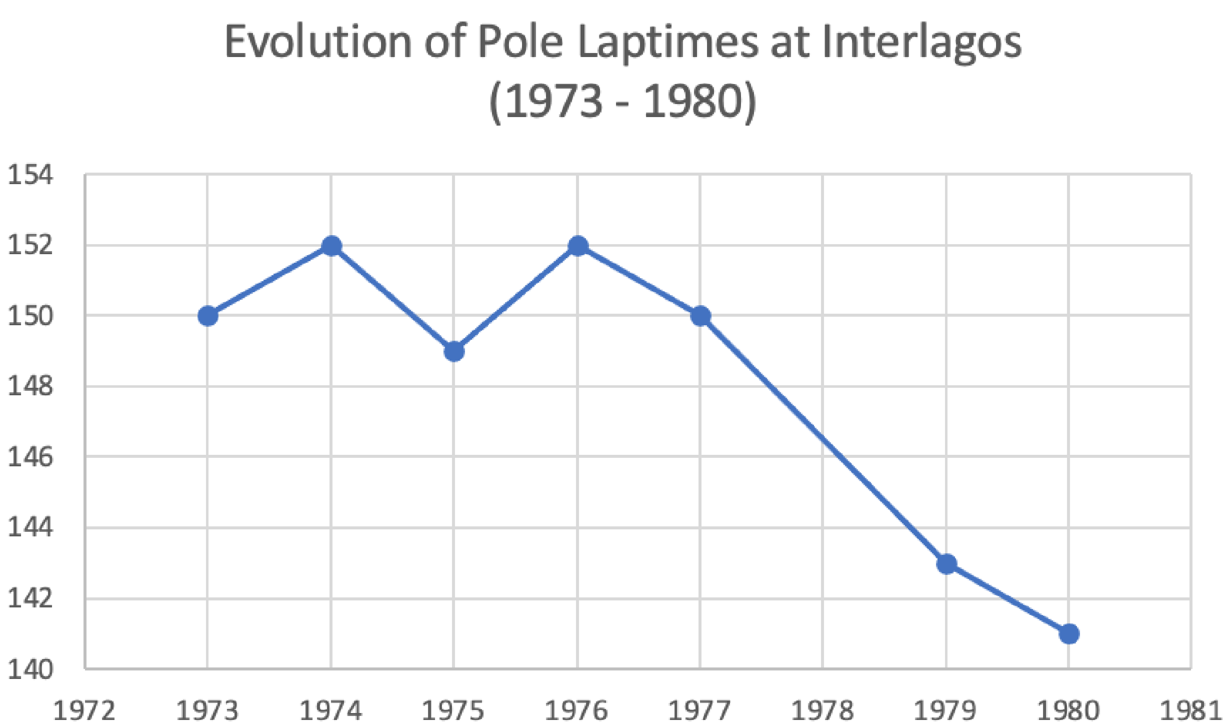

Chart 7. Data source: https://www.statsf1.com/it/circuit-interlagos.aspx

To provide context, the ground effect was first introduced in 1977 with the Lotus 78. A performance surge can be observed in both charts post that year. However, it's crucial to note that the discovery and development of the ground effect, along with the introduction of turbo engines, contributed to an approximate 3s time gain on the Buenos Aires circuit between 1978 and 1979. This gain is equal to the time saved between 1974 and 1977, a more extended period, which is quite impressive. This performance spike is even more evident on the Interlagos chart: prior to 1976, the times appear almost static, but a significant performance surge is noticeable from 1977. This surge halts after the 1983 ban on skirts but resumes in 1985 due to turbo engines. Given this substantial reduction in lap times, the ground effect is considered a radical innovation.

Even if I apply the one-adopter method used for active suspensions and adjust it to the ground effect, the conclusion remains the same.

