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Innovation in Racing: A Qualitative Study of The Role of Motorsport Competitions as Catalysts of Technological Progress

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1. Introduction

In the context of the automotive industry, technological innovation has always been a crucial element for the progress and competitiveness of companies. Notably, motor racing championships have historically played a central role in this process, providing a unique platform for the experimentation, development and diffusion of often cutting-edge technical solutions. Indeed, such competitions, due to competitive pressure, extreme conditions of use and public exposure, offer a unique environment in which to develop and test advanced technologies prior to their potential large-scale adoption in industry.

However, it cannot be said that all competitions have had, or still have, the same impact in terms of technology transfer to the reference industry, as there are considerable differences between them, which lie not only in the technologies developed, but also in the structure of the championship itself, its regulations, economic constraints and the design freedom granted to teams. It is in fact from these observations that the objective of this thesis arises, that is, to analyse the main factors that characterise motor racing championships as instruments of innovation, to understand their mutual interactions and to assess how these elements have an impact on the ability of each championship to generate innovation relevant to the automotive industry.

In particular, the work aims to investigate which combination of variables present in such competitions, including technical regulation, competitive pressure, collaboration with industry, economic sustainability, freedom of experimentation and sporting attractiveness, is most effective in fostering innovation and its transfer to the production sector. To do so, the analysis will focus on three different models of automobile competition, with the aim of understanding which among them has proven, historically and systemically, to be most efficient in fulfilling this function.

To this end, the first step will consist in defining the concept of staged competition, that is, a structured and repetitive form of regulated competition, used as a tool to stimulate innovation within a specific sector, and of which motor racing is the highest expression. Therefore, in this phase, the mechanisms that constitute the core of these competitions will be analysed, since an accurate understanding of these dynamics is essential in order to critically assess the structure of the various championships and their real effectiveness in generating technical progress transferable to the industry. In fact, this analysis will then provide the theoretical and methodological basis to compare the competitive models under study and to identify the conditions that best favour systemic innovation in the automotive sector.

Subsequently, the thesis will address, through an extensive historiographical analysis, the evolution of three relevant motorsport models: the initial phase of motorsport, as well as the Formula 1 and Formula E championships. For each of these cases, the main evolutionary phases will be examined, both from a regulatory and technical point of view, as well as the technical evolution of the cars themselves. In particular, the analysis will focus on the driving forces that have determined the evolution of each championship, whether technological, economic, political or cultural, with the aim of identifying the turning points at which the balance between experimentation and regulation has had a significant impact on the direction of technical development. This historical journey will thus make it possible to understand and highlight the three different approaches to the management of competitive innovation of these competitions, providing a solid basis for the subsequent comparative analysis of the models examined.

Finally, on the basis of the evidence gathered in the previous chapters, the systematic comparison between the three competition models analysed will be conducted, with the aim of identifying similarities, differences and recurring dynamics. This analysis will culminate in the construction of a causal model, aimed at representing in a structured manner the relationships between the main variables that characterise each of these staged motor competitions, making it possible, through this model, to assess the extent to which each championship has succeeded or still succeeds in fostering the transfer of technology to the automotive sector, and under what conditions this transfer is most effective. Furthermore, the model will make it possible to highlight the trade-offs and limitations inherent in each competitive system, thus offering a critical and comparative key to optimising the innovative impact of motor racing.

2. Innovation and Competition

In this chapter, we will analyse and explore the concept of staged competitions, firstly by giving a definition of this term, and secondly by trying to understand the importance of this type of event in relation to its ability to act as a catalyst for innovative development within a particular industry or sector. Subsequently, the main opposing forces underpinning the competitive dynamics analysed will be identified, namely the need to incentivise experimentation, on the one hand, and the need to contain costs, on the other. The tension between these two profoundly divergent instances will also highlights the need for a search for a balance that defines the right level of competitiveness within the competition. Finally, the aspects analysed in this chapter will subsequently be used in the following chapters, to provide an analysis of the evolution of internal dynamics and a comparison of the actual innovative value of three different types of motorsport competitions, some of which have left an indelible mark and continue to influence the automotive sector today.

In particular, the analysis will therefore examine motor racing from the first half of the 20th century, representative of the dawn of automotive and motorsport; the Formula 1 World Championship, historically considered the highest expression of this discipline; and the Formula E World Championship, the most recent of these competitions, specifically conceived as a platform for the development of new electric technologies. For each of these three types of competitions, the dominant forces that have driven their birth and evolution will be analysed. In addition, an attempt will be made to identify significant moments in which these forces coexisted, mutually influencing each other, or in which one prevailed over the others, marking a turning point in the paradigm underlying the competition.

2.1 The importance of Staged Competitions

As pointed out by Christopher A. Jensen in his study (Jensen, 2017) The automotive industry is currently recognized as a major area of technological innovation, representing an excellent example of technological progress and development. This sector stands out for its ability to excel not only in the development of new technologies, but also in the application of their integration, and above all in the large-scale adoption and dissemination of innovative ideas. The automotive industry has emerged as a paradigm of technological progress through significant investments in creative problem solving and their translation into practical applications, therefore demonstrating an amazing ability to translate innovations into tangible improvements for industry and society.

The aspect that, more than any other, has played a crucial role in defining the technological development of the automotive industry and maximizing its innovative potential is the existence of structured competitions, commonly known as '*staged competitions*' (Jensen, 2021), of which the world of motorsports serves as one of the most significant examples.

These staged competitions are based on a set of established rules, which may sometimes be defined by the participants themselves, or which are more frequently imposed by a regulatory body, which has therefore the power to freely determine the direction of the innovation effort. Participants compete for a prize, usually of a monetary nature, and they do so in artificial and repetitive events. Moreover, this kind of competitions are based on predefined challenges that focus on the creation of relevant innovation generation, design, prototyping and, in many cases, adoption back into the parent industry (Jensen, 2021). Most of the time, the regulator requires competitors to make the details of their innovations public, a practice that offers considerable advantages in terms of diffusion and adoption of new technologies, helping to further stimulate progress and innovation within the industry. These staged competitions therefore not only nurture healthy rivalry between different manufacturers but also promote close and synergetic collaboration with industry suppliers. Through these competitive events, manufacturers have the opportunity to put their technologies to the test in a dynamic and highly competitive environment that encourages continuous improvement and the search for cutting-edge solutions, which can subsequently find application both within the automotive industry itself and in other sectors, thus contributing to broader, transversal technological progress.

Therefore, the innovation philosophy adopted in these competitions differs profoundly from the one commonly adopted by companies I their day-to-day operations. In fact, companies do not directly aim at obtaining a monetary prize but focus their efforts more on the obtainment of patents, which may ensure a temporary competitive advantage, sometimes even leading to a monopoly position. However, the most relevant drawback of this approach lies in its focus on secrecy and technological appropriation, which significantly limits opportunities for collaborative development and hinders the diffusion and adoption of new technologies on a large scale.

Once that one has understood the significant benefits that so-called staged competitions bring in terms of technical innovation within the automotive sector, the question inevitably arises as to what are the most effective ways to design and implement such competitions in order to effectively stimulate innovation. This issue is particularly relevant since the championships that will be analysed in this paper fall within this specific category of structured competitions and share, although in different ways, a fundamental objective: to promote technological innovation within their sector.

2.2 The two forces driving the definition of the competition.

The creation and development of such competitions is not an easy undertaking. It necessitates meticulous preparation, the active participation of important parties like suppliers and manufacturers, and the establishment of guidelines and goals that support a balance between cooperation and competition. Therefore, it will be essential to examine these factors in order to comprehend how these competitions might continue to serve as catalysts for technical advancement and innovation.

In particular, the two main forces at odds with one another during the development of competitions of this kind, are the need to encourage widespread technological innovation and the desire to lower the participation costs. This last point, in particular, represents a fundamental objective for ensuring the economic sustainability of the competition as well as its sporting appeal, since the high costs associated with technological research, vehicle design and production, logistics and infrastructure risk limiting access to a few large manufacturers with virtually unlimited resources, reducing the variety and number of participants and generating not only competitive imbalances but also a decline in sporting and media interest. Therefore, reducing costs promotes a more inclusive environment in which independent and diverse entities can emerge, stimulating the circulation of ideas and innovation through direct comparison between different approaches, thus strengthening the technological, sporting and commercial value of the competition, ensuring its long-term survival and increasing its ability to attract audiences, sponsors and new investors.

2.2.1 Encouraging widespread experimentation.

One fundamental aspect to be considered in the creation of a championship, is the importance of fostering the widespread experimentation of new technological innovations among the competition participants. Here, the way in which the competition is structured and organized is critical, as it directly influences the level of innovation that participants can achieve.

As pointed out by Jensen in his study on staged competitions (Jensen, 2021), the main factors that can influence the development of new technical innovations are:

- The implementation of agile and dynamic rules that define the boundaries of the so-called '**solution space**', that is, the level of freedom allowed for innovation within the set parameters. In particular, a large solution space is a symptom of a competition with few rules and a tendency to have only one goal, such as crossing the finish line first. Conversely, a small solution space is a symptom of an environment characterized by strict and focused regulations, often including specific criteria for certain technical solutions. In the first case, participants will be given greater freedom to explore a wide range of approaches and solutions, thus fostering the development of radical solutions. In the second case, the possibility of exploration will be limited, and there will be a greater focus on specific improvements and the consequent promotion of incremental innovations. For this reason, the ability to draw up regulations and then continuously adapt them to align the participants' efforts towards the competition goal is of crucial importance in defining a competitive environment that fosters innovation, balancing the creative freedom of teams with the need to maintain fairness and relevance to the parent industry.

- The definition of an appropriate **frequency of competitions** is a crucial factor for innovative development in a competitive environment. Frequent repetition of events gives teams the opportunity to test their innovations in a real, competitive environment, thus establishing a continuous cycle of research and development in the factory and testing directly in the race. In addition, the more time teams spend competing, the more they can closely observe the innovations introduced by their competitors, thus fostering the spread of ideas and knowledge sharing. Therefore, this increase in trialability and observability thus contributes significantly to accelerating technological progress, promoting constant comparison between participants, which accelerates improvement. Furthermore, the frequency of competitions and the consequent need to be ready for the next event creates a time pressure that forces teams to develop solutions in a shorter time frame than in normal innovation cycles. Finally, allowing teams to implement changes between events makes each event a test bench that can provide immediate feedback on the performance of innovations, reducing the risk associated with experimental technology developments because ideas are constantly being tested and improved.

- The promotion of a **co-dependent relationship between teams and organizers** in order to establish a collaborative relationship that effectively balances the need to maintain a competitive balance in the competition with the need for each team to pursue its individual success, while also fostering greater alignment with the industrial world, by actively including the perspectives of its representatives, therefore effectively creating a relationship of interdependence and collaboration between the two parties. This delicate balance is a crucial element in fostering the achievement of mutually beneficial innovative results while ensuring the continuous and sustainable participation of the parties involved, which on the other hand, contributes significantly to the advancement of innovative knowledge over time, an aspect that tends to be missing in innovation competitions organized as one-off, isolated events.

- Facilitating and supporting **collaborations with external partners** to foster greater synergy between technical expertise and practical applications, creating a collaborative innovation ecosystem that amplifies individual results. External suppliers can offer advanced solutions and technologies designed to fit the specific needs of teams, which are often difficult to develop internally with only available resources, thus accelerating direct experimentation through this dissemination and sharing. Furthermore, external suppliers can introduce pioneering technologies that can then be adapted and improved in the specific contexts of teams. Moreover, collaborations with external partners are able to accelerate the diffusion of innovations among different teams, making emerging technologies available to all competing teams as well, thus effectively creating a dynamic environment in which technological advances are rapidly shared. For example, the outsourcing of critical parts, such as engines, brakes and aerodynamic systems, allows teams to reduce not only costs but also risk, while also incentivising suppliers to develop cutting-edge technologies that can also be applied in other contexts. Finally, competition between suppliers themselves leads to faster improvements in the technologies available to all teams. However, it is important to emphasize how the practice of establishing strategic collaborations with external partners differs profoundly from the adoption of standard components. In the first case, in fact, a shared technological development between internal teams and suppliers is promoted, giving rise to a synergetic process of co-creation that stimulates innovation and enables the development of customized and advanced solutions. In the second case, on the other hand, the approach is limited to the application and use of plug-and-play, pre-packaged and standardized components, on which internal teams have no possibility of intervention or customization, thus preventing any opportunity for autonomous or creative development.

2.2.2 Reducing costs

The other crucial aspect, which is opposed to the need to the need of fostering free experimentation, is the need to reduce costs. In fact, the automotive sector is inherently linked to large expenses in several crucial areas, including technology research and development, vehicle design and production, logistics for moving teams and equipment, and the maintenance of infrastructure required for elite racing. Moreover, cutting costs is also considered a key element in stimulating the participation of more players in the competition, helping to create a more inclusive environment where different players can be accommodated, thus fostering a greater diversity of ideas and technological solutions, since a greater number of participants not only enriches the competitive landscape, stimulating innovation through direct comparison, but also makes the competition more exciting and interesting from a sporting point of view.

There are several ways in which a regulatory body can incentivize and promote cost reduction in competitions of this kind:

- The introduction of a **cost cap** that is the same for all participants, with the aim of ensuring greater fairness and reducing the competitive gap between small and large players. However, the actual implementation of this measure may present some critical issues, such as the difficulty in accurately monitoring compliance with the expenditure limits and the risk of attempts to circumvent these limits, for example through undeclared expenses or the outsourcing of certain activities.

- The use of **standardized components** that are the same among all competitors, applied to some specific components, thus helping to reduce the total design and production costs, which in the example of Formula, the premier class of motorsport, can reach an average of up to 40% of a team's seasonal budget (Loník & Kotrba, 2023). On the other hand, the reliance on standardization also presents some potential criticalities, risking limiting innovation in areas heavily subject to it.

- Set time limits, budget limits, or other **restrictions on R&D and physical tests**, helping to contain the expenses associated with experimentation and testing of new technical solutions as well as preventing the richest teams from dominating thanks to superior resources. In fact, as pointed out by Loník & Kotrba (Loník & Kotrba, 2023), R&D expenditures represent the most influential variable in terms of obtaining a better position in the final Formula 1 championship standings, as well as the maximum number of points obtained in a season and the number of podiums. However, the main drawback of this type of strategy is to potentially slow down the overall technological progress of the industry.

- Imposing a **technological freeze,** or homologation period, and therefore limiting the possibility for teams to modify certain components for a defined period after type approval. However, although this contributes to easing the economic pressure on teams, it could, on the other hand, hamper the efforts of the less performing teams to close the gap to the technically more advanced realities.

- Introducing **simpler technical regulations**, with the effect of limiting the search for highly complex and costly engineering solutions, directing development in a constrained manner towards less sophisticated and cheaper components, thus decreasing the design and development costs for teams and making competition more accessible. However, the main drawback of this method is the need to find a balance between simplicity and technical innovation in order to maintain the interest of the public but above all that of the constructors and thus the industry in general.

2.3 Achieving an Optimal Balance: A Key to Success

Up to this point, we have outlined the concept of staged competition, exploring its vital function in an industry's innovation process, and realizing its importance in promoting technical advancement and the pursuit of creative ideas. As a result, we were able to identify the two primary factors that influence its structure and efficacy: the importance of encouraging the development and testing of new technologies and the necessity of lowering participant costs.

These two conflicting forces must be properly balanced, as their equilibrium is crucial to guarantee, on the one hand, accessibility to participating teams and, on the other, to promote technological innovation, the distinctive and characterizing element of such competitions. In fact, although cost reduction can in fact be achieved through, for example, the introduction of economies of scale, the use of standard components, single suppliers and regulations limiting necessary expenses, thus levelling the playing field and reducing economic disparities between teams, taking an extreme approach in this direction entails the risk of excessive standardization, ending up rewarding only the sporting gesture, sacrificing the innovative potential of the competition, since teams do not have sufficient margins of freedom to develop radical technological solutions. On the contrary, a competition that is heavily focused on promoting widespread and unrestricted experimentation and allowing participants complete freedom to explore new technologies and technical solutions, in most situations tends to disproportionately benefit teams with greater financial resources, since these teams can invest significantly in research and development, further amplifying their competitive advantage and increasing their likelihood of winning. (Judde, Booth, & Brooks, 2013).

Such an imbalance could undermine the fairness of the competition, leading to results strongly influenced by economic availability, and risking not only to marginalize the less financially endowed teams, but could also to reduce the overall attractiveness and relevance of the competition itself. Moreover, the fact of having only one extremely dominant team, capable of winning without a battle, can lead to the disinterest of the public, who might perceive a lack of balance and unpredictability, fundamental elements to guarantee entertainment and involvement (Budzinski & Feddersen, 2019). In a certain sense, therefore, the search for a balance between innovative freedom and cost containment also translates into a form of competitive balancing between participants not only on a purely technical level, but also on a sporting one. This equilibrium is in fact fundamental not only to guarantee a healthy and balanced competition, capable of ensuring economic and operational sustainability for itself and for the participants, but also to attract the interest of the public, contribute to the overall growth of the sports ecosystem, respond to the needs of sponsors and, above all, encourage the development of innovation.

In particular, the concept of competitive balance is closely related to the “uncertainty of outcome theory” proposed by Rottemberg in 1956, according to which spectators are more attracted to competitions in which the final outcome is uncertain and that the more the talent pool is dispersed among the various teams, the more intense and tight the competition will be. However, one must not make the mistake of thinking that the solution lies in taking the concept of competitive balance to extremes, because while it is true that a strongly and perpetually unbalanced competition would inevitably lead to a loss of interest on the part of the public and, consequently, to the collapse of the competition itself, also an excessive competitive uniformity is equally undesirable, as an overly balanced competition would risk flattening the sporting dynamic, depriving it of those elements of excellence and unpredictability that capture the attention of spectators, thus determining the consequent television revenues and media exposure for sponsors, which reach their peak in the presence of exciting seasonal duels between superstars, in which established teams fight for the title, and are occasionally challenged by victories by other smaller competitors. It is exactly this dynamic balance between dominant players and talented outsiders that maximizes the attractiveness of the competition, maintaining high audience engagement and ensuring the economic sustainability of the event (Judde, Booth, & Brooks, 2013).

Based on these assumptions, it can be concluded that the search for a proper competitive balance, achieved through a carefully designed regulation imposed by the regulator, is the best solution to harmonize the different requirements of a competition. This balance makes it possible, on the one hand, to guarantee equal opportunities to all participating teams, preventing the richest teams from monopolizing the competition, and on the other, to preserve the public's interest and the dynamism of the championship. When, in situations of excessive freedom of design, the economically more gifted teams dominate unchallenged, they tend to attract most of the available talent, creating an uninspiring championship for both spectators and participants, and risking alienating the smaller teams, which would have little incentive to invest and compete in an environment where success is perceived as unattainable. The natural consequence of such an imbalance is a competition with a reduced number of participants, less media visibility, due to a lack of spectator interest, and a consequent loss of attractiveness for sponsors. Moreover, a championship dominated by a few teams entails the risk of compromising technological progress, despite the huge investments in research and development by the richest teams, because, as pointed out earlier, technological innovation is not fostered solely by financial resources, but is above all stimulated by the competitive environment and the pressure that comes with it. Consequently, an ecosystem in which teams constantly challenge each other to outperform each other is the ideal context to stimulate creativity, the search for radical solutions and the adoption of innovative technologies. On the contrary, this dynamic cannot be realized if the competition is monopolized by a small number of participants, and therefore the presence of a wide and diversified starting grid is fundamental to create a virtuous cycle of innovation, competition and spectacle, capable of attracting the public and the investments necessary to sustain the championship.

On the other hand, it is equally important to avoid moving towards the opposite extreme of an excessively balanced competition model, because although fairness between participants is an important objective, a competition that is too evenly balanced tends to lose its attractiveness for the public, who find no interest in races without exciting duels between major protagonists. Moreover, an excessively balanced competition would require an extreme level of standardization, which would lead to the uniformity of technical components and the reduction of design freedom for teams, an approach that would end up suppressing technological innovation, which is instead one of the characterizing and distinctive elements of competitions such as motor racing.

The way a competition is defined, therefore, becomes crucial in order to guarantee a dynamic balance between these two extremes, for example by implementing an environment that, on the one hand, prevent the richest teams from accumulating a disproportionate advantage, while on the other, can be sufficiently flexible to leave room for innovation, preventing competition from turning into a simple confrontation between identical machines, lacking in originality and technological progress, while also at the same time being attractive from a media point of view.

In short, the concept of competitive balance should not be understood as a static objective, but as a dynamic and difficult to achieve element, to be constantly that must be sought and calibrated through the adaptation of regulations, and therefore of the championship itself, according to the evolution of both the competition and the needs of all the actors involved, since it is only through an effective balance between competitiveness, innovation and spectacle that the long-term sustainability of a competition and consequently its innovative impact can be guaranteed.

3. The emergence of motor racing

In this chapter, we will analyse the history of the birth of motor racing, starting with the earliest forms of motor racing that emerged as early as the end of the 19th century, when motor racing was still a pioneering event that took place on public roads and competed with vehicles derived exclusively from production models, all the way to the period immediately following the Second World War, when the world of motorsport, annihilated after the end of the conflict, decided to revitalize and organize itself in the form of a structured championship that could unite all the major motor racing events that had emerged up to that time. In fact, the racing sector annihilated after the end of the conflict, decided to revive and organize itself in the form of a structured championship, which could unite within it all the major motorsport competitions, which up to that time had evolved from being competitions characterized by a crude structure and an as-yet undeveloped notion of motor sport, to becoming increasingly structured and organized events, but still independent from one another.

Analysing this period will therefore be fundamental in order to understand how the presence of these competitions significantly stimulated innovation in the automotive industry, which at the time still represented an emerging and unexplored technology. Moreover, this will also be useful in order to highlight and understand the dynamics behind these competitions, enabling a subsequent comparison with the conceptual framework adopted by the other two competitions analysed in the following chapters.

The first motor racing competitions, which were held between the end of the 19th century and the beginning of World War II, played a crucial role not only in the technological development of vehicles, but also in consolidating their increasing superiority as increasingly powerful, sophisticated, and reliable means of transport. In this pioneering phase of motorsport, races were mostly endurance competitions, characterized by extremely demanding courses and the need to test both the performance and reliability of the cars in equal measure. For this reason, some of these competitions lasted for many hours and, in some cases, even more than a day, testing the mechanical strength of the vehicles and the physical and strategic abilities of the racing crews. In the early years, the racing cars were still two-seaters, and the regulations required the mandatory presence of a crew consisting of a driver and a mechanic on board, who had the task of assisting the driver and carrying out any repairs along the way. Unlike modern competitions, the mere fact of finishing a race was already a significant achievement, as the reliability of the cars was far from certain and mechanical failures were extremely frequent. In fact, the technologies used were still rudimentary and, above all, the racetracks were not specially designed circuits, but public roads, often rough, unpaved or without asphalt, which made the competition even more unpredictable and selective. It was only after the First World War that the first single-seater competitions, therefore without the presence of a mechanic on board, were born. Despite the difficulties related to the mechanical fragility of the first cars and the extreme track conditions, technological progress and the quest for maximum performance proceeded with incredible speed, leading to increasingly sophisticated engineering developments in just a few years.

Although technical evolution was always governed by some sort of technical parameters and regulations set by the regulatory bodies of the various competitions (Foxall & Johnston, 1991), the main objective of the manufacturers and engineers of the time was always to increase engine power, considered the main key to improving the performance of cars, a philosophy that quickly led to the experimentation of engines with the most disparate characteristics, both in terms of displacement and the number and arrangement of cylinders. Other aspects of vehicle dynamics remained unexplored at the time and would only be analysed and refined in the decades that followed. In these years, motor racing was not only a testing ground for technical innovation, but soon became a true national competition, in which each country participated with a strong patriotic spirit determined to prove its superiority in technology and industry directly through victories.

3.1 From the dawn of motorsport to the First World War

Motor racing was born at the same time as the development of the automobile itself. The first to realize the future potential and importance of this new means of transport and to devote special attention and passion to it were the French. They were the so-called pioneers, the first to engage with determination in the development of the automobile, bravely undertaking longer and longer journeys at ever-increasing speeds, with the aim of demonstrating the effectiveness and superiority of this innovative technology over the main means of transport of the time and to which it would soon be substituted: the horse. In fact, the most effective method of raising public awareness, which at the time was still sceptical and unaware of the possible effectiveness and usefulness of the car, was to organize competitions that not only highlighted its potential, but also generated enthusiasm among the public, helping to increase interest in the new means of transport, as well as providing a fundamental opportunity to test and perfect automotive technology. In fact, through these competitions, manufacturers could test the cars in real conditions, identify any criticalities and make the necessary improvements, while at the same time gaining visibility and prestige, which are both essential elements for attracting investment and gaining market confidence. In this scenario, the great French national roads became the first and most important testing ground for motor racing, serving as a testing ground for the new cars and contributing to the development of the first official races.

The first competitions were therefore events with a route from city to city, and among these, the first true automobile race was the Paris-Bordeaux-Paris, held in the distant year of 1895 (Boddy, 1978). However, it was only in 1903, following the interruption of the Paris-Madrid race by the authorities concerned about the numerous accidents, that it was decided to move automobile competitions to dedicated circuits. These circuits, although closed to the public, unlike today, were still made up of common roads, with all the associated risks: rough terrain, dangerous curves, and above all, the lack of asphalt. The continual and rapid increase in the number of cars entered and participating in these competitions led to the need to introduce a division into categories, based mainly on criteria such as size and power of the cars, and with the passage of time, technical restrictions regarding the characteristics of competition engines were gradually introduced.

Coinciding with the first automobile competition in 1895, we see the definition of what would become the first dominant design in the automobile industry, which was a technical layout with a front engine, mid-mounted gearbox and rear-wheel drive, a configuration initially adopted by a Panhard et Levassor, a car manufacturer which employed a twin-cylinder engine capable of developing 4 horsepower (Boddy, 1978). From this moment on, the evolutionary development of the automobile was oriented towards one predominant objective: increasing the power. Thus, in order to achieve superior performance, manufacturers began to systematically increase the size of their engines, seeking to impart ever greater speed to their vehicles, despite the fact that this progress took place in a context in which cars were still equipped with rudimentary brakes, wooden frames and suspension derived from carriages, making driving extremely dangerous. At the time, the main method of improving engine performance was to increase engine size, as engines of the time operated at constant revolutions and it was not yet considered appropriate to increase the number of revolutions in order to obtain more power, a strategy that would only be adopted later. This tendency to oversize engines led, in 1898, to the need to introduce an initial classification of competition cars, dividing them into two main categories: cars weighing between 200 and 400 kg, and cars weighing more than 400 kg, a subdivision that represented a first step towards regulating motor racing, laying the foundation for a clearer distinction between the different types of vehicles and a more structured technical development in motor racing (Boddy, 1978).

In the ten years between 1898 and 1908, car manufacturers intensified their technological development, concentrating on the production of ever larger and more powerful engines. Between 1900 and 1905, the Gordon Bennett Cup was established by the American James Gordon Bennett Jr., owner of the New York Herald. The primary objective of this competition was to promote the entry of the United States into international motor racing and to challenge the French supremacy, which had dominated the sector until that time. Moreover, this competition played a crucial role in the history of motorsport, as it marked the beginning of nationally based racing competition. Indeed, the regulations stipulated that each nation could enter a maximum of three cars, which had to be entirely produced within their national territory, driven by pilots of the same nationality, and must be painted in a distinctive national colour, further strengthening the sense of belonging and rivalry among the participating countries, among which there was for example the blue used for France, the yellow for Belgium, the green for Great Britain, and the red initially used for the United States was later assigned to Italian cars. The competition consisted of a single annual event, organized by the country that had won the previous edition. Finally, among the technical limitations imposed, there was a maximum weight of 1000 kg for the cars, to try to limit the pursuit of performance through the disproportionate increase in engine size.

Thanks to the Gordon Bennett Cup, automobile races ceased to be merely a testing ground for vehicle development and became a true competition between nations, a concept that would be further emphasized in the period between the two World Wars, when races took on an even stronger symbolic and propagandistic significance. Over the course of the six editions of the Gordon Bennett Cup, France emerged victorious on four occasions, consolidating its leadership in the automotive scene. This factor, combined with the difficulty in modifying the competition's regulations and the French dominance, led to the birth of a new model of national races, the first example of which was the Grand Prix of the *Automobile Club de France* (A.C.F.), held in 1906, and which was the first ever officially recorded Grand Prix, and which was designated as the Ninth French Grand Prix, in recognition of the eight prior races held on public roads within city limits, and which was won by a 12.9-litre Renault (Foxall & Johnston, 1991). During this decade, the number of cylinders gradually increased to six, while displacement ranged from the smallest 7.5-litre engines to the largest 18-litre engines. This steady increase in performance allowed the cars of the time to reach extraordinary speeds of up to 160 km/h.

These large engines remained in use until 1908, when new regulations, introducing a maximum cylinder bore and a minimum weight of 1100 kg, to avoid having excessively light cars, which is crucial for ensuring the right amount of structural integrity, imposed a reduction in maximum engine capacity, which stabilizes around 14 litres (Boddy, 1978). This regulatory change marked a turning point in engine development, as the quest for power could no longer be based solely on an increase in displacement but required an increase in engine speed. To achieve this, they began to adopt short-stroke engines, a philosophy that found its fullest expression in the revolutionary engine designed by Ernest Henry for Peugeot. This engine proved to be extremely effective, enabling the team to achieve a significant victory in the 1912 French Grand Prix with a car equipped with a 7.6-litre engine, with a twin overhead camshaft and four valves per cylinder, capable of delivering around 130 horsepower, and which set the standard for further development throughout the pre-World War I period. In fact, the line of development adopted by Peugeot marked the beginning of a new evolutionary cycle in engine design, centred on increasing engine revolutions rather than increasing displacement.

This approach focused on the reduction of the size of the engine led to the imposition in 1913 of a minimum and maximum dry weight limit for cars of 800 and 1100 kg respectively, and it was further reinforced in 1914, when new regulations were introduced that imposed a drastic reduction in engine size. The new regulations set an upper limit of 4.5 litres for cars classified as 'heavy' and 2.5 litres for those classified as 'light', thus redefining the development parameters of racing cars and further stimulating the search for engineering solutions to improve engine efficiency and performance (Boddy, 1978). From this point on, motor racing would come to a standstill due to the outbreak of the First World War and would only resume once the conflict was over.

3.2 The period between the two World Wars: a time of strong experimentation and innovation.

With the outbreak of World War I in 1914, motor racing in Europe suffered a drastic slowdown, as the entire continent was caught up in the conflict and most sporting activities were suspended, and it was not until 1918, with the end of hostilities, that motor racing gradually resumed, although the post-war economic and industrial situation still made it difficult to organize top-level events. On the contrary, in the United States, which was not directly involved in the conflict until 1917 and did not suffer devastation on its territory, racing continued uninterrupted, consolidating the country as a focal point for motor racing, among which, among the various competitions that continued to take place on a regular basis, the legendary Indianapolis 500 in particular emerged as one of the most prestigious races on an international level in those years, attracting increasing attention from drivers and manufacturers.

It was only in 1921, with the revival of the Grand Prix of the Automobile Club of France, which was disputed under restrictions that imposed a maximum displacement of 3.0 litres, a regulation derived directly from American racing, that European racing regained significant importance within the global motorsport scene. In fact, this event is considered the first Grand Prix of the post-war era and marked a turning point for the resurgence of racing in the Old Continent.

More in general, the conclusion of the First World War, sanctioned by the armistice of 1918, gave impetus to a general wave of innovation in the motorsport sector, a phenomenon mainly influenced by the significant progress made in the field of aero engines, which led to the development of advanced technical solutions that found application in both competition and everyday engines, affecting several areas, including component production, metallurgy and manufacturing methods. Post-war performance cars gradually began to adopt eight-cylinder engines, directly inspired by the powerful aircraft engine developed by Ettore Bugatti during the war, which also featured an eight-cylinder configuration, a development that marked an important step forward in the evolution of engine technology, as it allowed a significant increase in performance, contributing to the birth of a new generation of ever faster and more reliable racing cars.

In 1920, the technical regulations underwent a new change that imposed a reduction in the maximum permitted engine capacity to 3.0 litres, a decision aimed at curbing the extreme performance achieved by the cars of previous years and ensuring greater safety in competition (Boddy, 1978). At the same time, another technical innovation that was destined to revolutionize the entire automotive sector and become the dominant solution for both racing and everyday cars was the introduction of the hydraulic braking system, which made it possible to achieve evenly distributed braking action on all four wheels, an innovation which, as well as significantly improving the effectiveness of deceleration, brought about a significant change in driving dynamics, allowing greater control of the vehicle when braking, and contributed to a considerable increase in safety standards, both in racing and in everyday traffic.

In 1922, the technical regulations for racing underwent a new revision, setting an upper displacement limit of 2.0 litres and again introducing a mandatory minimum weight set at 650 kg, a change that prompted numerous car manufacturers to revise their design strategies, leading to a reduction in the number of cylinders and the adoption of different technical solutions, with the aim of improving engine efficiency (Boddy, 1978). The introduction of the 2-litre formula marked therefore the definitive demise of the refined engines developed during the war. It became clear that the future of automotive engineering would follow a very precise direction, characterized by a progressive reduction in masses, a more stringent fractioning of the displacement and the adoption of ever higher rotation speeds in order to maximize engine performance. This new design philosophy led, as early as 1923, to the appearance of the first supercharged cars by means of a compressor, an innovation that made simple displacement an almost secondary parameter. In fact, the introduction of supercharging made it possible to achieve an exponential increase in the power output of engines without the need to increase their volume, thus guaranteeing superior performance while respecting the limitations imposed by regulations. The first racing car to adopt a supercharger was a Fiat, equipped with a supercharged eight-cylinder in-line engine, which made its debut in the 1923 Automobile Club de France Grand Prix.

The large-scale adoption of supercharging marked such a significant technological evolution that, in 1926, the regulatory formula was again updated, imposing a further reduction in maximum displacement, which was limited to 1.5 litres, and lowering the minimum weight of the cars to 600 kg (Boddy, 1978). This restriction led the designers to an increasingly exasperated search for a reduction in overall mass, with particular attention to lowering the car body, in the conviction that this would reduce body roll. However, this philosophy clashed with the rigidity of the suspension schemes of the time, which were still rather primitive and underperforming, and which contributed to amplifying the phenomenon of the car's lateral slip, making driving particularly challenging and risky.

Although engine downsizing was leading to encouraging results in terms of performance, these successes were largely due to the adoption of turbocharging, an extremely expensive and complex technology. Due to the growing financial crisis, the decision was taken in 1931 to abandon restrictions on displacement and minimum weight, introducing the so-called “Free Formula”, which removed all regulatory constraints and allowed manufacturers to develop larger-displacement engines again (Boddy, 1978). This return to large-capacity engines marked the rebirth of authentic Grand Prix cars, among which were the prestigious Alfa Romeo, developed and elaborated by the Scuderia Ferrari, which in those years began to establish itself as one of the most competitive and ambitious on the motorsport scene.

In 1934, the motor racing scene underwent a new and significant change with the introduction of a regulatory revision that imposed a maximum weight of 750 kg for Grand Prix cars (Boddy, 1978). This change was intended to limit excessive reliance on brute power, a trend encouraged by the previous free-formula regulations, and to bring the focus back to more refined engineering solutions and the balance between performance, aerodynamic efficiency and drivability.

It was in this context that Nazi Germany made its overbearing entry into motorsport, driven by Adolf Hitler's desire to use racing as a tool for political propaganda. In fact, the Nazi regime, under the leadership of Hitler, decided to invest huge resources to ensure the success of the two German racing teams, Mercedes-Benz and Auto Union, financing them directly with government funds to enable the development of record-breaking cars, because these two manufacturers were called upon to dominate in all kinds of motorsport competitions, as their success was a key element in the prestige of the Nazi regime. These extraordinary investments enabled the German manufacturers to create avant-garde cars, characterized by the use of extremely light and particularly expensive metal alloys, which made it possible to drastically reduce the weight of chassis and engines in order to comply with the 750 kg regulatory limit. Furthermore, in addition to the exasperated quest for lightness, a further competitive advantage of the German cars came from the use of highly refined fuels, developed with advanced technology and capable of guaranteeing superior efficiency and power compared to the fuels used by competing teams. Thanks to these advances, German racing cars reached unprecedented levels of performance, creating extraordinary cars both technically and aesthetically, but made extremely difficult to control due to their combination of extreme lightness and high power, so much so that even the most talented German drivers of the time struggled to control them. This led the Nazi regime to hire the best foreign drivers available, including the Italian Tazio Nuvolari, who became one of the most famous protagonists of the period. The intense Nazi propaganda campaign in motorsport led, by the end of the decade, to Germany establishing itself as the dominant nation in motor racing, with Mercedes-Benz leading all other manufacturers. Its top cars, such as the W 125 before, and the W 154 later, represented the absolute pinnacle of motorsport technology of the time, so much so that they were capable of exceeding the extraordinary 300 km/h threshold, an achievement unthinkable just a few years before.

Precisely because of the clear and overwhelming German superiority, in 1938 the regulation formula was modified once again, introducing a maximum displacement limit of 3 liters (Boddy, 1978), a decision aimed at re-establishing a certain competitive balance and giving other European manufacturers, who had lagged behind in technological development in previous years, the opportunity to at least partially close the gap with the German teams. However, despite attempts by the other manufacturers to adapt, the progress made was not enough to counter the dominance of Mercedes-Benz, which, thanks in part to the introduction of a sophisticated supercharging system, continued to impose its technical and sporting superiority until the outbreak of the Second World War, an event that marked another dramatic halt for the world of motor racing.

3.3 From the end of World War II to the birth of the Formula 1 World Championship

Once again, the war brought motor racing to an abrupt halt, putting its survival at risk. However, even this time, it did not succeed in eliminating it once and for all, despite the fact that all the car factories at the time had been converted to aircraft or munitions factories. Sportscar racing resumed in France as early as 1945, but the real Grand Prix did not start again until 1946, this time without the presence of the Germans, the great pre-war rulers, who had seen all their industrial facilities destroyed as a result of the conflict and were thus morally and materially unable to compete. The desire to return to racing after the war was intense and, once again, the main promoters of the revival were the French, closely followed by the Italians. In fact, the latter, in particular Alfa Romeo and the Scuderia Ferrari, had received funding from Mussolini's regime, similar to what had happened in Germany for propaganda purposes. However, being in better shape than the Germans at the end of the conflict, the Italians had a strong desire to resume motor racing.

Therefore, the only thing that remained to be defined was the formula with which racing would resume, which would necessarily have to take into account the difficult post-war economic and infrastructural situation. With cities, housing and industrial plants still to be rebuilt, it was essential to adopt a realistic and sustainable approach to the resumption of motor sport.