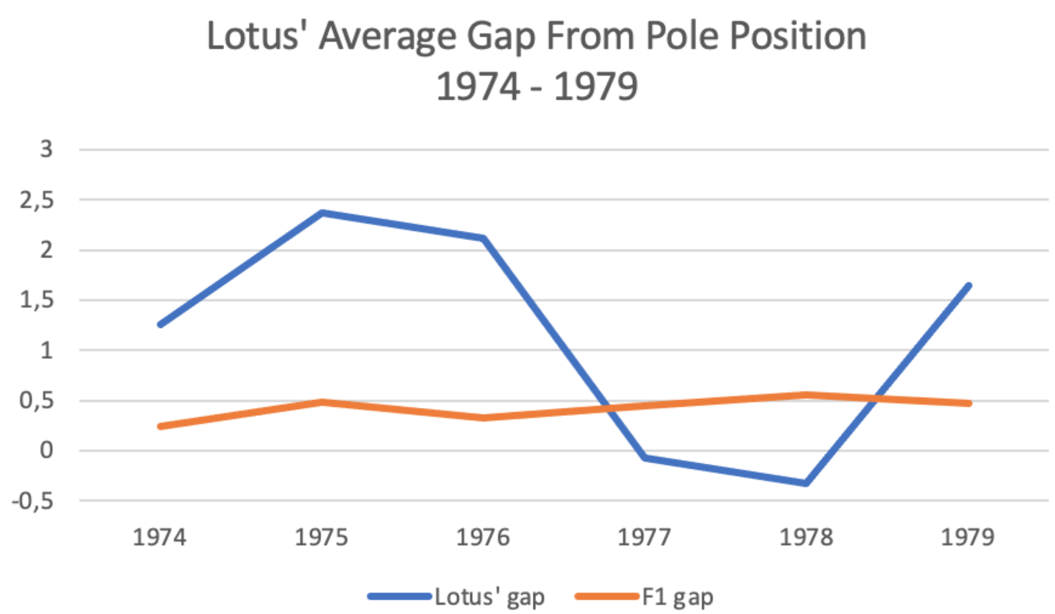

Chart 8. Data source: https://www.statsf1.com/it/lotus/pole.aspx

Having secured consecutive constructors' championships in 1972 and 1973 and contributing to Emerson Fittipaldi's first drivers' title in 1972, Lotus didn't perform as expected in the years 1974, 1975, and 1976. They were notably distant from the top positions, with an average gap from pole position of 1.884 seconds in those years, considerably higher than the F1 average of 0.367 seconds. However, their performance significantly improved after introducing the first ground effect car in 1977. By 1978, post the innovation's development, they had an average advantage of 0.312 seconds over the other teams, as depicted in the chart. In 1979, as other teams developed their ground effect cars, Lotus's competitive edge declined.
To close this section, it can be stated that Formula One witnesses both radical and incremental innovations. The radicalness of an innovation is measured by the advantage it provides to the team if the innovation is adopted by one team, and by the surge in overall lap times if the innovation is adopted by multiple teams or the entire field.

3.3: Impacts of Innovation in Formula One

Innovation or technological advancement is always triggered by certain factors. These include external shifts, serendipity, and competitive pressure from the environment. The second chapter explored the trajectory and history of innovation in Formula One, outlining the birth and evolution of new technologies. Based on this path of innovation, the primary drivers of innovation in Formula One are twofold:

- Changes in the regulation
- Catching-up situations

3.3.1: Changes in the regulation:

Some of the major concerns in Formula 1 include:

- Safety
- Costs and Budget Caps
- Competitive Balance
- Environmental Impact
- Technological Changes
- Diversity and Inclusion

Despite significant advances in safety over the years, motor racing will always carry inherent risks. The FIA continuously works to enhance driver, team and spectator safety. Safety is paramount in Formula One rule-making. Regulations often evolve to enhance driver safety. For instance, in 1961, engine displacement was reduced from 2.5 to 1.5 liters. Significant changes also followed the tragic deaths at Imola in 1994 and in 1998. While safety-focused regulations, aimed at slowing cars down, usually maintain grid stability, radical changes can bring unexpected leaders, as seen when McLaren dominated in 1998 after a fourth-place finish in 1997.

F1 is a highly expensive sport, with teams spending hundreds of millions of dollars annually. To level the playing field and ensure the sustainability of the sport, the FIA has introduced cost caps, which have been a point of discussion.

There is often concern about a lack of competitive balance in F1. Some teams with larger budgets have tended to dominate, which can make races less exciting for fans.

The environmental footprint of F1, including the carbon emissions of the cars and the impact of hosting races around the world, is a significant concern. The sport has been taking steps to address this, including plans to be carbon neutral by 2030.

Regular changes to technical regulations can pose challenges for teams, who must continuously innovate and adapt their cars to comply with new rules.

F1 has historically lacked diversity, both on the track and in the teams behind the scenes. There are ongoing efforts to address this issue and make the sport more inclusive.

3.3.2: Catching-up situations:

Catching up situations in Formula One occur when a trailing team seeks to close a performance gap with the frontrunner by either overcoming their disadvantage or gaining an edge in another aspect of their vehicle. These situations can lead to innovative, unconventional solutions that disrupt the grid order. For instance, in 1978, Lotus successfully applied ground effect technology in their Lotus 78 and 79 cars to regain competitiveness. However, not all catching up efforts succeed. In the mid-70s, Tyrrell's six-wheel car failed to meet its goals despite promising performance, leading to the project's cancellation. While innovation often stems from smaller, agile firms, it's worth noting that leading teams in Formula One also continue to innovate, regardless of their standings.

3.4: Consequences of Innovation in Formula One

When an innovation is unsuccessful, the innovating team typically abandons it, and other teams do not adopt it. However, if the innovation proves competitive, then two scenarios can be followed:

- Adoption
- Prohibition

In the former, rivals may replicate the innovation or introduce their own advancements to regain competitiveness, as seen with wing cars, turbo engines, carbon fiber, and rear-engine cars. The simplicity of these technologies facilitated further innovation. Alternatively, teams might petition the FIA to declare the innovation illegal if it provides a significant advantage to a competitor. The FIA has the final say on whether to ban it, as with the Brabham fan car, or rule it legal. For safety reasons, the FIA can also independently deem an innovation illegal, like it did with turbos and wing cars in the 80s due to the high speeds they enabled.

Before going to the conclusion of this chapter, I'd like to talk about Red Bull's "triple DRS". The triple DRS in Red Bull refers to three things:

- The standard DRS, available to all teams.
- A power boost when the DRS is open, giving them a higher top speed than the rest of the grid.
- A power boost on the straight without DRS, allowing them to be faster than others on the straight without DRS.

Red Bull does not have three DRS on its car, but the combination of all these positive effects allows them to have a monumental lead over the rest of the field, in all conditions (with or without DRS).

How do they do it?

They have designed a rear train that gives them two significant advantages, the rear wing and the "beam wing[33]" (this is the lower rear wing). If the beam wing is so important, it is probably because it is what allows Red Bull to have so much lead over its competitors.

[33] https://www.motorbox.com/auto/sport/f1/news/dizionario-f1-che-cosa-e-beam-wing

On the beam wing, there are "flaps", these are wavy carbon parts placed at the back of the car and usually there are several on the beam wing. Red Bull has a more aggressive design than the competition on the shape of the lower part of the beam wing (much wavier than at Ferrari and Mercedes for example). The beam wing is a part that allows teams to optimize the airflow to gain stability and improve the performance of the diffuser. But it can also be used to reduce aerodynamic drag, which improves straight-line performance.

The beam wing reproduces the DRS effect on the back of the car. Red Bull has made the rear part of the car work as a single tool. A tool that reduces aerodynamic drag in all conditions. On the straight with the DRS, they get a power boost, that's two DRS. But in fact, this "fake DRS", also applies to the whole race, so it's three DRS.

For comparison, at Ferrari the beam wing has been shaped in a very different way, it is smaller and the elements at the back of the car are arranged differently. Back to Red Bull, it's not only thanks to the shape of the beam wing that the car is so performant, it's thanks to the excellent coordination of the rear train.

The beam wing is not the only element responsible for the effectiveness of the DRS, we should also talk about the shape of the rear wing, or rather its lateral extremities. It's a very sensitive area to drag and it's common to observe a vortex effect in this area (air accumulating and slightly braking the car on the straight).

3.5: Strategy in Formula 1

Tactics in F1 is absolutely everything. It can be the difference between winning and losing. Minor fractions of a second lost due to a bad strategy call can be worth millions when all is said and done at the end of the season. One of those crucial decisions that F1 teams and drivers have to go through is when to take their pit stops and what tire to go on? Now on the term undercut is thrown around a lot in commentary.

But what they actually mean?

The 2021 American grand prix is going to be our based-on example. Lewis Hamilton versus Max Verstappen.

- The undercut: is definitely the most fun strategy option if you're a driver, it allows you to go on the aggressive and potentially gain a few places by pitting sooner than the cars you're chasing ahead using COTA (Circuit of the Americas) in this example.