Consequently, in 1946, the body that had until then regulated the main motor racing competitions, the *Association Internationale des Automobiles Clubs Reconnus* (AIACR), founded in 1904, was reorganized and renamed the *Fédération Internationale de l'Automobile* (FIA). This new institution was tasked with defining the formula that would regulate future motor racing. The new regulations, initially known as Formula A, introduced the possibility of using two different types of engines (Boddy, 1978):

- Supercharged engines with a maximum displacement of 1.5 liters.
- Naturally aspirated engines with a maximum displacement of 4.5 liters.

This solution laid the foundation for the birth of the future Formula One World Championship, and it was well suited to the post-war context, as it allowed the racing teams to choose between two options: smaller-displacement engines, which were more expensive but capable of higher speeds thanks to supercharging, or larger-displacement engines, which were less expensive as they were equipped with simple carburettors.

Starting in 1947, in fact, the regulation formerly known as Formula A officially changed its name to Formula 1, which marked a significant evolution in motor racing, even if only on a formal level, as it was only in 1950 that the FIA officially introduced the Formula 1 World Drivers' Championship (WDC), with the aim of awarding a world title to the most talented and competitive drivers. Before then, drivers did not compete for an international title but focused exclusively on winning individual events. Rather than accumulating points for a championship, their main goal was to achieve success in the various competitions by receiving prize money or trophies.

Moreover, in 1948, in order to counter the ever-increasing costs of participating in Grand Prix races due to the continual refinement of the cars, the FIA introduced Formula 2, an alternative category that included:

- Supercharged engines with a maximum displacement of 0.5 liters.
- Naturally aspirated engines with a maximum displacement of 2.0 liters.

In the period between 1947 and 1950, the reference car in the Grand Prix category was the Alfa Romeo 158, a model that represented a continuous refinement of an already extremely good design, launched just before the outbreak of war in 1938, and characterized by a 1.5-litre, eight-cylinder supercharged engine.

4. Formula 1

This chapter traces the entire history and development of the Formula 1 World Championship, from its inception to the present day, in order to understand not only the events that generated it, but also the transformation that has made it one of the most popular and profitable sports in the world. In fact, over the course of its history, the sport has seen a series of significant changes, both technical and at the regulatory level, which have progressively altered its structure, level of competition and level of spectacle.

The date that marked the turning point in motor racing in the last century was 1950, when the *Fédération Internationale de l'Automobile* (FIA) formally established the Formula One World Championship, therefore creating a championship which brought together the most important motor racing competitions of the time in a single event with the same technical and sporting rules, and which immediately established itself as the pinnacle of motorsport, attracting the best drivers and constructors from all over the world. A alongside the advancement of the cars, also the championship's structure has gone through significant changes over the years. It began as a competition-based championship where technical innovation and competition drove development, but it has since then evolved into a true global business that can generate $3.2 billion in revenue at the end of 2023, with a remarkable 25% increase from 2022 (Brittle, 2024). In this regard, marketing and economic interests have become increasingly important, to the point where Formula 1 is now not only the pinnacle of motorsport but also a global industry by itself.

This chapter will therefore retrace the entire history of this prestigious motorsport competition, with the aim of understanding and analysing the dynamics of innovation that have characterized it over time, starting from its inception and continuing to the present day, paying particular attention to the forces that have contributed to making it a point of reference for technological progress in the automotive sector. Furthermore, in addition to retracing the key moments in its history, ample space will be dedicated to the analysis of technical regulations and their evolution, assessing their impact on the development of single-seaters, exploring in particular ways in which these regulations have influenced innovation, sometimes by widening the solution space, favouring the development of new technologies, and sometimes by imposing restrictions to limit costs or guarantee higher safety standards. Therefore, through a detailed analysis, this chapter will illustrate the main evolutionary stages of Formula 1, highlighting the indissoluble link between competition, technology evolution, and regulations.

4.1 From the birth of the Formula 1 World Championship to the transition to rear engines.

The first Formula One Grand Prix was held in England, at the Silverstone circuit, on 13 May 1950, a race that was entirely dominated by Alfa Romeo, which imposed its technical and strategic dominance. Although the technical regulations adopted for the competition remained unchanged from those introduced in 1946, this event represented a real turning point between historic and modern motor racing, marking the official start of the Formula One World Championship.

The first edition of this famous championship saw the participation of a limited number of official teams, including the Italian Alfa Romeo and Ferrari, who were joined by numerous private teams and paying drivers, known as “gentlemen drivers”, who competed mainly in private or modified cars, including the Italian Maserati, the French Talbot-Lago and the English E.R.A. (English Racing Automobiles). Although the races of these early years did not differ significantly from those held before the establishment of the World Championship, the main difference was their organization into a proper championship, consisting in its first edition in 1950 of a calendar of seven races. The first Formula One World Championship was won by the Alfa Romeo 158, a car that proved dominant for the entire season. Alfa Romeo's success continued the following year, in 1951, thanks to its evolution, the Alfa Romeo 159. However, despite the great successes achieved up to that point, Alfa Romeo decided to withdraw from competition at the end of the 1951 season. This decision left the 1952 starting grid with only one truly competitive car, Ferrari, resulting in a reduced participation of teams in the championship, and for this reason, the FIA opted for a regulatory change, stipulating that the 1952 and 1953 championships would be contested with smaller, less sophisticated Formula 2 cars. The aim of this change was therefore to reduce costs, incentivize the participation of new teams and ensure a greater number of entrants to the championship, which was otherwise in danger of losing interest. In particular, among the manufacturers taking part in the 1952 championship was the British Cooper, which entered as a supplier of private drivers' cars.

In 1954 the Formula One regulations underwent another change, abandoning the Formula Two rules adopted in the previous two years and introducing a reduction in the maximum displacement for naturally aspirated engines. This went from 4.5 litres in the Formula 1 regulations in force until 1951 to 2.5 litres in the new formula (Boddy, 1978). The motivation for this change was not so much the need to reduce the speed of the cars, as had happened in the past through limitations on displacement, but rather the intention to encourage research and development of non-supercharged engines, with the aim of favouring technology more aligned to the needs of production cars, since it had been realized that engines equipped with compressors were too complex, expensive and noisy for use in production cars. Again, the regulatory change pushed some manufacturers out of Formula One, while others decided to enter or to return to compete. The most notable of these were the return of German manufacturer Mercedes-Benz, and the entry of the British Vanwall. The cars of the period all adopted 2.5-litre engines powered by carburettors, as no manufacturer chose to develop 750 cm^3 supercharged engines, despite the regulations allowing this. The engines of this generation were capable of developing around 300 horsepower, with the power being transmitted to the wheels through tires produced by various companies, including Dunlop, Pirelli, Continental and Englebert, and the average weight of the cars was around 700 kg. From a technical point of view, meanwhile, the general trend favoured the use of tubular chassis and De Dion bridge suspension, while also paying particular attention to weight distribution, concentrating the masses in the centre of the car body to optimize its cornering behaviour. In fact, thanks to the increasing reliability of the new engines compared to the pre-war ones, in this period the teams began to devote more and more attention to the study of the chassis, as well as to the adjustment and adaptation of the suspension and set-ups according to the characteristics of each circuit. These elements, in fact, became increasingly important over time, until they became as fundamental as the power of the engine itself.

Again, with a view to improving the balance of the cars, the most significant contribution in this direction was made in the 1950s by the Cooper Car Company, which, thanks to its experience gained in minor formulae such as Formula 2 and Formula 3, Cooper introduced the first rear-engine single-seater, the Cooper T43, in the 1957 Formula 1 Championship. This choice stemmed from the approach taken by the team from its early days in Formula 3, where the cars they designed used motorbike engines, where the layout of the transmission in these engines made it natural for the engine to be positioned at the rear of the chassis, thus eliminating the need for a transmission shaft. This solution not only simplified the mechanical design, but also allowed for lighter and better balanced single seaters. This new construction philosophy soon became popular also among the more traditional teams, who initially remained tied to the concept of the front-engine car for a few more years, an approach that was well represented by Enzo Ferrari's thinking that it was the ox, i.e. the engine, that should pull the wagon and not vice versa. However, Jack Brabham's victory in the 1959 World Championship in a rear-engine Cooper definitively established the success of this configuration, and from that moment on, the rear-engine design established itself as the new standard in Formula 1.

The 2.5-litre Formula did not end with the 1959 World Championship, as originally planned, but was extended for another year, on the condition that petrol was used as the only fuel. Until that time, in fact, most teams used special blends, which not only guaranteed slightly higher performance but also helped to improve engine durability. Therefore, at the end of the 1960 season, the 2.5-litre Formula was definitively abolished, having introduced significant innovations in several areas: from chassis design, to the refinement of suspensions, to the adoption of disc brakes, to the transition from front-engine cars to rear-engine single-seaters, an evolution that not only allowed the cars to reach record minimum weights of less than 500 kg, but also marked an epoch-making turning point in Formula 1, radically transforming its construction philosophy. From then on, in fact, the cars would no longer be designed as simple extensions and enhancements of production cars, but would follow an independent design, developed exclusively for competition, without any reference to the world of road cars.

Finally, the competition acquired a new dynamic with the introduction of the Constructors' Championship in 1958, which soon captured the attention of spectators, shifting the focus not only to the technical characteristics and performance of the cars, but also to the rivalry between the teams. This change marked the beginning of an evolution that, in the years that followed, would help transform Formula 1 into a truly global spectacle, increasingly taking on the international “circus” aspect that still characterizes it today.

4.2 From the 1500cc formula to a return to the big engines.

By the end of 1960, racing had undergone a radical transformation, evolving into an increasingly technically and commercially sophisticated business. The prospect of significant financial returns had stimulated the entry of new constructors, fostered the growth of a large number of specialized technicians and contributed to increased public interest, attracting more and more spectators to competitions.

In 1961, the Formula One regulations were again changed (Boddy, 1978) to adapt to the technical evolution of the cars in the preceding years, marking another turning point in the category. The new regulations imposed a maximum displacement of 1.5 litres, a minimum weight of 450 kg, and the obligation to use commercial fuels.

The rear-engine philosophy was now widely accepted, and all teams exclusively developed single-seaters with this configuration, while in the technical arena, simplicity had become the key word, with solutions aimed at optimizing compactness and lightness. In 1962, the founder of the Lotus team, Colin Chapman, designed the Lotus 25, the first single seater ever to mount an aluminium monocoque chassis, a revolutionary solution that quickly decreed the end of the traditional tubular chassis, and allowed Jim Clark to win the world title in 1963, winning seven out of ten Grands Prix and demonstrating the superiority of the new structural concept.

A major selling point for Lotus in those years was undoubtedly the adoption of the Coventry Climax V8 engine, a highly competitive power unit produced by the British manufacturer, at the time one of the highest performing in Formula One. Coventry Climax did not supply its engine exclusively to Lotus, but also to Cooper, the newly formed Brabham and several smaller racing teams. This distribution began to outline the first advantages of the so-called assembler teams, in other words those teams that, although they did not build their own engines, were able to develop competitive chassis using engines produced by external suppliers, a philosophy that was to become dominant in the following years.

At the end of 1965, the 1.5-litre formula, after having contributed to significant progress not only in chassis design, but also in suspension and tire development, was abolished in favour of a return to larger and more powerful engines, from 1966. However, despite several years' notice, the new regulations caught Coventry Climax unprepared, and as Climax was not ready to develop larger engines, it decided to withdraw from Formula One, leaving the British teams that had relied on its engines up to that point in uncertainty.

4.3 The Cosworth DFV engine and the era of aerodynamic wings.

The 1966 rule change marked the beginning of one of the most exciting periods in Formula 1 history, if not the most exciting in terms of technical innovations. In fact, the striking similarity in car designs among highly competitive teams in the early 1960s indicates that these teams had likely reached the limits of gaining a comparative advantage through further fundamental advancements in automotive engineering principles, and the advantages were instead pursued through the relatively continuous development of individual components. (Foxall & Johnston, 1991).

The new 1966 regulatory formula included the following changes: a maximum displacement for naturally aspirated engines of 3.0-litre, or a maximum displacement for supercharged engines of 1.5 litre, a minimum weight increased to 500 kg, and the obligation to use commercial fuel (Boddy, 1978). This increase in engine displacement was able to raise the power output of the carriers to around 500 horsepower, whereas the previous 1.5-litre cars produced just over 200 horsepower (Foxall & Johnston, 1991).

With the abandonment of Coventry Climax at the end of 1965, the British teams that had hitherto prospered thanks to the availability of this engine found themselves in a very difficult situation in 1966, without a competitive power unit. Once again, it was Colin Chapman's Lotus that filled this void, initiating a joint venture between Lotus, Ford Motor Company and Cosworth Engineering (Jenkins & Floyd, 2001). Out of this collaboration came the famous Ford Cosworth DFV, which made its debut in the 1967 Dutch Grand Prix, powering a Lotus 49, and immediately proved successful, winning the first race with Jim Clark at the wheel. The introduction of this engine represented one of the most significant moments in Formula One history, profoundly marking its evolution. The Cosworth DFV, a powerful and light V8 engine, was designed to be used as an integral part of the chassis, thus reducing the size of the monocoque and, consequently, the overall weight of the car, providing a considerable technical advantage. Furthermore, although initially reserved exclusively for Lotus, the engine was also made available to other teams from the 1968 season onwards, at a price of £7,500 (Jenkins & Floyd, 2001). The first teams to benefit were McLaren and Matra, followed by Brabham in 1969. The impact of the Cosworth DFV on Formula 1 was overwhelming: within a few years, most teams adopted this engine, appreciating its low cost and high performance. Between 1969 and 1973, the DFV completely dominated the championship, winning every race of those seasons, a unique event in Formula 1 history in which a single engine established itself as the absolute benchmark for such a prolonged period.

The availability of a competitive engine at low cost, combined with the possibility of buying other ready-made components on the market, definitively sanctioned the beginning of the era of the assembler teams and the so-called ‘kit cars’, a concept initially initiated by Coventry Climax with its engine, but which had not been fully realized until the introduction of the Cosworth DFV. From then on, with very few exceptions, no team was responsible for the complete design of its car. Instead, an increasing number of specialist suppliers began to offer technical support to optimize the performance of their components within the single seaters. With this new sharing of elements between teams, the need to gain a competitive advantage became even more pressing. As a result, the teams developed a growing awareness of the importance of balancing experimentation and innovation with the practical demands of weekly racing, thus shifting the focus towards constant, focused development that could guarantee even the smallest performance improvement, which could make the difference in racing (Jenkins & Floyd, 2001).

Thanks to these innovations, in the years that immediately followed Formula 1 was the scene of some of the most ingenious technical evolutions, including the first experiments with four-wheel drive cars and, above all, the introduction of aerodynamic appendages. As early as 1968, the first teams began testing single seaters equipped with wings and other appendages designed to increase vertical thrust and improve cornering grip. However, these early solutions were still fragile and dangerous, so much so that the FIA quickly intervened in 1969 to regulate their use and ensure greater safety. The teams then faced a new engineering challenge: balancing the loss of speed on the straights with the increased cornering grip generated by the aero wings. As a result, Formula 1 single seaters began to progressively abandon the classic cigar shape that had characterized them up to that point, to assume more sophisticated and aerodynamically functional lines. Over the next ten years, much of the research and development focused on optimizing aerodynamic effects, triggering a continuous evolution of the single-seaters and a constant improvement in their performance on the track.

In the decade between 1966 and 1976, numerous technical innovations followed one after the other on the Formula One grid, some with great success, others with less incisive results. Among the most iconic and influential cars of this period are the Lotus 72 and the Tyrrell P34. The first, the Lotus 72, designed by Colin Chapman, debuted in 1970 and remained competitive until 1975, marking a profound change in aerodynamic design. Its main innovation was the integration of chassis and aerodynamics, moving the radiators from the front of the car to the sides, thus introducing the concept of side pods, which would become the dominant standard in Formula 1 to this day. This modification resulted in its characteristic arrow shape, improving stability, aerodynamic efficiency and weight distribution, helping to make the Lotus 72 one of the most revolutionary cars of its era. The second, on the other hand, the Tyrrell P34, was the result of the extreme search for performance and innovative creativity that characterized that period, in which racing teams were willing to experiment with daring and unconventional solutions to gain a competitive advantage. This car, which made its debut in 1976, completely displaced the competition by presenting a unique design with six wheels, two at the rear and four smaller ones at the front. The aim of this configuration was to minimize the front section of the single seater to improve top speed, as well as to increase grip and stability under braking due to the larger contact area of the front tires. Despite being competitive and winning several podiums and a victory, the concept only remained in Formula One for two seasons. The main reason for the abandonment was the difficulty in developing specific and competitive front tires in the required dimensions, making the project unsustainable in the long run.

In this decade, the sport underwent a radical transformation with the massive entry of sponsors into competition. These began to appear on single seaters as early as the late 1960s, marking the transition from a model based solely on support from car manufacturers to one also financed by companies outside the industry. This change coincided with the growing commercial interest in motorsport, fuelled by the spread of television and the increase in the global racing audience (Foxall & Johnston, 1991). The introduction of sponsors has profoundly transformed Formula One, since thanks to funding from sponsors, teams have been able to increase their investments in aerodynamic research and technological development, guaranteeing them greater competitiveness (Cobbs, Jensen, & Tyler, 2022), while at the same time, the growing presence of sponsors has helped professionalize the championship, elevating it to a global industry with an economic value of billions of dollars, allowing the teams to consolidate their identity through advanced marketing strategies, transforming them into true internationally recognized brands. The first example of a Formula One car with a fully sponsored livery was at the 1968 Monaco Grand Prix, when Team Lotus presented the Lotus 49 in the colours of the Gold Leaf cigarette brand, marking a historic change for Formula One, as until then the cars had been painted in the national colours of their respective teams or manufacturers. It was this agreement between Lotus and Gold Leaf, that started the era of commercial sponsorship, transforming the way teams financed their activities and paving the way for numerous sponsors to enter the championship. Today, the dependence on sponsors has become so significant that they contribute up to 70 per cent of a team's budget, thus making it certain that, without adequate financial support from sponsors, many racing teams would not be able to meet the costs necessary to compete in the championship (Cobbs, Jensen, & Tyler, 2022).

Finally, as far as the technical regulations are concerned, from 1966 to 1976, they underwent a gradual evolution with the aim of improving safety and defining car specifications in more detail. As specified before, in 1966 the technical regulations did not yet provide for precise restrictions on dimensions, which were introduced from 1968. Moreover, from now on, always more attention is being focused on safety, for example by imposing the compulsory adoption of the roll-bar, of a dual braking circuit, and more effective safety standards for the fuel tank which started to be designed to reduce fuel leakage in the event of impact thanks to reinforced materials and increased resistance to impact. Always with regards to safety, mobile aerodynamic appendages were banned while regulations continued to focus on passive safety, imposing deformable structures and stronger materials to protect drivers in the event of an accident.

4.4 The Ground Effect and the Turbo era.

The period between 1977 and 1988 was characterized by two of the greatest revolutions in Formula 1 history: the introduction of ground effect and the adoption of turbo engines, innovations that radically transformed the performance of single seaters, redefining the concept of aerodynamics and power in motorsport.

The ground effect represents one of the most significant aerodynamic innovations in racing history, completely revolutionizing single-seater design in the late 1970s. The rationale behind ground effect is the creation of a low-pressure zone underneath the vehicle, generating an aerodynamic load that crushes the car to the ground and increases road handling, especially when cornering. This effect is achieved thanks to the particular conformation of the car's floor, characterized by so-called Venturi channels that accelerate airflow and create a sort of suction underneath the single seater. The implementation of this technology has drastically improved the performance of the car, reducing body roll and allowing unprecedented cornering speeds (Jenkins & Floyd, 2001). The practical introduction of ground effect in Formula One is once again attributed to British manufacturer Lotus, again under the leadership of Colin Chapman, with the revolutionary Lotus 78 that made its debut in the 1977 season. Lotus, finding itself in an increasingly difficult competitive situation in the early 1970s, with the single seaters of other teams such as Tyrrell and Ferrari becoming more and more powerful thanks to improvements in engines and suspension, was thus pushed to explore new areas of development and identified aerodynamics as a possible key. In particular, the team noticed that the car's underbody could be used to generate downforce without increasing overall drag, a significant advantage over traditional wings that produced drag and limited top speed (Jenkins, 2010). The discovery of the ground effect came about almost by chance during wind tunnel tests, when the Lotus team noticed that sealing the sides of the car's underbody generated a considerable vacuum, dramatically increasing downforce. This led to the development of “side skirts”, which are flexible strips of material positioned along the edges of the bottom of the car to seal off the area underneath, preventing air dispersion and maintaining maximum downforce. This allowed the Lotus 78 to gain a significant advantage over the competition, and the concept was further refined with the Lotus 79, which proved to be one of the most dominant single-seaters in Formula 1 history (Jenkins & Floyd, 2001). However, not all teams were immediately able to capitalize on this innovation, such as Ferrari, who initially ignored the ground effect and continued to develop their Flat-12 engines, the bulk of which prevented the optimal adoption of Venturi tunnels under the chassis. Brabham also faced similar difficulties, finding itself limited by its Flat-12 Alfa Romeo engine, which was too bulky to effectively exploit the Venturi tunnels, and so, to try and compensate for the aerodynamic deficit, the team developed an extremely innovative solution, adopted by the Brabham BT46B, known as the “fan car”. This car featured a large rear fan that sucked air from under the car, creating an artificial ground effect and generating enormous downforce, a system that proved so effective that the BT46B immediately won the 1978 Swedish Grand Prix. However, it was quickly banned by the FIA, both because of regulatory issues and the risk of debris being sucked up and shot towards other cars (Foxall & Johnston, 1991). The ground effect led to a drastic increase in cornering speeds and increased competitiveness among the teams, but also to safety problems, as the need to maintain a constant airflow under the car meant that any unevenness of the track or damage to the side skirts could cause a sudden loss of downforce, leading the car to lose grip uncontrollably. This made the single seaters of the 1980s particularly unstable in emergency situations, increasing the number of spectacular accidents (Jenkins & Floyd, 2001). Because of these concerns and accidents, the FIA intervened to regulate the use of ground effect, and in 1981 sliding skirts were banned, while in 1983 a flat bottom was introduced, effectively eliminating the principle of ground effect as it had been conceived up to that time. These restrictions marked the end of the era of pure ground effect cars and forced the teams to look for new aerodynamic solutions, leading to a return of the predominant role of the wings and, more in the future, to a greater use of active suspension to control the car's stance (Jenkins, 2010).

While the introduction of ground effect represented one of the greatest aerodynamic innovations, the introduction of turbocharged engines in Formula One represented one of the greatest technological and performance revolutions in the history of motorsport, profoundly changing not only the power of engines, but also the way single seaters were designed and run in races. The first team to introduce a turbocharged engine was Renault, which debuted in 1977 with the Renault RS01 equipped with a small 1.5-litre turbocharged V6. The application of turbo technology in motor racing was not an innovation introduced by Formula One, as it had already been used in some racing and high-performance road cars. However, Formula One played a crucial role in perfecting this technology, optimizing its efficiency and reliability to the point where it could be fully utilized in any motorsport context. In fact, the idea of using turbo engines derived from some experience gained in American racing, particularly in IndyCar, where turbochargers had already been successfully implemented in the 1960s and 1970s. However, the competitive and technical context of Formula One was quite different: the single seaters required great responsiveness and acceleration and deceleration capacity, and the main problem with turbocharging was the delay in throttle response, known as "turbo lag" (Foxall & Johnston, 1991). Despite this initial disadvantage, Renault persevered in the development of the technology, improving the reliability and efficiency of its power unit, until it scored his first Formula 1 victory in 1979 during with the Renault RS10, and therefore marking a historic moment for Formula One, proving that turbo engines, until then considered unreliable and unsuitable for long-duration racing, could compete and win against traditional naturally aspirated engines. In the early 1980s, the advantages of turbocharging became evident, because while 3.0 litre naturally aspirated engines reached around 500 horsepower, turbocharged units began to exceed these figures, reaching around 650 horsepower in 1983, 800 horsepower in 1984 and even 900 horsepower in 1985 (Foxall & Johnston, 1991). This increase in power made turbocharging the compulsory choice for anyone who wanted to be competitive. Ferrari, BMW, Honda and Porsche joined the turbocharging race, developing their own turbocharged engine variants to challenge Renault, who had an early lead but struggled to maintain it due to reliability. Despite the incredible performance offered by turbos, their rise brought with it a number of problems, including high costs and growing safety concerns. Indeed, the single-seaters became extremely powerful and difficult to control, especially in low-grip conditions or in the rain. Moreover, during qualifying, teams began to use extreme versions of their engines, capable of over 1,200 horsepower, but designed to last only a few laps. This escalation in power, therefore, began to worry the FIA, who introduced several regulations to try to limit performance and costs, including reducing fuel tank capacity and banning refuelling in races, forcing teams to optimize fuel consumption and redesign race strategies (Foxall & Johnston, 1991). Despite the FIA's attempts to limit the power of turbocharged engines, the situation continued to be economically unsustainable for many teams, and so it was decided to ban them permanently from the 1989 season, imposing a return to naturally aspirated engines, marking the end of an era, with the Honda-powered McLaren MP4/4 winning 15 of the 16 races held in 1988, with Ayrton Senna and Alain Prost as protagonists (Jenkins, 2010).

Beyond the ground effect and the advent of the turbo, this decade also brought a series of technical innovations that profoundly changed the sport. First and foremost, the introduction of the carbon-fibre chassis, which represented a profound step forward in the field of safety and performance of cars, which until then had been fitted with chassis made mainly of aluminium. In 1981, McLaren, under the technical direction of John Barnard, developed the MP4/1, the first car with an all-carbon fibre monocoque, a new material that offered unprecedented rigidity and impact resistance, improving driver protection, and reducing the car's weight. Its efficacy was demonstrated when John Watson survived a high-speed crash during the 1981 Italian Grand Prix, thus highlighting the superiority of carbon over aluminium and thus becoming the dominant standard in the category, which has endured to this day (Jenkins, 2010). In addition, the carbon also found use in braking systems with the introduction of carbon-fibre discs, which, compared to traditional steel brakes, provided greater heat resistance and weight reduction, improving braking performance and reducing wear. In parallel, another key innovation was the introduction of telemetry, which allowed teams to collect real-time data on various car parameters, such as brake temperature, fuel consumption and engine behaviour, thus enabling them to optimize race strategies and improve tuning between sessions (Foxall & Johnston, 1991).

More specific, by analysing the official FIA technical regulations from 1977 to 1988 (FIA, s.d.), we can observe what were the major evolutions in the regulatory field in both aerodynamic and engine terms. In 1977, cars were still free to develop aerodynamics with banned moving appendages, but with front and rear wings that were not yet rigidly regulated. 1978 saw the spread of moveable skirts, made possible by a regulatory vacuum, so in 1979, the FIA introduced a first attempt to contain ground effect, requiring skirts to have a minimum opening of 20% of the total perimeter and setting the maximum length of cars at 5 meters. The year 1980 saw further aerodynamic restrictions, with a ban on adjustable components above 90 cm above the ground, while in 1981, the FIA imposed restrictions on moveable skirts for the first time, stipulating that any aerodynamic device had to be rigidly attached to the suspended part of the car, banning active ground effect adjustment systems and moving skirts, although fixed miniskirts remained legal, maintaining a high aerodynamic load, with the result that in 1982, the regulations definitively banned miniskirts and imposed a minimum ground clearance of 6 cm, but it was not until 1983 that the definitive end of pure ground effect was sanctioned, with the introduction of the compulsory flat bottom between the front and rear axles, eliminating aerodynamic ducts under the car. In 1984, the FIA introduced the first limit on fuel capacity for turbo cars, set at 220 litres, while turbo pressure remained unrestricted, and in 1985, the fuel limit was lowered to 195 litres. In 1986, the use of titanium and ultralight materials in the wings was banned to avoid deformation at high speeds, and in 1987, the FIA introduced a distinction of aerodynamic specifications between turbocharged and aspirated cars and increased the maximum displacement of aspirated engines to 3.5 litres, in an attempt to make them a viable alternative to turbos. In addition, turbocharged cars were limited to a maximum pressure of 4.0 bar, with fuel capacity reduced to 180 litres. Finally, in 1988, the last year for turbocharged engines, the FIA further lowered the maximum turbo pressure to 2.5 bar and reduced the fuel tank capacity to 150 litres, drastically limiting the power of turbochargers, so that the aspirated cars that remained free of restrictions became the regulatory basis for the future of Formula 1. Finally, during this decade, numerous regulations were introduced to improve the safety of drivers and the sport as a whole. For example, starting in 1984, crash tests became mandatory to assess the single-seater's resistance to impact, leading to significant improvements in protective structures, especially roll cages and anti-intrusion devices, while the protection of the cockpit and the driver's legs was also further strengthened, reducing the risk of serious injury in the event of an accident.

4.5 The rise of electronics within Formula 1

The abolition of turbocharged engines from the 1989 season onwards effectively sanctioned the end of an era in which the search for competitive advantage was based mainly on increasing power, obtained by optimizing the supercharging capacity offered by the turbocharger. In fact, this regulatory change shifted the teams' attention to new areas of development and, in conjunction with the increasing popularity and performance advancement of computers, this context favoured the massive entry of electronics into Formula 1, transforming the approach to competition by shifting the focus from pure engine power to the car's ability to respond more effectively and precisely to driver input, thanks to the implementation of advanced control systems and related technologies, which, between 1989 and 1993, transformed the performance of single-seaters and the way they were driven.

One of the most significant innovations was the introduction of the electro-hydraulic gearbox, which made its debut with the Ferrari 640 in 1989, and which radically changed the way drivers interacted with their car. In fact, this system, developed by Ferrari, eliminated the need to use the clutch in gearshifts allowing drivers to maintain constant acceleration and reduce shift times, as well as allowing them to keep both hands on the wheel at all times even when braking and cornering, thus facilitating a change in the drivers' driving style and making it even more extreme. The technology's potential was immediately shown by Nigel Mansell's victory at the 1989 Brazilian Grand Prix, a result that highlighted the benefits in terms of driving fluidity and reduced errors associated with manual gearboxes, although the technology was still immature and presented some reliability problems. The electro-hydraulic gearbox was not only a technical innovation that laid the foundation for all future assisted shifting solutions, it also marked a turning point in the competition between the racing teams. In fact, both McLaren and Williams, after seeing the performance advantages offered by this solution, began rapidly developing their own versions of the system to close the technological gap with Ferrari. This led to an acceleration in the development and adoption of electronic technologies over the next few years.

At the same time, electronic innovation, supported by advances in the processing capabilities of on-board computers, extended to several critical aspects of single seaters, helping to profoundly transform the dynamics of competition. Among the most relevant technologies of this period were the active suspensions, a system capable of dynamically adjusting the car's ground clearance according to track conditions, providing significant advantages in terms of aerodynamics, allowing a constant set-up to be maintained at every stage of the race, reducing tire degradation and improving cornering stability, and traction control, designed to optimize the management of the power transmitted to the rear wheels, preventing skidding, and thus significantly improving traction coming out of corners, guaranteeing superior efficiency in the management of the power delivered by the engine, thus increasing the competitiveness of cars equipped with this technology. The team that managed to best interpret and implement both of these solutions was Williams, who, under the technical guidance of Adrian Newey and Patrick Head, refined these technologies first on the FW14B of 1992 and later on the FW15C of 1993, two extraordinarily high-performance single seaters that outclassed the competition and dominated the Formula One scene, winning two consecutive world titles.

The introduction of such driving aids generated a fierce debate within the world of Formula One, as well as among the public, racing enthusiasts and the drivers themselves, since these technologies, while guaranteeing a clear improvement in performance and safety, had profoundly modified the relationship between driver and car, significantly reducing the driver's influence in managing the grip and stability of the single-seater, making driving more assisted and less dependent on individual skill. Consequently, the controversy caused by the increasingly widespread use of these solutions led the FIA to intervene with regulatory measures aimed at rebalancing the competition, and starting in the 1994 season, the Formula One governing body decided to ban traction control and active suspension, with the aim of returning more centrality to drivers' driving skills and reducing dependence on technology, thus reaffirming the fundamental principle that driver talent and skill, rather than technical innovations, should remain the determining factor in achieving success on the track.

Between 1988 and 1993, the most significant regulatory changes primarily concerned the abolition of turbocharged engines in 1989, with the introduction of a maximum displacement of 3,500 cc for naturally aspirated engines and a limit of 12 cylinders, also banning the use of Wankel, Diesel, two-stroke, and turbine engines, a decision made to limit performance and, above all, costs. At the same time, the maximum limit on the amount of fuel allowed in a race was removed, and a uniform minimum weight of 500 kg was established for all cars, regardless of the type of engine, as until 1988, turbocharged cars were subject to a higher minimum weight, set at 540 kg, compared to those with naturally aspirated engines due to their technical requirements as well as their competitive advantage. In 1990, the regulations were further updated to include detailed specifications on fuel, imposing a maximum limit of 102 RON for octane rating and a maximum oxygen and nitrogen content of 2% and 1% by weight, respectively, a measure introduced to prevent the use of special fuels that could artificially enhance engine performance. Another significant regulatory evolution concerned the reduction of the maximum car width, which was set at 215 cm from 1989 to 1992, while in 1993, it was reduced to 200 cm, a change aimed at reducing aerodynamic performance, which was already facilitated by the use of driver assistance systems. Furthermore, several safety modifications were also implemented throughout these years, such as more rigorous crash tests for the survival cell with increasingly demanding specifications to enhance driver protection in the event of an accident. Even though the category was not significantly altered by the regulatory changes of this era, a major change was made in 1991 when it was mandated that all cars competing in Formula 1 events have an onboard camera or an equivalent ballast system. This was done to improve television broadcasting and guarantee that all cars had the same weight, whether or not they used cameras.

4.6 The strengthening of security measures and the transition to stricter regulations.

As already pointed out in the previous paragraph, 1994 marked the end of electronic driving aids, so the cars lined up on the starting grid at the beginning of that season had to be without traction control, active suspension, four-wheel steer, launch control and anti-lock braking systems (FIA, s.d.), today commonly known as ABS. This regulatory change caught the participating teams rather unprepared, but above all had devastating effects on the safety of those cars that were in fact mere evolutions of the previous year's cars, since these were designed to be driven on the limit, but assisted by electronic controls. From the start of the championship there was therefore plenty of unfortunate incidents, but the point of no return was reached during the tragic weekend of the Imola Grand Prix, where the world witnessed what went down in history as the blackest weekend in the history of Formula 1, which began on Saturday with Rubens Barrichello's unfortunate accident and the tragic death of Roland Ratzenberger, and ended on Sunday with the death of Ayrton Senna. The death of the Brazilian driver took the world, but especially Formula 1, by surprise, and risked effectively putting an end to the sport. After this tragic event, the focus of the organizational body shifted to only one thing: safety. In fact, the federation immediately set to work to modernize the circuits and make them safer, as well as making changes to the cars to try to make them less fast and safer, including radiating the size of the aerodynamic appendages to reduce cornering resistance, while in the following years, the weight of the cars was drastically raised from 505 to 595 kg, the engine was reduced from 3.5 to 3.0 litres, and other more stringent safety measures were adopted for the survival cell, fuel tanks, and fire safety (FIA, s.d.).

The ten years following, from 1998 to 2008, were characterized by a greater convergence towards dominant designs, driven on one hand by increased investments from car manufacturers, and on the other by increasingly strict regulations aimed at reducing the performance gap between the cars and, above all, cutting costs. (Jenkins, 2010). For this very reason, the regulatory change of 1998 introduced significant modifications to the cars, reducing their overall dimensions by decreasing the width from 200 cm to 180 cm to limit aerodynamic effects. Additionally, grooved tires were introduced to reduce the grip generated by the wheels. Furthermore, starting from 2000, the use of 10-cylinder engines was made mandatory for all teams, and in 2001, traction control was reintroduced. For the 2006 season, engine dimensions were further reduced, both in terms of the number of cylinders, which dropped to eight, and the displacement, which was lowered to 2.4 litres.

It was precisely during this decade that regulations became increasingly detailed and, in a way, more restrictive, forcing the teams to seek their competitive advantage mainly through incremental innovations rather than radical changes, pushing them to concentrate on refining and enhancing the synergy between the chassis, aerodynamics, and engine.

However, despite this progressive narrowing of the space for solutions due to regulations that slowly began to become more and more stringent, this decade was nevertheless characterised by a strong possibility for experimentation and innovation in all areas of single-seater design. Although always within the regulations, the competitive advantage could still be sought in virtually any aspect of the single-seater, leaving the teams the choice of which area to focus on, whether the engine, the chassis, or, for example, the electronics, in order to make their single-seater as competitive and unique as possible In fact, it was one of the most dynamic and prolific periods in the history of the championship, which also coincided with the beginning of what is commonly referred to as “the era of the big manufacturers”, namely the phase in which numerous leading car manufacturers, including Toyota, Honda, BMW, Ford and Renault, decided to actively participate in the championship, driven by both technical and brand image motivations. Their entry radically transformed the structure of the competition, bringing a huge influx of economic resources and significantly raising the overall level of investment required for car development. At the time, there were no limits to either testing or budgets, which allowed teams to undertake extensive development programmes. Thus, manufacturers were competing not only on the track, but also and especially in the factories, allocating extraordinary financial resources in the hope of gaining a competitive advantage and a consequent return in sporting, economic and image terms. In most of the cases, however, these investments proved to be unsustainable, leading some manufacturers to withdraw from the championship after failing to achieve the desired results. However, during this period the technical level of competition therefore increased progressively, and it was also accompanied by a rapid and disproportionate growth in the size and organisational complexity of the teams, which began to employ thousands of people, consequently raising the economic threshold necessary to participate competitively to unprecedented levels. Precisely for these reasons, in the following years, the issue of cost containment became an increasingly central issue for both teams and regulators.

4.7 Energy recovery technologies and the era of Turbo-Hybrid engines

The arrival of the 2009 season marks the beginning of the latest chapter in the history of Formula 1, which will be marked by a strong push towards emissions reduction and environmental sustainability.

The first step towards this greener transition of the championship is represented by the introduction of an Energy Recovery System called KERS, or Kinetic Energy Recovery System, which, as its name suggests, is used to recover the kinetic energy generated during braking, which would otherwise be lost and dissipated in the form of heat. The operation of this device was handled by a motor-generator known as the MGU, which had the task of converting kinetic energy into electrical energy, which would then be stored inside special batters, ready to be reconverted into kinetic energy, providing a temporary increase in vehicle power of around 60 kW, equivalent to around 80 horsepower. In the same year, this major regulatory change also imposed a simplification of the aerodynamics to facilitate overtaking, with the ban of all aerodynamic devices other than the simple front and rear wings, marking a return to aerodynamically simpler cars, and moreover, it also saw the abandonment of tires with grooves to reduce the grip generated by the tires, and the subsequent return of slick tires. The following year, given the technical problems encountered in the development of the KERS technology, all teams unanimously agreed to stop using this technology, which meant that in fact no car on the 2010 grid was equipped with this device. Also in this year, the decision was made to abolish refuelling during the race. It was not until the following year, 2011, that the KERS system was reintroduced, along with the DRS (Drag Reduction System), a movable wing at the rear of the car, which opened up on the straight and allowed the car to reduce its aerodynamic resistance and thus make overtaking easier, which had become increasingly difficult in previous years due to the sophistication of the single-seater aerodynamic systems. These regulations remained more or less stable until the arrival of the 2014 season, when the KERS system was finally abandoned and replaced by the new and efficient engines of the hybrid era.