Lewis got the lead at the start and the Red Bull couldn't make a move on track so, it turned to strategy to get max track position. The best solution was to pit early, come off the wearing tires that have been on since the start of the race and put on a fresh set. Now each team knew that the other had to make two stops due to the nature of tire degradation around the circuit. So, it immediately, at this point in the race, gave Verstappen the pace advantage on his new set of hard tires. The fact that he was much quicker than Lewis on his first lap out the pits meant the

Mercedes and Lewis couldn't react to this strategy call by Red Bull and had to commit to staying out longer.
So, what were Mercedes thinking with leaving Lewis out? If he pit the next lap, they would have become victims to the undercut as Max would have passed them on track and they wouldn't have really gained any advantage whatsoever other than one lap fresher tires which wouldn't be enough to pass Max on track. Therefore, if we skip ahead to the second round of pit stops Lewis and Mercedes executed the overcut.

The overcut: can be used in a few different situations but two main one's springs to mind.

- One is when a track is far too difficult to overtake and you're stuck behind a much slower car and simply wait for them to pit, use whatever is left in the tires and pass them by having much more pace over the next few laps and then taking the pit stop
- The second, is what we saw in the US Grand Prix. Hamilton was utilizing the extra few laps he went in the first stint over Max, to then extend even further into the second stint.

This wasn't to try and pass the Red Bull in the pit stops because he was much slower. The aim of doing this was to have a massive tire advantage in the last 20 or so laps in the race. This element of the overcut is aggressive in its own right but just later on in the race when the undercutters start to struggle because they committed their strategy to pitting early. Red Bull had decided early doors that they were going to go on the aggressive, pit early both times and get track positions. This was most likely because they knew they had the best package and also the fact that Verstappen had a much lower top speed. So, overtaking Hamilton on track was going to be difficult. There was maybe a small window of opportunity for Lewis as he closed up on his first set of hard tires to try the undercuts but he just wasn't able to get close enough for the Mercedes strategy team to decide that pitting him one lap earlier popping in a stonking out-lap would have been enough to jump the dutchman.

This was a strategic masterclass by Red Bull, not only with Max but also with Sergio. They also technically undercut him too against Lewis, which forced Mercedes to react sooner than they would have wanted. Otherwise, Sergio Perez on his fresh rubber would have passed Lewis after the first round of pit stops.

To sum up, there are many factors that teams can take into account when deciding to undercut or overcut. Overcutting in most examples is for teams that have a pace advantage over their competitors or if they simply have to try something different in order to beat a team that they're very close on pace with (what we saw in the US Grand Prix). Undercutting, is primarily for obtaining track positions, which works much better at circuit where it's very difficult to overtake.

3.6: Conclusions

In this chapter, I've outlined a framework for innovation within Formula One. To recap, we've established that:

- Innovations in Formula One can be categorized as either incremental or radical
- The radical nature of an innovation in Formula One is determined by the time advantage gained by the innovating team. If the innovation is adopted by multiple teams, its radicalness is assessed by the overall increase in championship speed
- The primary drivers of innovation in Formula One are regulation changes and attempts to catch up
- The outcomes of innovation can either be imitation by competitors or prohibition of the innovation by the ruling authority.
- Strategy can give a serious advantage to teams when it's about winning races.

Chapter 4: The Modern F1: Implementation of Budget Cap and Updated Regulations

As discussed in the previous chapter, regulation alterations are a significant catalyst for innovation in Formula One. We noted that the more transformative a regulation change, the more likely a shift in the established order becomes. Therefore, it's crucial to comprehend how new regulations can alter Formula One's competitive dynamics and how teams adapt to these new rules. In this chapter, I'll use the 2022 regulation changes as a case study to explore the rationale behind F1's decision to amend the rules, how teams navigated the new sports code, and the resulting shifts in the competitive landscape.

4.1: Purpose and Implications of the 2022 regulations

In 2017, FIA enacted one of its most significant rule modifications in its history. The cars at the time were deemed too simplistic to operate, too sluggish, and lacked aesthetic appeal. To address these issues, F1 initiated a radical transformation: the cars were made larger, their bodywork was entirely revamped with additional aerodynamic features, and the tires were upsized. Consequently, the 2017 models were, on average, 2.6 seconds quicker than their predecessors and possessed a more attractive look. However, as years went by and development continued, the cars became increasingly aerodynamically sophisticated. According to Formula One data, by the end of 2021, a car could lose between 35 and 46% of its downforce while pursuing another car. This downforce loss made overtaking more challenging, leading to less exciting races often decided by strategy and pitstops.