The year 2014 marks another significant change in the history of Formula One, as it marks the definitive abandonment of traditional internal combustion engines, with the abolition of naturally aspirated eight-cylinder engines, and imposes a significant transformation in engine design and management, introducing new six-cylinder turbo-hybrid engines with a maximum displacement of 1.6 litres. At the heart of these new engines is the so-called power-unit, a sophisticated combination of an internal combustion engine and two electric motor generators: the MGU-K, or Motor Generator Unit-Kinetic, which, similarly to KERS, uses the kinetic energy recovered during braking to provide an increase in engine power, while the MGU-H, or Motor Generator Unit-Heat, uses the exhaust gases to reduce turbo lag at low speeds and recover excess energy at high speeds. (Bopaiah & Samuel, 2020). Thanks to the use of these two electric motor-generators, the new power units were able to achieve exceptional results in terms of efficiency, achieving thermal efficiencies of more than 50%, compared to the 25% to 40% efficiency of conventional heat engines (Elmagdoub & Samuel, 2021). The arrival of power-units also marked the beginning of the dominance of the Mercedes team, which from 2014 onwards, was able to win eight consecutive constructors' titles, thanks to the great initial advantage accumulated thanks to the performance of its power-unit, which exploited a pre-combustion chamber system called TJI, Turbulent Jet Ignition, which allowed it to increase efficiency and reduce consumption, outperforming the technologies adopted by competitors. Continued development of power units was therefore the dominant factor in the search for performance for many seasons following the introduction of this regulatory change, since many manufacturers struggled to bring their power-units up to the level of those of Mercedes. However, at the end of the 2021 regulatory cycle, during which there had been an increase in both the size and weight of the single-seaters, all constructors were able to develop their power units, managing to almost completely close the huge gap that had accumulated over the course of the first few seasons.

This season also saw the introduction for the first time in the history of the sport of a season-long budget-cap for all teams, with the aim of further flattening the gap between the smaller teams and the top teams, which, being able to enjoy greater financial resources, tended to win more, while the following year, 2022, saw the introduction of a new regulatory cycle, and the reintroduction of ground effect cars, with the aim of once again creating aerodynamically simpler cars that could battle closer together, without being affected by the aerodynamic influence of the car in front of them, and in this way increase the spectacle. In the same year, it was also decided to impose a freeze on power-unit development, forcing teams to concentrate their development efforts solely on aerodynamics, without being able to make changes at the engine level. This measure will come to an end with the advent of the 2026 season, when power-units will undergo a complete overhaul, increasing the influence of the electric motor, bringing it to generate up to 50% of the total power, compared to around 15% for the current power-units.

5. Formula E

This chapter explores the evolution of the third and final competition considered in this analysis, the Formula E World Championship. As for the previous competitions, the focus will be on uncovering the foundational philosophy that shaped the series, as well as examining the strategic motivations behind its creation, particularly in terms forced innovation in the field of electrification in the automotive sector. We will do so by examining the three main eras of the sport, marked by three generations of cars, each with very different characteristics. Moreover, we will also focus on the competitive dynamics within the competition itself, which is not intended to be a simple alternative to other motorsport championships, such as Formula 1, but aims to redefine the very concept of motorsport, defining a completely new paradigm of competition, capable of attracting and above all involving a heterogeneous public, creating spectacular racing dynamics, while also maintaining a strong commitment to sustainability.

The FIA Formula E World Championship was created in 2014 as a new alternative racing competition with the aim of advancing sustainability and electric mobility in the automobile industry, while also addressing the technological and environmental issues faced by the motorsport in that particular time. The two founders, Alejandro Agag, a Spanish entrepreneur with expertise in both politics and motorsport, and Enrique Bañuelos, a business magnate, came up with the idea of creating an all-electric single-seater championship, which would have to position itself as a new sporting competition, as well as a platform for technological innovation for automakers, with the goal to develop technologies that can subsequently be directly transferred to the automotive industry and applied to mass-produced electric vehicles.

The Formula E Holdings, the company Agag founded, was therefore granted the exclusive right to organize a single-seater electric championship until 2039 by the *Fédération Internationale de l'Automobile* (FIA), the world's motorsport governing body, which saw Formula E as a way to lessen the environmental impact of car racing while offering at the same time a test bench for the development and experimentation of advanced technologies in the electric car sector, thus accelerating the transition to more sustainable mobility (Næss & Tjønndal, 2021). A great number of major automakers, like for example BMW, Mercedes-Benz, Audi, Porsche, Jaguar, Nissan, and DS Automobiles have chosen, over the past ten years to compete in the championship, in order to test and develop new electric mobility solutions, thus enhancing the importance and credibility of the Formula E in the development and creation of innovative solutions in the field of electric mobility.

However, the idea of an electric car championship is not entirely new, in fact, smaller competitions have been developed in the past. Nevertheless, Formula E represents the first attempt to create a world-class series with the direct support of international governing bodies and major car manufacturers. Furthermore, the fundamental concept behind Formula E is to combine technological innovation with a unique and revolutionary race format designed to bring motorsport directly into cities and make it more accessible to a younger and environmentally more conscious audience. In fact, one of the most distinctive aspects of Formula E is precisely its innovative competition format, with races taking place exclusively on street circuits, a strategic choice that has two main objectives: the first is to bring motorsport to a wider audience by staging races directly in major metropolitan areas, and the second one is to promote electric mobility in urban environments by demonstrating the feasibility of zero-emission technologies in a real-world context. In addition to this, Formula E has implemented strict policies to minimize its environmental impact, which include the exclusive use of renewable energy to power the events and the adoption of measures to limit CO_2 emissions associated with the championship's logistics (Sturm, Andrews, Miller, & Bustad, 2024).

One of the main features of Formula E is its strong sustainable positioning, which is reinforced by the fact that it was the first motorsport championship to receive ISO 20121 certification in 2018. This certification attests to the fact that the championship adheres to sustainable practices in all aspects of its organizational structure, from resource optimization and carbon offsetting to waste management and the development of a legal register, which is a document that collects and monitors all applicable environmental regulations governing all the operations and activities of the championship in the various countries where races take place, therefore ensuring that each event is organized in compliance with local regulations, while also improving the transparency and environmental compliance of the championship itself. These efforts have helped Formula E to become the first sport to achieve carbon neutral certification in 2020 (Næss, 2021). However, despite its commitment to sustainability, the championship has faced some criticism over its actual environmental impact, with some academics accusing it of greenwashing, arguing that it emphasizes its environmental commitment without fully addressing critical issues such as emissions, energy management, the high environmental impact of logistics and the temporary infrastructure required for urban racing (Sturm, Andrews, Miller, & Bustad, 2024).

In addition to its commitment to environmental sustainability, Formula E also stands out for its significant social impact and ability to attract new forms of sponsorship. In fact, a unique aspect of Formula E is its funding model, which relies heavily on sponsorship to generate around 50% of its revenue, therefore differing from other championships, such as Formula 1, which generates most of its revenue through race hospitality fees and is less dependent on sponsors, who contribute only about 15% of the total. This financial model has made Formula E particularly attractive to companies seeking to enhance their "green" and technological image, who see electric motorsport as a strategic opportunity to promote their values of innovation and sustainability. In fact, unlike other motorsport championships, which have traditionally relied on sponsors linked to fossil fuels, Formula E has attracted brands a lot of major brands interested in associating their image with innovation and sustainability (Næss, 2020). At the same time, Formula E has adopted innovative strategies to redefine the relationship between sport and the public, focusing on digitalization as a key tool to engage spectators. In particular, the championship has developed initiatives aimed at reaching a young and technologically connected audience, using digital and interactive platforms, as well as elements of gamification to increase audience engagement (Sturm, Andrews, Miller, & Bustad, 2024), an approach that also confirms its pioneering role in the evolution of sports marketing strategies and audience engagement dynamics.

5.1 First-generation cars suffered from the technological limitations of the time.

On September 13, 2014, the Beijing E-Prix officially inaugurated the FIA Formula E World Championship, which was the first international racing event exclusively for electric vehicles. In particular, the cars that took part in that race belonged to the first generation of Formula E cars, which are better known with the term Gen 1, and which remained in force for four consecutive seasons, starting in 2014 until the end of 2017. Ten teams took part in the inaugural Formula E season, each of which started with two drivers on the grid, making a total of twenty cars. However, only five of these teams were represented by car manufacturers, namely

Renault, Audi, Mahindra, Venturi and NIO, at the time racing under the name of Team China Racing, while the remaining five were independent teams. The second season of 2015 also saw the entry of a new manufacturer, the French DS Automobiles in partnership with the Virgin Racing team, while 2016 also saw the addition of Jaguar, further expanding the presence of car manufacturers in the championship.

In order to ensure an initial level playing field between the various teams and to keep initial costs down, all teams were equipped with the same single-seater for the first season: the Spark-Renault SRT_01E, supplied directly by the Spark Racing Technology, and whose chassis was made by the Italian company Dallara, while the power unit and electronic management system came from McLaren Electronics System. In addition, the gearbox was supplied by Britain's Hewland, the batteries by Williams Advanced Engineering and the powertrain management, consisting of battery and power unit, was performed by SRT-Renault. This configuration effectively made the championship a single-make championship in its inaugural season, and it wasn't until the following season, in 2015, that teams were allowed to develop and modify specific components, which included the electric powertrain, the gearbox and the inverter, a key element for energy transfer between battery and engine. However, the batteries, known as the Rechargeable Energy Storage System (RESS), and chassis remained standardized and supplied directly by the FIA.

Moreover, according to the official Formula E regulations, which are available on the FIA website, once components have been homologated at the start of the season, they cannot be changed during the entire homologation period of two years. As a result, the development of physical parts is essentially frozen during the championship. However, this restriction does not apply to software development, which remains free to be updated and improved throughout the season, thus becoming the de facto central element of intra-season development for the various teams, being decisive in energy management and recovery during the race. The first-generation Formula E cars had therefore uniform technical characteristics regarding aerodynamics and chassis, with very minimal differences between the various teams, limited only to the engine, a fact that was accentuated even more also due to the regulatory continuity that remained unchanged for four consecutive seasons. In particular, these single seaters were characterized by standard dimensions, with a maximum length of 5 meters, a width of 1.78 meters and a height of 1.05 meters. The minimum weight imposed by the regulations was 900 kg, while performance allowed a top speed estimated at around 225 km/h. The power output varied according to the stage of use: in qualifying it was set at 200 kW, while in the race it was progressively reduced over the course of the seasons, going from 150 kW in 2014 to 170 kW in 2015, up to 180 kW for the 2017 and 2018 seasons. This limitation was due to the inefficiency of the first-generation batteries, which only allowed 28 kWh of available energy, a value that, regardless of the driver's power management, was not sufficient to complete an entire race, as the maximum regeneration capacity was set at 200 kW and, in the course of a competition, only 15% of the battery could be recharged. Consequently, as it was impossible to exceed this technological limit, in the first four seasons each driver had two cars and was obliged to change cars mid-race in order to complete the race.

Being severely limited by technological and regulatory constraints, the pursuit of performance focused in part on optimizing the suspension set-up and aerodynamics to better adapt the cars to the specific characteristics of each circuit. However, from a technical point of view, the efforts of the engineers, who were only allowed to develop their own powertrains, focused mainly on reducing energy losses in the transmission of power at high speeds, thus improving the overall efficiency of the powertrains. Thus taking advantage of the progress in energy efficiency, which made it possible to reach in a short amount of time an efficiency of around 95% starting from the second season, teams began to develop gearboxes with a different number of ratios, with some teams which kept the traditional five-speed configuration, while others opted for a reduction in the number of gears, adopting solutions ranging from one to four gears. The initially most effective choice proved to be that of Renault, which for the 2015 season designed a gearbox that was particularly light and which had only two gears, one dedicated to the start and the other optimized for the rest of the race, even though, at the beginning of the fourth season, the most widely adopted solution was the one with a single-gear gearbox.

Finally, the first three seasons of Formula E were characterized by the dominance in the constructors' championship of the Renault, while in the fourth season the title was won by Audi, a result that therefore underlines how teams supported by large manufacturers can have a significant competitive advantage, thanks to their technical resources and ability to develop more advanced powertrains than independent teams. Despite the great successes of four years of competition in the electric world, Renault nevertheless decided at the end of the fourth season and on the eve of the new regulatory change to withdraw from Formula E to concentrate more on the Formula 1 world championship, In its place, however, enters the Japanese manufacturer Nissan, effectively replacing the French manufacturer.

5.2 Second generation cars revolutionize the sport.

The start of the fifth season brings a wave of novelty to the championship, introducing what will be the new generation of electric single seaters, the Gen 2. These cars represent a huge leap forward compared to the first generation of single-seaters, and also entail a major paradigm shift in the electric racing per se, as the new cars, equipped with batteries supplied by Mclaren Applied Technologies, can store up to 52 kWh of power, almost twice as much as in Gen 1, thus making it possible to finish an entire race with the same single-seater, thus also revolutionizing the way of racing and race strategies.

The Gen 2 regulations remained in force for a period of four seasons, until the end of the eighth season of 2021-2022, and always to follow the line of cost reduction, Formula E stipulated also for this new regulatory cycle to provide substantially all the aerodynamics as well as a new chassis, again designed by Spark and Dallara, leaving it up to the teams to develop only the engine components, always subject to biennial homologation, and the software, which was continually updated during the season. The second-generation cars, however, were extremely different from their predecessors. Thanks to the new, more powerful battery, performance increased to 250 kW in qualifying and 200 kW in the race, enabling these single seaters to reach speeds of up to 280 km/h, a considerable increase compared to the first generation. In addition, the regeneration power under braking is also increased, rising by up to 25%, which together with the more powerful battery and aerodynamic measures, such as the route fairing and the reduction of the rear wing to two small single flaps, allows the cars to complete the entire race.

With the introduction of the second generation of cars, a new competitive dynamic aimed at increasing the strategic options during the race was introduced, called Attack Mode, which allowed the engine power to be temporarily increased by an additional 25 kW. In order to be activated, the driver had to leave the ideal trajectory and pass through specific sections of the track designated for activation, a mechanism which ensured that the advantage of the power increase was partially offset by a temporary loss of time due to deviation from the optimal path. Starting with the sixth season, the second in which the second-generation cars were used, the Attack Mode power was increased to 35 kW. At this early stage, there were no fixed rules on the duration of the boost, or the number of activations allowed per race, as these parameters were set on a case-by-case basis according to circuit conditions. However, even the introduction of this new mode was not only intended to expand the strategic possibilities in the race, but was also part of the philosophy behind the championship to implement interactive and gamification elements, with the aim of attracting a young and technologically oriented audience. In fact, the concept of Attack Mode presents a remarkable resemblance to one of the typical features of Mario Kart, a famous Nintendo video game, in which by passing over certain areas of the track it is possible to obtain a temporary speed boost. Although this innovation has been generally accepted and has not caused any particular controversy, the same cannot be said of FanBoost, which was introduced in the inaugural season of 2014, and which has therefore been a distinctive element of the Formula E championship since its beginnings, but which, unlike Attack Mode, has always generated a fiercer level of debate. In fact, the FanBoost involves the allocation of a temporary power boost to the 5 most voted drivers, who then receive a surplus of 50 kW, which they can use for up to five seconds in the second half of the race. The aim of this system was always to encourage public involvement, making the competition more interactive and attractive to a young, technologically oriented audience (Næss & Tjønndal, 2021). However, although both modes allowed drivers to gain extra power, the logic behind them was quite different, as the former tended to inflict a time penalty to offset the subsequent advantage gained, while the latter introduced an external factor that favoured certain drivers regardless of their performance on the track. Furthermore, in some race situations, the combined use of both systems could create an extremely large artificial gap between the drivers, greatly reducing competitive fairness, which is why, with the advent of the Gen 3 regulatory cycle, the FanBoost dynamic was permanently abolished.

To conclude, concerning the entry and exit of new participants, at the start of its fifth season in 2018, Formula E saw major changes among the teams and manufacturers. In fact, in addition to Nissan, which entered the championship, taking over from Renault, DS Automobiles changed its partnership from Virgin Racing to Techeetah, and won two consecutive constructors' championships in 2019 and 2020. Furthermore, in the same year, BMW officially entered the competition, making a deal with the Andretti team, while the following year, with the start of the sixth season in 2019, the two new German manufacturers Mercedes and Porsche entered the category. However, at the end of the seventh season in 2021, both Audi and BMW instead announced their withdrawal from Formula E, and at the end of the eighth season in 2022, before the imminent regulatory change and the introduction of the Gen 3 cars, Mercedes also followed the same path, announcing its retirement after winning two consecutive constructors' championships.

5.3 Third generation cars bring innovation, more efficiency and sustainability.

As previously mentioned, with the start of the ninth season of the Formula E championship in 2022, we also see the debut of a completely new generation of cars, called Gen 3, in continuity with its predecessors. As happened in the past with the regulatory transition from Gen 1 to Gen 2, this transition also introduced substantial changes compared to the previous version, revolutionizing the competition and the driving dynamics. In particular, the new single seaters marked a significant advancement in many respects, most notably a significant increase in power, an overall reduction in weight and an improvement in efficiency, factors that combined mean only one thing: higher performance. However, the distinctive element of this new generation lies mainly in the focus on environmental sustainability, which has always been a fundamental pillar of the championship, with technological solutions and materials that aim to further reduce the ecological impact of the single seaters as well as the competition in general.

In particular, as usual, the chassis and aerodynamics of the new cars are standardized, identical for all teams, and are supplied directly by the Federation, and have been developed by Spark Technologies in collaboration with Dallara. From an aesthetic point of view, the new generation single seaters adopt an even more futuristic design, characterized by an arrow shape, directly inspired by that of a fighter jet. As far as performance is concerned, power increases to 350 kW in qualifying, limited to 300 kW for the race, allowing the car to reach a top speed of 320 km/h. The new single seaters are also equipped with a second electric motor positioned on the front axle, which only has the function of energy regeneration, and which when coupled to the rear engine is able to bring regenerative power up to 600 kW, more than double the previous generation, which stopped at 250 kW. This enormous increase in the powertrain's regenerative capabilities means that 40% of the race can now be run solely on energy recovered during braking. In addition, the new batteries, supplied by Williams Advanced Technologies, are designed to handle an ultra-fast recharge of up to 600 kW, which makes it possible to take energy-refuelling pit stops during the race, a feature that, however, due to problems during testing, was not introduced immediately, but its adoption was postponed until the eleventh season. In addition, thanks to the new regenerative power of the two electric motors, it has been possible to reduce the size of the battery, a factor that, coupled with a slight reduction in the overall dimensions of the car, also leads to a significant weight reduction of around 50 kg. The most innovative feature of the new cars, however, is the complete absence of mechanical brakes on the rear axle, which are replaced entirely by the regenerative action of the electric motor during the race. However, this solution must also be combined with a traditional braking system to be used for emergencies, or during the first few laps of the race, when battery power is still at its maximum and consequently there is no regeneration of energy. Additionally, the new cars include several characteristics that show how much attention the competition organizers put into sustainability. For the first time, the car's bodywork is also partially composed of recycled carbon fibre, and the batteries created for this competition are also made to be recycled at the end of their life. Furthermore, Hankook's new tires are made of 26% recyclable material and will be fully recycled at the conclusion of every race.