In an effort to enhance race excitement and boost the number of overtakes, F1 executed one of the sport's most radical regulation transformations. The car's bodywork was stripped of most of the aerodynamic extras and the front and rear wings were simplified. To offset the downforce loss, FIA reintroduced the ground effect in Formula One for the first time since 1982 by permitting Venturi channels at the car's floor. As per Formula One data, these changes helped reduce the downforce loss in trailing situations to between 4 and 18%. Furthermore, the tires were upsized (from 13 to 18 inches) for a lower profile, with more space allocated to the rims. To make the championship more sustainable and aim for net-zero emissions by 2030, Formula One initiated research into sustainable fuel, mandating that from 2022, every car's fuel must contain 10% ethanol. However, a year earlier, one of the most crucial innovations was introduced, not in the technical domain, but in the financial arena.

4.2: The fiscal limit aka the "budget cap"

In 2021, Formula One made an unprecedented move in its history by instituting a budget cap to restrict team spending on development and other factors that confer a competitive edge. The Cost and Performance Cap, which covers only certain expenses that provide teams with an advantage, such as R&D and manufacturing, was established at $145 million for 2021. This was subsequently reduced to $140 million for 2022 and will further decrease to $135 million in 2023, where it will remain until 2026, at which point it will be reviewed. An initial effort to introduce a budget cap in 2010, to mitigate the impact of the 2008 global financial crisis, led to a dispute[34] between FIA and FOTA (Formula One Teams Association), which nearly resulted in the collapse of the 2010 season. Over a decade later, the budget cap became an essential feature of the Formula One championship.

Specifically, following the 2014 rules change, which led to the adoption of hybrid engines, the cost of competing in Formula One began to skyrocket. Over time, this resulted in a significant issue concerning the so-called positive feedback loops in the championship. A positive feedback loop is a system where the outcome of an effect enhances the effect itself. In this manner, the consequences "cause the causes" of themselves, leading to continual growth as long as they persist. To illustrate this concept, consider the example of a fire. If you ignite a pile of wood with a match, a fire will start. The fire, to sustain itself, needs heat. When it finds it, the fire expands, generating more heat, leading to a larger fire, which in turn produces more heat, and so on.

In Formula One, every team's goal is success, which requires talented drivers, competent engineers, financial liquidity, and robust partnerships. If a team has all these elements, it's likely to be successful. This success means that the prosperous team will attract the best drivers and engineers due to the winning opportunities and potential for personal growth it offers, the best sponsors and higher prizes will inject more funds into the team, and better partners will come forward. All these factors will result in more success, which will then enhance the components mentioned earlier.

A positive feedback loop also operates in reverse: if a team is less successful, it could lose its best drivers and engineers to a more successful team, the prizes and sponsorship agreements might not be as lucrative, and the partnerships may not be of the same quality as those of the top teams, leading to even less success. While positive feedback loops have always existed in Formula One, their growth in the last decade has been unprecedented.

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

Wins in F1 per Team 2014 – 2022:

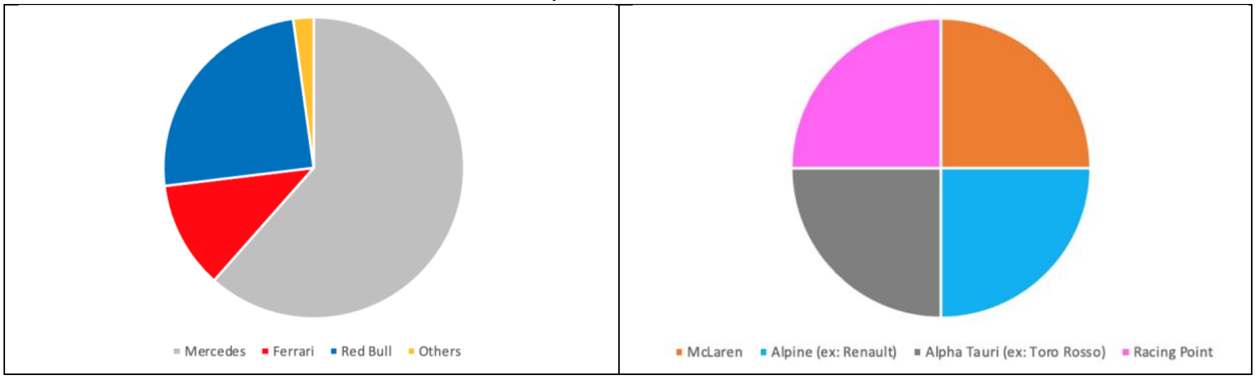

Chart 9. Data source: https://www.statsf1.com/it/saisons.aspx

The dominant trio of Mercedes, Ferrari, and Red Bull have claimed victory in 178 out of 182 races contested, meaning these three teams alone have won over 98% of the races. The only other teams to taste victory during this period were McLaren, Alpine (formerly Renault), AlphaTauri (previously Toro Rosso), and Racing Point. However, these victories have all occurred in the last four seasons and were largely in unpredictable, non-linear races.

Over the past decade, the soaring costs have transformed Formula One into a playground for the most affluent. The "competitive elevator", which once allowed fewer wealthy teams or outsiders to aspire to a championship win, has effectively ceased to exist. Currently, Red Bull, Ferrari, and Mercedes possess significant technical and financial advantages over the rest of the field. If a race proceeds without major incidents, one of these three is almost certain to claim the win, leaving the others with little to no chance of even securing a podium finish. Moreover, having more resources at their disposal, these teams are better positioned to explore and implement innovative solutions, effectively diminishing the chances of lower-ranked teams making groundbreaking discoveries.

Given this competitive landscape, it's difficult for anyone to contemplate forming an F1 team and realistically aspire to win races and championships. The introduction of the budget cap was aimed at creating a more balanced championship, where smaller teams such as Haas or Alfa Romeo could at least begin on equal financial footing with the frontrunners. The coming years will reveal whether the budget cap achieves its intended results.

CONCLUSIONS:

Formula One provides an optimal environment for exploring the mechanics of innovation and understanding the shifts in technology and power structures. As highlighted in my previous work, the annals of the Circus are replete with tales of teams scaling the rankings through ingenious, audacious innovations, securing their place as leaders in the pack.

However, recent times have seen significant changes. The cost of running an F1 team has escalated dramatically over the past decade, an unparalleled trend. The financial gap between the top-tier and lower-ranking teams continues to widen each year. Consequently, the "competitive elevator", which once enabled smaller teams to compete for leading positions, has ground to a halt. The larger teams leverage their budget surplus to explore a myriad of car improvements, a luxury not afforded to the less well-funded teams. As a result, the established teams - currently Mercedes, Ferrari, and Red Bull - have created a quasi-oligopoly, monopolizing victories, podium finishes, and World Championships.

Alongside these financial challenges, Formula One and its teams are grappling with a crucial technological hurdle. Rising environmental concerns have rendered normally aspirated engines obsolete, necessitating the development of more sustainable engines. This gave rise in 2014 to the hybrid-turbocharged power units currently in use and likely to be retained in the foreseeable future. These power units are technological marvels, boasting a thermal efficiency of 50%, double that of conventional engines. However, their complexity and high cost make them unsuitable for everyday road vehicles.

These dual challenges pose a significant barrier to entry for smaller constructors and even major manufacturers and represent an existential threat to Formula One itself, though efforts to address these issues are underway.

Financially, as discussed in the previous chapter, Formula One has introduced a budget cap aimed at fostering more equitable competition, at least in financial terms.

Regarding engine technology, Formula One is devising new engine regulations for 2026, targeting the development of less complex and more sustainable power units. The exclusive use of fully electric engines, a characteristic of Formula E until 2039, is not currently an option. Therefore, Formula One is exploring the development of a new 100% non-fossil fuel to power the engines. From 2026, the engines will remain hybrid, but without the MGU-H, making them less expensive and possibly aiding major manufacturers in developing new engines for their road vehicles. This prospect is attracting significant manufacturers like Audi and Porsche to consider participation in the championship. On the sustainability front, Formula One has launched an initiative to achieve net-zero carbon dioxide emissions by 2030, an ambitious target.

Thus, Formula One is engaged in two simultaneous struggles - one financial, the other technological - that will shape its future and potentially determine the continuity of the Circus.

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