However, unlike the previous two generations of single seaters, which remained in use for four years without significant modifications, the third generation of cars underwent a major evolution at the beginning of the eleventh season., when in 2024, the Gen3 EVO made its debut. The car is an update to the current single seater that, as the name suggests, and does not represent a radical change comparable to those typically introduced with new regulations. Instead, it is a refinement of the existing version, aimed at further enhancing its performance. The most significant innovation in this evolution concerns the motor mounted in the front axle. In fact, while in the previous two seasons this component was used exclusively for energy regeneration during braking, with the Gen3 EVO it is now also employed to generate traction under the Attack Mode. This effectively transforms the car from a rear-wheel-drive vehicle into the first all-wheel-drive single seater in Formula E history. Additionally, this technical modification is accompanied by an update to the Hankook tires, which now feature a softer compound capable of generating a higher level of grip. This improvement, combined with the implementation of all-wheel drive, results in an average reduction of one second in lap times. Furthermore, the car will be able to accelerate from 0 to 100 km/h in less than two seconds, making it 30% faster than a current Formula 1 single-seater. Furthermore, this year also marks the debut of the postponed in-race energy recharging during pit stops. This new feature, known as Pit Boost, requires a mandatory 30-second stop in the pit lane, during which cars can take advantage of the new battery packs' 600 kW fast-charging capability to recover up to 10% of their capacity, an innovation that brings a significant shift in race dynamics, profoundly impacting the energy management strategies adopted by teams, which have always been a fundamental aspect of Formula E.

Finally, with regard to the panorama of teams and manufacturers in the championship, in 2022 with the arrival of Gen 3 some teams have made their entry into the competition, including the Italian Maserati, which used engines supplied by partner DS Automobiles, the British McLaren with Nissan client powertrains, and the Spanish CUPRA, which for the first two seasons used a Mahindra client powertrain, while as for the Constructors' World Championship, in 2023 it was won by the Envision Racing team, with a Jaguar client engine, while in 2024 it was won by Jaguar itself.

6. Comparative Analysis of Staged Competitions: Divergences and Convergences between Three Motorsport Paradigms

After having analysed from a historical point of view the birth, development and evolution of these three staged competitions, namely the motor racing competitions of the early 20th century, and the Formula 1 and Formula E world championships, this chapter will proceed with a comparison between these different realities, with the aim of highlighting their similarities and differences, investigating the reasons behind their birth and the intrinsic aims underlying each competition, also highlighting how these aspects have transformed and evolved over time, reflecting the technological, cultural and social changes that have accompanied the development of motorsport.

Therefore, an attempt will be made to identify which of the factors analysed in Chapter 2, namely, the trade-off between encouraging widespread experimentation and reducing participation costs, has prevailed throughout the evolution of each competition. Furthermore, it will investigate how these factors have contributed to either amplifying or limiting the innovative impact within the competitions themselves.

Subsequently, the analysis will extend to examining the extent and the dynamics through which each of these championships has fostered innovation beyond the confines of the competition itself, specifically within the automotive industry. By doing so, particular attention will be given to assessing the actual innovative impact and value generated, as well as exploring the relationship between the magnitude of technological transfer and both the underlying philosophy and the regulatory structure of each championship.

6.1 Solution space

The correct definition of solution space, as already mentioned, is a fundamental element in fostering innovation and, above all, widespread experimentation within a competition.

6.1.1 The first motorsport competitions were born as an open space for manufacturer-led experimentation

As far as motor racing between the late 19th and early 20th century is concerned, the solution space was almost infinite, in fact, such competitions were truly pioneering, and in a certain sense even anarchic events, held on public roads and with vehicles obtained directly from mass production. In this period, with the exception of a maximum or minimum weight limits sometimes set by the organizing bodies of specific events, there were essentially no regulatory constraints that could in any way direct technological development. The first motor racing events were therefore true technological showcases, in which each manufacturer could freely experiment and compete with any type of technical solution, thus creating a context of great design freedom, a scenario that favoured the birth of an exceptional variety of configurations, with engines of all types and sizes, from twin-cylinder engines to enormous units of over 18 litres, heterogeneous chassis layouts and construction materials ranging from wood to metal, in a continuous process of trial and error.

In fact, the objective of such compositions, unlike today, had nothing to do with creating a spectacle to entertain an audience, but had the sole objective of overcoming the technical limits of the time. Precisely for this reason, the manufacturers concentrated almost exclusively on the search for pure speed and the mechanical resistance of the components, as the only true elements capable of providing competitive advantage, and able to demonstrate the technical superiority of this new innovation called the automobile.

Indeed, in this context, the car itself was an emerging and not yet consolidated technology, which is why each competition acted as a test bed under real conditions, creating a direct link between competition, experimentation and industrial progress. Thus, the absence of a structured regulatory framework stimulated a veritable race for radical innovation, in which each race could bring revolutionary solutions to the track: from the first engines with complex architectures to the first rudiments of aerodynamics, obtained more out of empirical necessity than out of a real scientific understanding of the phenomenon.

The intervention of the regulator began to be more pronounced from the period immediately preceding the First World War, with the introduction of the first limits concerning the imposition of a maximum displacement for car engines entered in races, often coupled with a maximum or minimum weight limit. These restrictions, which continued to follow one another on a regular basis after the end of the conflict, had basically two objectives, firstly to support the main trends in technological development, therefore creating smaller and more reliable engines and cars, and above all to make competitions safer by limiting technological excesses such as the uncontrolled increase in displacements and power, which led to out-of-control speeds and mechanical failures.

Taken as a whole, therefore, it can be deduced that, from the point of view of creative freedom, motor racing in the first half of the 20th century, although beginning to introduce some initial attempts at regulation, essentially adopted an extremely open and permissive approach, stimulating widespread experimentation that extraordinarily accelerated the development of a still emerging technology, while also aiming at directing technical development towards solutions more in line with market needs. In fact, in the space of just a few years, this competitive environment transformed the automobile from a simple technical novelty into a sophisticated object of advanced engineering, whose main areas of progress were intense engine experimentation, which saw a rapid transition from big and heavy naturally aspirated engines, to smaller displacement but supercharged units capable of higher speeds, the development of increasingly lighter and stronger materials and chassis architectures, the first engineering reflections in the area of suspension and dynamics, and a growing focus on safety, which led to the birth of the first all-wheel drum braking systems and later the introduction of hydraulic braking systems. In addition to these aspects, there is also the constant search for greater reliability, which has become an essential requirement in long-lasting competitions, pushing manufacturers to develop increasingly refined solutions in the thermal and mechanical management of their vehicles, thus creating a solid technological basis on which the entire evolution of the modern automotive industry would be built.

6.1.2 The solution space in Formula One has evolved from creative freedom to regulatory constraints

The Formula One World Championship was born as the natural evolution of the most prestigious motor racing competitions that preceded it. However, what profoundly distinguishes it from the races that took place in the early decades of the 20th century is the fact that it was conceived from the very beginning as a unitary and centralized championship, regulated by a single reference body, the FIA, while in the previous era, the motor racing scene was characterized by regulatory fragmentation, with races organized and regulated by a plurality of bodies, whose international coordination role was played by the AIACR, but the actual management of individual competitions remained strongly influenced by national motor clubs.

The birth of Formula One, therefore, represents a break with the past: for the first time, a world championship is no longer a sum of independent events, each subject to the authority of its national club, but becomes an organic competition regulated in a uniform manner, with common technical and sporting rules and a single central regulator, marking the beginning of an integrated regulatory system, where the FIA assumes the dual role of technical arbiter and sporting guarantor, with the power to freely define the solution space, and consequently direct the technological development of the championship as a whole.

Presenting itself as the direct heir to the motor racing of the first half of the 20th century, the technical regulations that characterized the early years of Formula One, between the 1950s and 1960s, were essentially essential and not very detailed, leaving the designers wide margins of creative freedom. The technical constraints imposed by the FIA were mainly limited to basic parameters, such as the maximum engine capacity and a minimum weight to be respected, without significantly intervening on aspects such as mechanical layout, aerodynamics or chassis solutions. So, in this context, Formula 1 in its early years was still fully within a competition paradigm with an extremely open solution space, in which manufacturers were free to experiment and introduce radical and often spontaneous innovations, including some of the most revolutionary innovations in the entire history of Formula 1, such as moving the engine to the rear of the car, the introduction of the aluminium monocoque chassis and the first experiments with aerodynamic appendages.

From the 1970s onwards, as the design diversity and technical complexity of the cars on the grid increased, the regulator's intervention began to become progressively more incisive, introducing regulatory changes almost annually and regulating the development of new components in ever greater detail. Despite this increasing regulatory attention, however, the design freedom between the 1970s and 1980s remained extremely high, as evidenced by the many radical innovations introduced during the period. However, this process of constant updating, and revision of the technical regulations marked the beginning of a gradual but noticeable downsizing of the solution space and the need to focus more on incremental development to keep up with changing regulatory specifications.

It was precisely in this context that the FIA began to exercise a reactive role, intervening mainly a posteriori with respect to the emergence of innovations that, although technically brilliant, risked compromising driver safety or altering the competitive balance, unbalancing it excessively on the technical level. Emblematic examples were first the management of ground effect, banned in the early 1980s, and the subsequent increasingly stringent regulation of turbo engines, until their definitive ban at the end of the decade, and then the ban on electronic driving aids in the early 1990s. Decisions to limit the solution space, at this stage, essentially responded to two needs: on the one hand, the need to contain the uncontrolled escalation of development costs, which we will analyse below, and on the other hand, the emergence of safety as a regulatory priority, which from the 1970s onwards began to be considered a fundamental objective, capable of directly influencing both the technological evolution and technical innovation of the category, reaching its peak from the mid-1990s onwards, when, following Ayrton Senna's fatal accident, the FIA began to take an increasingly proactive role, imposing a series of regulations to increase safety, but with important side effects on the solution space as well, no longer limiting itself to merely following and sometimes correcting the technical and innovative evolution made by the various teams, but proactively guiding it.

From the end of the 1990s and especially with its entry into the early 2000s, Formula One therefore entered a new phase, which was characterized by the growing complexity and specificity of the technical regulations, which became progressively more detailed and voluminous, going on to regulate every aspect of the cars, from engines to aerodynamics, up to the choice of materials and test management. The regulatory body takes on an increasingly central and interventionist role, not limiting itself to defining general guidelines, but imposing precise technical specifications, such as the same cylinder capacity and number of cylinders for all engines and establishing compulsory geometries and dimensions for many aerodynamic components, thus drastically reducing the design freedom of engineers.

As a result, the focus of technical development shifted away from the major conceptual revolutions typical of previous decades towards an approach based on incremental innovation, and therefore on the refinement of minor details and the optimization of existing components.

For this reason, in this context, the ability of teams to interpret the rules correctly, exploiting the so-called grey areas of the regulations to gain a competitive advantage, becomes increasingly important. Significant examples of this dynamic include some of the most iconic technical solutions of the period, such as the Mass Damper introduced by Renault, the F-Duct system of McLaren, the double diffuser of Brawn GP, the blown diffuser of Red Bull or, most recently, the DAS system developed by Mercedes, all innovations born from the ability to read between the lines of increasingly rigid regulations, and which represent the demonstration of how, even in a strongly regulated context, creativity and ingenuity remain crucial elements to emerge in one of the most technologically sophisticated championships in the world.

To summarize, solution space in Formula 1 can be divided into three distinct evolutionary phases, starting from the first decades of the championship, in which technical regulation was essential and left ample room for designers' creativity, and therefore favouring the introduction of radical innovations, passing through a transitional phase, in which the FIA's attitude progressively changed, becoming more and more interventionist, progressively restricting the solution space, while still allowing radical innovations and incremental developments to coexist, until reaching the era of modern Formula One, with an extremely prescriptive and detailed regulatory phase in which every technical aspect of single-seaters is meticulously regulated by the FIA, reducing design freedom and completely abandoning the quest for radical innovation in favour of a process of incremental improvements.

6.1.3 Formula E as a model of controlled and directed innovation

As for the Formula E World Championship, it was born with the clear intention of accelerating the development of electric technologies in the automotive sector, representing a unique case in motorsport. Unlike other competitions, which have seen a gradual evolution of their regulations over decades of activity, Formula E was conceived from the start with a detailed and strongly binding regulatory framework, a choice that had the immediate effect of delimiting an extremely narrow and rigidly defined design space from the outset, significantly limiting the participants' possibilities for free technological exploration, underlining the fact that the competition itself was not conceived as an open arena of technological experimentation, oriented towards the proliferation of radically innovative solutions, but on the contrary, as a highly focused and controlled technological laboratory, in which innovation is channelled towards specific objectives, closely linked to energy efficiency, environmental sustainability and the affordability of competition.

On a technical level, Formula E's regulatory rigidity translates into a high degree of component standardization, to prevent teams from concentrating their efforts on other areas considered of lesser interest, and significant restrictions on the design freedom of teams, an element that appears to be in apparent contrast to the innovative vocation that the championship claims to pursue. In fact, although teams are allowed to develop their own powertrain hardware, this development is subject to a strict two-year homologation process, preventing substantial updates or evolutions during the championship, which instead are limited to the development of energy management software.

A further distinctive aspect, which further emphasizes the closure of the solution space, is the transition between the different generations of single seaters. In fact, contrary to what happens in other competitions, the passage from one generation to the next does not entail a real expansion or change in the design freedom margin granted to the teams, since even with the introduction of new technical platforms, the superior performance of the cars does not derive from the autonomous research and development capabilities of the individual teams, but rather from the adoption of key components developed externally by official suppliers selected by the FIA. Particularly for this reason, the performance growth that accompanies each new generation of cars, appears not as a result of a natural competitive process between teams, but rather as a development predefined by the regulator, which sets, independently or with the collaboration of the teams and the external suppliers, the expected performance levels and areas of improvements, preconfigures them into a new “car package”, and transfers them directly to the teams through standardized components.

This type of approach significantly reduces the opportunity for teams to explore radically innovative technical solutions, therefore limiting the technical competition to a kind of software and energy management competition, defining Formula E's identity not as an arena for pure experimentation, but as a regulated tool to foster selective and functional innovation, theoretically closely linked to the needs and prospects of the mass-market electric car industry.

In conclusion, if the motorsport of its origins can be described as a context characterized by creative chaos, and Formula 1 represents an example of regulated innovation, in which the margins of design freedom have been modified over time as a function of regulatory evolution, Formula E, on the other hand, is configured as a model of directed and strongly controlled innovation, in which each team is called upon to seek its competitive advantage by operating within an extremely restricted and rigidly predefined design perimeter, within which the possible directions of technological development are not the result of a free interpretation by the teams, but derive from choices made upstream by the regulator. In fact, it is the latter that has established which areas and which solutions are considered most useful and relevant for technology transfer to mass-produced automobiles in the context of electric mobility, effectively minimizing the possibility for manufacturers to experiment with alternative paths of innovation.

6.2 Cost Reduction

After having understood the initial approach and the subsequent evolution of the solution space in different competitions, we now focus on the analysis of the main factor contrasting the need to promote innovation within a motorsport championship, that is, the strategies aimed at favouring the reduction of entry and participation costs in the competition.

As emerges from the historiographical analysis presented in the previous chapters, early motor racing was characterized by a purely pioneering and experimental approach, in which cost regulation was not even considered. However, with increasing competitiveness and the development of increasingly sophisticated technologies, the need to contain expenses and ensure wider participation has gradually emerged to become an increasingly relevant issue nowadays, especially due to the fact that the costs required to participate in this type of competitions have increased exponentially, making access to such events much more difficult for many, and thus also raising important issues related to fairness and inclusiveness within the competitive world.

6.2.1 In early motorsport, cost control was not a priority but sometimes a necessity dictated by times of crisis

In early 20th century motorsport, cost containment was a secondary aspect, as participation in competitions was reserved exclusively for the industrial and aristocratic elite. Motor racing, in fact, was an exclusive and elitist event whose main objective was the pursuit of technical supremacy, to which also a dimension of national affirmation was later added.

Motorsport retained its identity even after the end of the First World War, which had temporarily halted competition. With the exception of a brief period of economic readjustment immediately following the end of the conflict, motor racing quickly regained popularity, as the war had introduced a series of technical innovations derived directly from military applications. Consequently, instead of slowing down the cost escalation caused by the increasing sophistication of the automobiles of the time, the conflict acted as a real catalyst, therefore fostering further growth in expenditure related to the search for new technical solutions, with a particular focus on reducing the weight and displacement of vehicles. At the same time, the major authoritarian regimes, particularly the Nazi and Fascist regimes, chose to aggressively intervene in the world of motor racing and to turn it into an effective propaganda tool, therefore granting massive state funding to the national car manufacturers. As a result, this fostered a true race for technological innovation on a national scale, in which technical progress became a strategic element for the assertion of industrial and political superiority, a process that continued until the outbreak of the Second World War, when military priorities again absorbed resources and attention, temporarily halting development and competition in the automotive sector. Following the Second World War, racing had a renaissance in a Europe severely damaged by the battle. In this context, cost containment became evidently necessary to promote greater participation and support the motor industry's comeback.

Therefore, in the early stages of motor racing development, cost containment was not a central priority when defining the rules and structure of championships, a phenomenon that can be attributed to a combination of factors. Indeed, on the one hand, the sector was initially populated by industrialists and motor racing pioneers with ample financial means, who were more interested in demonstrating the technological value of their companies than in managing expenses. On the other hand, the relative technical and mechanical simplicity of the cars of the time made the development and production of a competition car proportionally less costly than today's standards, thus enabling even less wealthy companies to take part in competitions, at least in the early stages. Moreover, as already mentioned, as public interest in motor racing increased, it began to take on a symbolic value of national importance, often prompting governments themselves to intervene with huge public investments to support the most representative racing teams.

However, it is important to emphasise that even in early motorsport there were also moments when cost containment was necessary, although not motivated by demands for fairness or inclusiveness, as is the case in contemporary competition, but there were several moments when, as a result of broader socio-economic and political circumstances, it became necessary to introduce regulatory measures to limit expenses. Financial crises, periods of post-war reconstruction and situations of competitive imbalance due to state support for certain manufacturers prompted organisers to impose technical limits on weight, engine capacity or components, like for example the “Free Formula” of 1931 in response to the economic crisis, and the formula regulations introduced after World War II to revive competition in a Europe deeply scarred by the conflict.

In conclusion, these cases demonstrate how, from the very beginning, economic sustainability has been a recurring need in motorsport, even when it was primarily driven by factors external to the sport. Indeed, throughout its history, motorsport has had to adapt to the socio-economic and political conditions of its time in order to survive, often introducing cost-cutting measures, through regulatory constraints, technical limitations or alternative lower formulas, in order to ensure the continuity and accessibility of competition, especially in times of crisis or imbalance.

6.2.2 Rising costs push the transition to financial sustainability in Formula 1

The Formula 1 championship was created as a result of a process that started with the goal of establishing common rules on a global scale. Initially, the championship was designed to be relatively inexpensive, following the line drawn by the post-World War II competitions, with teams frequently being operated by small craftsmen or family-owned enterprises. Indeed, in the first ten years following its inception, the necessity to lower the championship's expenses was evidently demonstrated, first by the choice to use Formula 2 class cars for two seasons in order to encourage the entry of new competitors, and then by the use of small-displacement engines, both because they were easier and less expensive to develop but also because they were more in line with the technologies present in production cars.

However, starting from the 1960s, Formula One began to reinvent its identity, progressively drifting away from the original concept of a motor racing championship, which was still intimately linked to motorsport's historical foundations, marking the beginning of a more organized and professionalized structure, laying the groundwork for the transformation of the championship into a true industry, characterized by increasing technical specialization, in which racing car design began to detach itself from the concept of the road car. The introduction of the Cosworth DFV engine, the adoption of aerodynamic appendages and the massive diffusion of sponsorship inevitably led to an increase in the technical sophistication of the cars. In fact, between the early 1970s and the late 1980s, Formula 1 probably went through its greatest period of growth, characterized by considerable creative freedom and the proliferation of innovative and ingenious engineering solutions. This development profoundly marked the evolution of the championship, not only from a technical point of view, but above all in terms of an exponential increase in costs and the budget required for team participation, a fact that led the FIA, as regulator, to introduce measures to limit expenses, mainly by banning certain particularly onerous solutions and imposing more restrictive regulations to contain the escalation of costs.

Therefore, starting with the ban on turbo engines, the focus on cost control became an increasingly important element, especially with the entry of the big manufacturers in the late 1990s and early 2000s. In fact, since the latter were able to dispose of significantly greater financial resources than the other teams, they raised the level of technological competition, making the need for regulatory interventions to limit the exponential growth in expenses increasingly evident. Therefore, starting from this period, the FIA progressively intensified its cost control measures, introducing restrictions on engine sizes and unique suppliers for minor components, simplifying aerodynamics, and even banning private testing during the season.

Despite these restrictions, the costs of competing in the championship remained extraordinarily high, causing some teams to go bankrupt and forcing some large constructors to exit the sport. Therefore, in order to address this issue, the FIA, for the first time in the history of Formula One, decided to introduce a seasonal budget cap, with the aim of reducing the technical gap between the larger teams and the smaller ones, thus guaranteeing greater economic sustainability of the championship and definitively putting a stop to the uncontrolled and uncontrollable escalation of costs that had characterized the championship up to that point.

To sum up, in its early years, the motor racing championship still manifested a certain focus on the containment of costs, mostly conditioned by the difficult post-World War II economic situation. However, with the passage of time and the evolution of the sport, the attention on this aspect was gradually abandoned, making way for an approach more similar to that of early 20th century competition, where regulations did not place particular limits on spending. In this context, it was the teams themselves that sought strategies to contain costs, for example by resorting to technical solutions already available on the market or by building cars with components purchased from external suppliers, as in the case of so-called kit cars or the assembler teams. However, despite these attempts, the rapid growth of technological progress within the competition has led to an exponential increase in costs, bankrupting many teams. By way of illustration, in the course of the more than seventy-year history of the championship, 167 teams have participated to it, but only 45 of these, therefore just over 25%, have taken part in more than five editions (StatsF1, s.d.), so for more than five years, a fact that highlights the sustained economic, and of course sporting, pressure associated with remaining in the championship.

Thus, in response to this continuous escalation of costs, the first regulatory measures aimed at containing them were introduced gradually, from around the late 1980s onwards, with interventions aimed at prohibiting particularly onerous technical solutions or placing strict limits on specific construction aspects. However, these measures did not translate into a real reduction in expenditure: teams, constrained on certain fronts, simply shifted their investments to other areas, further increasing the overall level of expenditure, a phenomenon that was particularly evident in the early 2000s, when the presence of numerous official manufacturers and the absence of limits on expensive activities such as private testing, despite the introduction of technical restrictions on components such as engines, continued to fuel a race for ever higher investment.

Although awareness of the need for structural cost containment has been growing for some time, concrete measures have only been implemented relatively recently, with the first official cost cap introduced in 2021, which set a spending limit of approximately $145 million, from which however, several significant cost items, such as the salaries of top engineers and key team personnel, are excluded, effectively increasing the actual level of expenditure even more. Although this measure represents a significant step towards greater financial sustainability, the threshold remains considerably high. This reflects the fact that, despite efforts to control costs, Formula One continues to position itself as the pinnacle of motorsport, both in terms of technological innovation and global media and commercial influence.

6.2.3 Formula E prioritises economic sustainability over technological progress

With regard to the latest Formula E championship, from the very beginning, special attention was paid to controlling the costs of participation and component development, an approach that immediately prevented an escalation of expenses, as occurred in the other competitions analysed above.

Indeed, one of the key objectives of the category was to create an affordable and sustainable competition, attracting not only large manufacturers but also smaller and independent teams. To this end, the competition has been structured around fundamental pillars, including, for example, the extensive use of standardized components, such as the chassis, aerodynamics and batteries, the introduction of two-year homologation cycles for certain components and limitations on the opportunity to carry out private tests, replaced by simulator sessions, as well as the introduction of a seasonal budget cap, however, set at a value of between 10 and 15 million dollars, an amount approximately ten times less than that of the Formula 1 championship.

Almost ten years after its debut, Formula E has remained largely committed to this original philosophy, and in fact, the championship continues to be governed by strict cost regulation policies, including standardised components and restrictions on development freedom. This framework has proven to be effective, on the one hand, in ensuring competitive balance, preventing excessive financial disparities between teams and promoting a more inclusive and sustainable competition model, but on the other hand, this same model inevitably imposes constraints on the pace and scope of technological innovation, by limiting the degree of experimentation and performance evolution that teams might otherwise pursue in a less regulated environment. Thus, if Formula E seeks to stand as an example of a progressive and economically responsible approach to motorsport and innovation, it does so by inevitably accepting certain compromises in terms of technological progress.

6.3 Technological Transfer

After having historically examined the evolution of these three motor sport competitions and subsequently analysed their similarities and differences with regard to their basic structure, in particular the definition of technical regulations and the resulting solution space, as well as the strategies adopted to reduce participation costs, it now remains to be determined whether these three so-called staged competitions were actually able to bring about, and to what extent, significant technological innovations in the reference sector, that is, the automotive industry.

6.3.1 Racing was the engine of early automotive progress

Speaking of technology transfer in early motor racing means describing an implicit and structural phenomenon, since, as already discussed in the previous chapters, in the pioneering stages of motorsport between the end of the 19th century and the first decades of the 20th century, there was no clear separation between racing cars and road cars, and the vehicles used in racing were often the same commercial models, slightly adapted, and racing was in fact the most effective test bed for testing technical solutions under extreme conditions. In this context, every innovation aimed at improving performance, reliability or resistance, whether in terms of materials, mechanical solutions or structural configurations, found immediate application in series production, transforming competition into a natural extension of the industrial development process, where the boundary between laboratory and racetrack was almost non-existent, and where the circuit represented not only a showcase for manufacturers, but also a privileged context for direct experimentation, significantly accelerating the technological evolution of the entire automotive sector.

In fact, these competitions were almost exclusively attended by car manufacturers or, in some cases, private drivers, the so-called gentlemen drivers, who in any case competed with cars purchased from manufacturers, possibly modified or tuned to improve performance. Among the most active manufacturers in this pioneering period there were names that have now disappeared, such as Talbot-Lago, Duesenberg, Sunbeam, ERA, Delage and Auto Union, but also, many of the car manufacturers that dominated competition back then still exist today and are major players on the global automotive scene, as is the case, for example, with Peugeot, Renault, FIAT, Bugatti, Alfa Romeo, Mercedes-Benz, Ferrari, Maserati, Aston Martin and BMW. This panorama, of course with manufacturers who have participated more or less actively in motor racing, clearly suggests how, at the time, participation in competitions was considered a natural extension of a manufacturer's industrial activity, as racing was used to increase visibility and reinforce the prestige of the brand, an effective marketing tool, but above all it represented a fundamental field for developing new technical solutions and testing reliability in extreme conditions. In practice, it was impossible to think of building cars without racing: racing was an integral part of the very identity of a car manufacturer.

6.3.2 From technical autonomy to the return of synergy between Formula 1 and the automotive industry

As for the Formula One World Championship, during this initial phase, almost all teams were directly responsible for the design and construction of the chassis and engine, a practice that reflected a deep connection between competitive racing and mass automobile production, with manufacturers and teams adhering to the traditional philosophy of doing everything in-house, but above all, this approach was indicative of a competition still deeply rooted in its role as a test bed for technological innovation in the automotive sector.

During the first period, racing car design was still strongly influenced by the concept of the car intended for mass production. In fact, although there were some differences in terms of technical and, above all, performance, the Formula 1 single seaters built in the first decade of competition tended to deviate to a limited extent from what was then considered the dominant design of the production car. This approach therefore reflected an innovation model focused on direct technology transfer between the track and road production. Exemplary, in this sense, after two seasons (1952 and 1953) raced with cars conforming to Formula 2 regulations, which stipulated a maximum displacement of 2.0 litres, was the decision to adopt, starting from the next season (1954), engines with a maximum displacement of only 2.5 litres, which was reduced to 1.5 litres some years later (1961). This choice was in response to the objective of directing engine development towards solutions more in line with the needs of the automotive industry of the time, which demanded a greater focus on small displacement, naturally aspirated engines, because the supercharging technology, in fact, was still considered too expensive and complex for large-scale deployment in production vehicles.

However, the situation began to change as early as the late 1950s and early 1960s, marking the beginning of a profound transformation in the panorama of technical innovation in Formula One. In fact, the introduction, and subsequent widespread adoption, of the rear-mounted engine, together with the adoption of the monocoque chassis, represented two key innovations that radically redefined the design of racing cars. In addition, these innovations were accompanied by the emergence of manufacturers who specialized exclusively in engine development, and which supplied engines to several teams without producing complete cars. All these factors contributed to the start of a structural change in the approach to innovation, marking the gradual abandonment of the traditional model centred on a direct technology transfer, which was instead replaced by a new design philosophy, based on an a more indirect technology transfer, in which single-seaters were conceived completely from zero, with the exclusive objective of maximizing performance in a competitive environment, no longer adhering to the design constraints and industrial logic of the mass-produced automobile sector. The racing cars thus began to detach themselves more and more from the dominant design of road cars, taking on a completely autonomous technical and functional identity.

From this moment on, in fact, with the initial introduction of the Coventry-Climax engine and, to an even more significant extent, with the advent of the Ford-Cosworth DFV engine in 1967, the very structure of Formula One racing teams began to change profoundly. In fact, teams were no longer obliged to develop their engines in-house or to rely on traditional car manufacturers, so, in this new context, independent teams began to assert themselves, with no direct connection to car manufacturers, specializing solely in chassis design and aerodynamic development. These teams (such as Lotus, Tyrrell or McLaren), which were not involved in the production of production cars, oriented all their design activity exclusively towards competition, completely disengaging themselves from the industrial and commercial logic of the traditional automotive industry.

The result was a radical change not only in the technical and management configuration of the racing teams, but also in the dynamics of innovation within the championship. As a result, Formula One progressively ceased to be an experimental extension of the automotive industry and turned into an autonomous technical laboratory, where engineering solutions were designed solely to optimize performance on the track. Innovation thus became increasingly sectoral and hyper-specialized, and technology transfer to road cars assumed an indirect character, limited to individual concepts or technologies later adapted with different criteria and purposes compatible with large-scale production, as was the case, for example, with aerodynamic appendages, turbo engines, the use of composite materials and the development of driver-assistance technology solutions such as steering wheel gearboxes, ABS, traction control and many others, all innovations that originated spontaneously with the sole aim of improving performance on the racetrack, and which are now widely used in most production road cars. However, this does not mean that the innovative importance of the championship has drastically diminished over time, but rather that the nature of the innovations sought by the championship has changed. This is mainly due to the fact that in the early years of motorsport, racing cars and production cars shared a largely similar architecture, which made the transfer of knowledge and solutions more immediate and linear. With the progressive specialization of Formula One, however, this architectural convergence gave way to a clear separation, where racing prototypes were no longer directly comparable to mass-produced vehicles, and the possibility of transferring innovations at a systemic level was reduced. Nevertheless, this change did not interrupt the flow of technological spillovers, which instead began to occur predominantly at the component level. Therefore, fundamental advances developed exclusively to maximize performance on the track have subsequently found their way into road cars, although adapted to the criteria of cost efficiency, safety, and durability required for industrial production, therefore demonstrating how, even in a context of growing divergence between the architectures of racing and production vehicles, the competitive pressure of motorsport has continued to play a decisive role in stimulating solutions with long-term industrial and commercial applicability.

A particularly significant figure, which highlights the degree of specialization achieved by Formula One in the course of its evolution, concerns the number and nature of the teams that have taken part in the world championship. According to the data reported by the StatsF1 website, from 1950 to 2025 there were a total of 167 different teams that participated in at least one season of the championship, however, only 13 of these were teams belonging to major car manufacturers, as illustrated in Table 1. The vast majority of the teams were therefore independent entities, often created with the sole objective of competing in the racing world, thus confirming the evolution of Formula 1 into an increasingly autonomous technical and sporting sphere, increasingly detached from the traditional automotive industry dynamics.

***Table 1**: F1 Constructors Backed by Major Automakers (1950-2024)*

Constructor	Number of Grand Prix	Number of Seasons	Years
Ferrari	1098	75	1950–2024
Renault	400	24	1977–1985, 2002–2011, 2016–2020

Mercedes-Benz	317	17	1954–1955, 2010–2024
Alfa Romeo	214	14	1950–1951, 1979–1985, 2019–2023
Toyota	139	8	2002–2009
Aston Martin	95	6	1959–1960, 2021–2024
Alpine	88	4	2021–2024
BMW	88	5	2006–2009
Honda	88	8	1964–1968, 2006–2008
Jaguar	85	5	2000–2004
Maserati	70	11	1950–1960
Porsche	31	7	1957–1961
Lamborghini	6	1	1991

It is important to emphasize that, in the selection of the 13 teams attributable to major car manufacturers, some special cases were excluded. In fact, Lancia and Bugatti, for example, were not considered, as their participation in the championship was extremely limited, to just 4 and 1 Grand Prix respectively, and had no structural impact throughout the competition's history. Similarly, Matra was excluded, despite having contested 60 Grands Prix, as it could not be considered a major manufacturer in the industrial sense of the term, and also Talbot-Lago, as it was a small manufacturer active only in the very early years of Formula One. Furthermore, although McLaren and Lotus have a very high number of participations to their credit, 970 and 605 Grands Prix respectively, they too have been excluded, as they were originally born as independent racing teams, focused exclusively on motorsport, while their activity in the road car sector in fact only began later, as a commercial strategy to generate additional revenue, and did not represent their original identity nor their main structure for much of their history.

Despite the fact that less than 8% of the teams that took part in the history of the Formula One World Championship were the direct expression of major car manufacturers, this does not imply that the competition was not of strategic and innovative interest to the automotive industry. On the contrary, while maintaining a relatively limited presence in terms of direct participation as full manufacturers, many major car manufacturers chose to be involved predominantly from an engine perspective, an approach which allowed them to obtain significant benefits in terms of know-how acquisition and technology transfer, exploiting Formula One as an advanced test bed for engine development, without having to bear the high costs associated with running a proprietary team. Supplying engines to independent teams was, in fact, an effective strategy to enter the championship, benefiting from a highly competitive environment, stimulating from an engineering point of view and characterized by a dense network of collaborations with highly specialized technical partners. This model allowed manufacturers to enhance their core competencies, focusing on engine innovation and also benefiting indirectly from the visibility and results achieved by their client racing teams. In fact, according again to the statistics reported on the StatsF1 website, in the course of the entire history of the championship, a total of 69 different engine manufacturers have participated to the championship. Of these, 19, or about 27,5%, were major automobile manufacturers.

The following two charts illustrate the trend over the years in the number of major automobile manufacturers participating in the championship as team owners, as well as the trend in the number of different engine manufacturers affiliated with automotive companies that have taken part in the championship each year.

Figure 1: *Number of Major Automobile Manufacturers Participating as Team Owners per Year.*

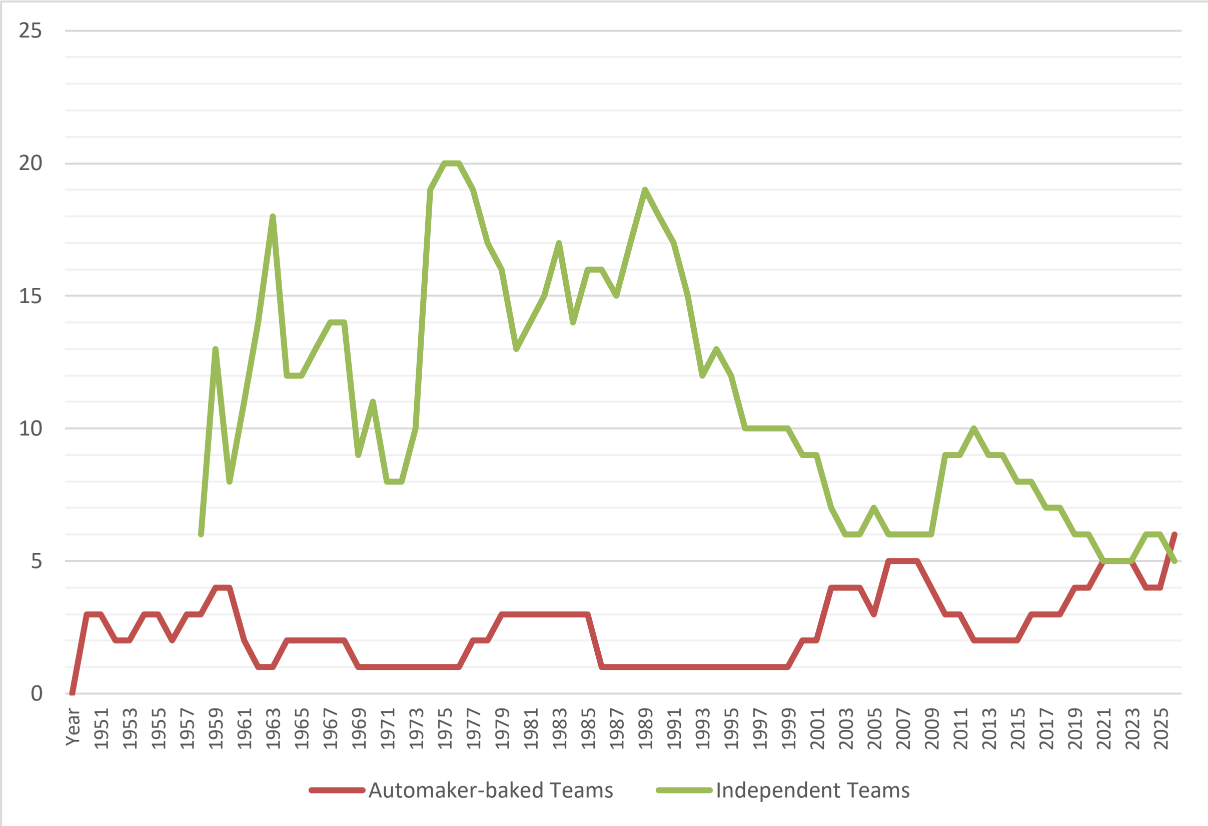
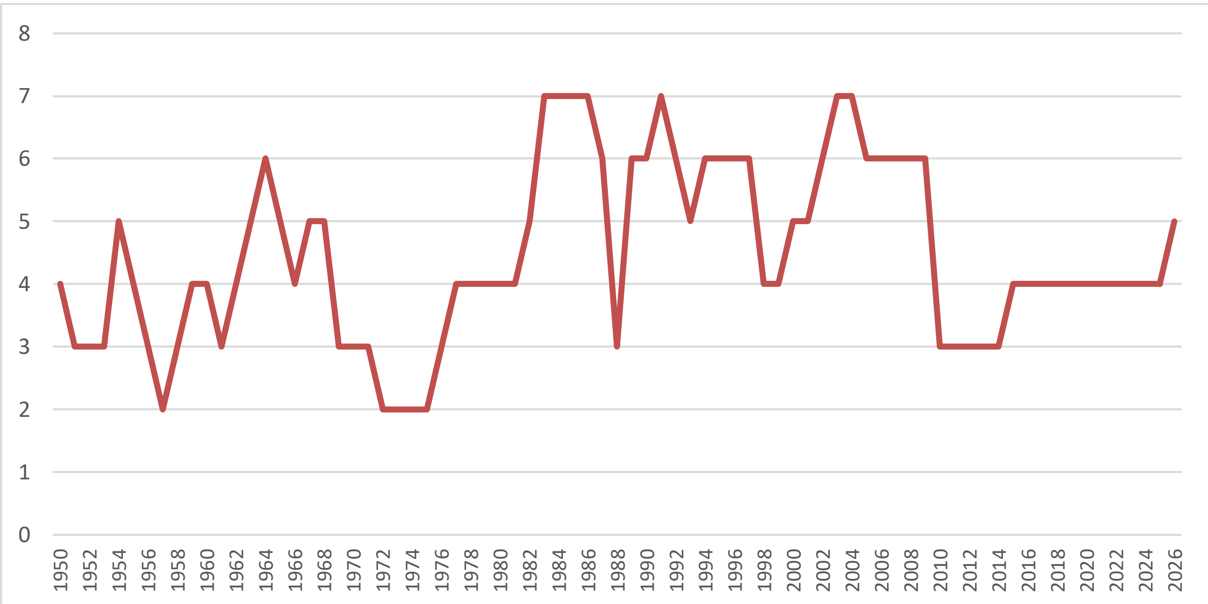


Figure 2: *Number of Engine Manufacturers from Automotive Companies per Year*



The first clue provided by Figure 1 is that the share of teams belonging to large car manufacturers has always been a minority compared to the total number of teams participating

I the competition every year, confirming the predominantly independent nature of the F1 ecosystem. However, when interpreting this data, it must be considered in relation to the historical structure of the championship, as until 1958, the absence of a Constructors' Championship and the frequent presence of small privately-owned teams and temporary entries by individual drivers made the perimeter of the teams fluid, and a nominal count of participants tended to overestimate the number of actually organised structures, easily reaching more than thirty different independent entities in the first years of the championship. It can nevertheless be noted that in the early stages, the relative technical simplicity and architectural proximity to production cars facilitated access for small manufacturers, specialised workshops as well as single wealthy individuals. The difference between automaker-baked and independent teams increased profoundly with the era of assembler teams and "kit cars" in the late 1960s and early 1970s, a mechanism that multiplied the number of entities that could register per season without proportionally increasing the presence of teams belonging to industrial entities, thus accentuating the gap between the total team curve and that of manufacturing teams. Furthermore, it can be seen from Figure 1 that, since the 1990s, the number of independent teams has gradually declined, while the number of teams supported by major car manufacturers has gradually increased. This process led to a situation of near balance in the early 2000s, coinciding with a period characterised by a strong presence of manufacturers and very high participation costs, which prompted several privately-owned teams to leave the competition. The gap between the two types of teams widened again between 2010 and 2014, coinciding with the introduction of hybrid power units, before stabilising at levels of substantial parity in recent years. A particularly significant change will take place in 2026, when, for the first time in the history of the championship, the number of teams supported by manufacturers will exceed that of independent teams. This development represents a historic moment, once again underlining the central role of Formula 1 as a technological laboratory, in a context where the introduction of new hybrid power units and the adoption of synthetic and bio-renewable fuels are of strategic importance for the entire automotive industry.

On the other hand, if we only look at automaker-backed teams, we can see that throughout the history of the championship, manufacturers' interest in participating has not been uniform, but has followed alternating phases characterised by moments of strong involvement and periods of lesser presence, outlining a cyclical trend characterised by waves. In particular, in the early years of the championship, up to the 1960s, the presence of teams belonging to the big automobile manufacturers was discrete, probably due to the fact that this type of competition still had strong links with the motor racing experiences of the past and was characterised by lower participation costs and less technical complexity of the cars, making it not only more affordable but also more advantageous in terms of direct technology transfer. It then flattened out until it almost disappeared altogether, between the 1960s and the late 1970s, possibly due to the fact that the emergence of the first assembler teams, favoured by the presence of Coventry Climax and Ford-Cosworth engines, radically changed the essence of competition and, as discussed in detail above, began to detach it somewhat from market logic, changing its innovative dynamics.

It was only at the end of the 1970s, when the entry on the scene of Renault and its turbocharged engine on the side, that we can see a resurgence of interest from manufacturers in the championship, probably driven by the new wave of innovation brought about by turbo engines and their potential applications in road vehicles. However, from the beginning in the mid-1980s, the situation flattened again, again leaving Ferrari as the only manufacturer team on the grid until the early 2000s. Precisely since the beginning of the new millennium, in fact, there has been a growing interest on the part of the major manufacturers in the Formula One championship. In fact, driven by the great global visibility of the championship and the consequent benefit in terms of marketing and a great economic growth ache facilitated the availability of budget, BMW, Honda, Ford (with the Jaguar brand), Renault, and Toyota, joined the championship with proprietary teams, populating the grid with large manufacturers as never before. Many of these teams however unfortunately some because of poor results, some because of the very high cost of participation, abandoned the championship after a few editions. Large manufacturers have started to reappear after a brief drop in attendance brought on by the 2014 introduction of new hybrid technology engines. This indicates that the championship has once again been successful in establishing itself as a productive testing ground for emerging technologies that are closely related to the automotive industry.

On the other hand, as can be seen from the second of these two graphs (Figure 2), in the course of history, the large manufacturers, have always been more interested in participating as engine suppliers, rather than as manufacturer teams, reaching particular peaks between the 1980s, 1990s, and 2000s. In particular, these peaks coincide with the rise and diffusion of the turbo engine in the competition in the 1980s, the introduction of advanced electronics within the engine management components in the 1990s, and the struggle between large manufacturers in the 2000s. Strangely, however, since the introduction of new measures to increase engine efficiency, i.e., starting in 2009 with the introduction of KERS and since 2014 with hybrid power units, the level of motorists belonging to large manufacturers has stabilized at slightly lower levels compared to historical peaks.

Moreover, as shown by both graphs, the new technical regulations planned for the 2026 season, which will introduce further development and enhancement of hybrid engines and propulsion systems and biofuel and e-fuels technologies, have already attracted the interest of major new car manufacturers: Audi, General Motors and finally Ford, which will return to the championship after years of absence. The first two will enter the championship with official teams. In particular, Audi will be present right from the start as an engine manufacturer, making its own power units, while General Motors, in the initial phase, will use power units supplied by Ferrari, with the aim of later becoming an engine manufacturer itself. On the engine manufacturers' side, the championship will see the exit of Renault as engine supplier for the Alpine team, mainly due to high development costs and disappointing results in terms of performance, but at the same time, there will be the return of Ford, who will collaborate with Red Bull as an external technical partner in the development of the new power units. All these movements, between new participations and returns, are a clear sign of the continued attractiveness of the Formula One championship, which in addition to being the highest expression of motorsport at a global level, still manages to confirm itself as a technological platform capable of stimulating the interest of manufacturers, offering highly advanced technical challenges closely linked to the needs of the automotive market.

To conclude, we can say that, although Formula One was born as a championship closely linked to the world and the automotive market, with the passing of time, it has begun to detach itself more and more, becoming a sector and an industry in itself, super specialized, and from which more or less occasionally, certain innovations, which were developed only to go faster on the track, were then later also readapted to the road world. It is only in recent years that the championship has begun to move closer to the needs of the automotive sector, in crisis due to the stringent regulations on emissions and engine efficiencies, thus returning to what had been in a certain sense the nature of its beginnings, that is, to be the pinnacle of motorsport, but to do so by trying to align itself with the needs of the market to favour and accelerate innovation.

6.3.3 After an initial success, the technical relevance of the Formula E championship is at risk of declining

With regard to Formula E, on the other hand, as previously pointed out, it is a championship created with the exclusive intent of accelerating and encouraging the development of the technologies present within electric vehicles, a factor that makes the championship a de facto unique model in motorsport. However, precisely because of its particular structure, already highlighted in the preceding paragraphs, consisting of a strong focus on cost reduction and a restricted solution space, it is not easy to determine the actual extent and effectiveness of this technology transfer, as the presence of radical innovations, which make this process of technology transfer clearly observable and identifiable, is essentially reduced to zero. In addition, publicly available information on the extent of such technological transfer is virtually absent or too vague, in fact making it extremely difficult to identify and quantify such knowledge exchange between track and road vehicles. However, the focus of technology transfer between the Formula E project and production development is to be found in energy management and energy efficiency, the transfer of power electronics software from racing to production, and the improvement of power density of electric motors.

Moreover, although the presence of big automotive manufacturers within the championship is discrete, despite the short history of the championship, it has already seen the entry and especially the exit of quite important names including Renault, BMW, Audi and Mercedes. This fact is particularly interesting, as all of these automakers have faced and are still facing a major transition to electrification of their vehicle ranges, largely driven by strict European regulations, but despite this, Renault and Mercedes, have still preferred to remain involved with Project Formula One, while Audi has chosen to also join the Formula One championship, starting with the 2026 season, with the advent of the regulatory change at the engine level that will take hybrid technology to the extreme. The apparent reasons for this abandonment by these car manufacturers are mainly related, according to some of the most important journalistic heads of the sector, to the fact that the return in terms of marketing, but especially on technological transfer brought by the championship was no longer sufficient to justify the investment, believing that the championship, once it reached a certain level of technical maturity, was less useful for the development of electric technologies, precisely because of the limits set to the rules, which reduced the possibility of research and development.

Unfortunately, however, relying on these articles is not enough to fully understand the motivations that have led some teams, belonging to high-profile automakers, to abandon the competition, while others continue to blindly believe in the project and the validity of the championship. At this point, the best way to better understand what the Formula E ecosystem is, and its internal dynamics, and the magnitude and effectiveness in terms of technological development of the championship, and of the consequent interest and relevance for the major automakers, is to seek more direct and less filtered information, possibly coming from direct industry representatives.

In this regard, the strategy adopted was to seek to interview prominent figures in the automotive landscape of the championship in question, the Formula E World Championship, in order to ask them a series of predefined questions aimed at investigating the reasons that prompted these manufacturers to take part in the championship and how such participation affects, to a more or less significant extent, the development of mass-produced electric vehicles. In essence, the goal was to understand the effectiveness of Formula E as an acceleration tool in the technological development of the electric sector.

Although the highly specialised nature of the industry, the difficulty of reaching key professionals directly, and the confidentiality typical of the motorsport and engineering world, further complicated by the fact that some teams are no longer active, posed significant challenges, it was still possible to obtain an interview with two prominent figures belonging to one of the currently most important constructor teams in the Formula E championship: the Team Principal and the Director of Factory Engineering, respectively. This conversation allowed for the collection of their opinions regarding their experience in the championship, with an emphasis on the contribution that competition participation has made to the advancement of technology. Furthermore, their answers also provided valuable information about how well Formula E works as a platform for innovation and as a means of developing technologies that can be applied to the production of electric vehicles, and finally, they also helped to clarify the reasoning behind the championship's regulatory decisions and provided valuable insights into the competition's future developments and inevitable evolution.

The information collected during the interview will be presented in the following paragraphs. However, in order to ensure the privacy of the sources and protect the confidentiality of the content that emerged, the data will be reported anonymously.

- *What were the initial objectives of the parent company when it decided to enter Formula E? Was the goal mainly to develop new technologies for series-production electric vehicles and acquire specific know-how, to improve brand awareness in the EV sector, or was it just simply about competing and nothing more?*

Put simply, it was a fifty-fifty, as the decision to enter the championship was made both for marketing reasons and obviously for technological development reasons. On the first hand, the company wanted to reach new target groups, and at their said formula E had already proven to be the right championship to do so, as the intrinsic DNA of the competition is extremely different from that of other competitions, in that it is strongly focused on city centre racing, had an extremely close competition among teams and drivers and above all the championship is at the forefront of technological innovation in electrification. On the other hand, as far as technological development is concerned, the company was, and still is, convinced that the future of mobility will be electric, and a therefore sought to enter a competition that could provide it with the highest level of expertise in that area.

- *How is the technical interaction between the Formula E team and the parent company managed in practice? Is there a relationship of autonomy or collaboration? What are the main communication and collaboration channels between the Formula E team and the parent company's R&D departments? (Rotation of engineers, regular meetings, data transfer, joint projects, etc.).*

In order to facilitate technical collaboration between the race team and I tea dedicated to the development of road cars, the company has decided to structure its organization according to a matrix structure. In this way, the race team is not set up as an independent reality detached from the development of the road cars, but rather, when the race team engineers are not on the track working on race cars, they work in the same facilities and share the same offices as the road cars team, collaborating and sharing information on a daily basis.

- *How is the process of technology transfer from racing to production vehicles structured? Does it take place systematically, or according to the needs of the moment?*

According to the sources, their flagship electric production car shares most of its technology with that developed expressly for Formula E single-seaters. As far as racing cars are concerned, the development cycles of the product are obviously shorter than those of a normal production car, but above all what changes is the type of use of the vehicle itself, which substantially differs between racing and road cars, especially in terms of the duration of use of the vehicle's full power. Precisely for this reason, before the technologies developed by the racing department are applied to road cars, there is typically an intermediate step with the development of a prototype, which serves to make the necessary changes, do that the components can be applied to road vehicles. In particular, the process of technology transfer is therefore constant, and involves hardware parts, software, use of new materials for certain components, but also testing and problem management procedures, which are developed in the course of testing with track cars. Software transfer is easy and quick, on the other hand, as mentioned before, hardware development for road cars takes longer, since the requirements for road vehicles are different, and the hardware needs to be modified accordingly. To give an idea of the time lag between development on the track and adoption on the road, the source mentions that the DC-DC converter, a particular hardware component, derived from earlier Gen2 cars, was first implemented in a prototype, and is only now in development for road vehicles. This means that although road vehicles lag a few years behind electric cars in technological development, the gap is not as wide as one might think.

- *Are there specific technological areas in which Formula E has been a particularly strong stimulus for innovation for the parent company? (For example, powertrain development, thermal management, energy management software, lightweight materials, etc.). What are the areas in which collaboration is closest (e.g. powertrain development, software management, simulations)?*

Energy recovery is definitely one of the areas where there is more transfer. In fact, in this area, Formula E has always been a pioneering area. In fact, from Gen2 to Gen3 it has gone from 250kW of regenerative power to 600kW, and according to sources, the road cars are also following the same line, they started from about 100kW and are now already at over 300kW. For this reason, of great importance is the study of braking management, which in a race car is extremely complicated. Indeed, in Formula E, in order to brake, the single seaters are equipped with hydraulic brakes on the front, a power train on the front common to the teams, and a power train on the rear, which is developed directly by the teams. These three systems must be used in combination and at the same time but with different targets. In fact, you have to both brake, but also recover energy, and so you have to use the friction brakes as little as possible. All this study of braking management, which is mainly software engineering work, pours directly into production vehicles. Formula E in this is way ahead. Another aspect that has been strongly influenced by track development has been the voltage level, which, even for production cars, now stands at 800V, just as in electric single seaters. This figure is particularly important in an electric car because it allows more power to be obtained, but using lower currents, and ensures greater efficiency of the electrical system and faster reloading.

- *Has the Formula E championship, with its strict regulations and technical limitations, in any way hindered the possibility of experimenting with relevant innovations?*

The sources report that obviously, as engineers, you want to do as free as possible and develop as much as possible. But when you see the global picture, the Formula E is still a very young championship (only 10 years), and to make it sustainable, you can't make sure that there is too much or complete freedom to develop. In fact, you must create the reach, the fanbase, a sustainable business case for the manufacturers, and so for them this is the right approach. In fact, despite the very stringent regulations, there has been a great potential for growth and development between generations. For example, from Gen1 to Gen2, there is a radical change from having to use two cars per race to one, while between Gen2 and Gen3, there is a dramatic increase in the regenerative capacity of the single seaters, from about 25% of energy recovered during the race to up to 55%, depending on circuit. With this steep learning curve especially for powertrains, differentials, gearboxes, e-motors and inverters, the regulations are not hindering them, also because, even with the 2-year homologation cycle, you do not stop the development. As soon as you have homologated the part, you immediately start developing the next one. So, the development is non-stop, the only thing that changes is that you know that for two years you're going to have a certain kind of performance from those components, and you can't change them, but still you're already working on a future upgrade.

- *Looking to the future, do you think Formula E's role as a platform for innovation will grow, or will it turn into something different?*

According to the sources, for the future, since the energy efficiency of electric single seaters is now close to 100 percent, it follows that there is not much room for improvement in this area anymore, and therefore a new area should be found to target for the future, where instead sip bones still make a difference. Indeed, although now the efficiency of internal combustion engines is about 40-45% in the best cases, in Formula E is above 97%. Moreover, their sentiment is that these new areas of development will necessarily have to be in the battery, the energy storge, the cooling, the infrastructure, the weight of the energy storage, the energy density and so on. Carrying out research and development in that area is very expensive, however, so the series needs to develop some more before they can afford such investments, but they are confident that they are on a good way. Also, another area where there will probably be changes in the future is the very marked addition of downforce. In the beginning, in fact, you had to make sure you didn't put any downforce in because the battery and the technology wasn't yet ready to support too much aerodynamic drag, but now with the cars being so efficient, you can start to add more downforce and increase the drag, so that the single seaters go even faster. Furthermore, they claim that with the parts that they can currently by regulation develop in-house, they can make a difference to other teams, but that this difference is purposely not large, because they want to preserve the fact that it is an exciting sporting product. In fact, if you were to be much more open to innovation, in fact expanding the solution space, the difference you could make against your competitors would, on the one hand, certainly be more significant, but you would run the risk of having extremely dominant manufacturers, thus risking making the sport less exciting from a competitive point of view. In fact, for the championship, extreme importance lies in understanding what level of competitiveness and spectacle is required by fans and spectators, and in their opinion, this mix of technical product and sporting product, is currently able to satisfy both sides: the engineering side and the entertainment side. In conclusion, according to sources, these strong limits set by the regulations are not hindering them, for now, but in the future, almost certainly, they will have to start focusing on different spots of the car, and above all it will be crucial to understand how much the series can afford to expand the construction freedom of the teams, in order to be able to spend more money on R&D, without distorting too much the competitive balance of the championship.

- *Is there active collaboration between the regulators and the teams, or are rules simply imposed from the top down?*

The team collaborates through dedicated sporting, technical and commercial working groups, working closely with the promoter and the regulatory body (FIA) to provide a clear vision of how the future might evolve. In fact, manufacturers often have more in-depth knowledge of emerging technologies and future trends than regulators or promoters, so there is constant dialogue between the two parties to ensure that future development possibilities are useful, realistic, and in line with market needs and the maturity level of the technology. The task of the teams is therefore to provide the developer and the regulator with constant and informed feedback throughout the process. However, it is crucial to bear in mind that they must keep a close eye on cost control. Indeed, some manufacturers may certainly have more resources to develop innovations than others, and so it is ultimately up to the relevant bodies to decide what to actually include in the regulations.

- *What do you think about the FanBoost and the Attack Mode?*

As for FanBoost, they were not particularly happy with it because it was never quite clear how it was assigned or influenced. On the contrary, Attack Mode is a useful function because it allows the true potential of the car to be shown. In fact, if you think that normally cars run with 350 kW in rear-wheel drive, but with Attack Mode they switch to 600 kW in all-wheel drive, this changes not only the power, but also the balance and dynamics of the vehicle in a radical way, since under normal conditions, such a transition would require a completely different set-up of the car (with modifications to camber, anti-roll bars, etc.). However, thanks to the advanced functions on the car, such as brake-by-wire and active differential management, it is possible to adapt the car's behaviour curve by curve, allowing an extremely rapid and precise response to changes in the transmission configuration. In a way, Attack Mode is a showcase for the true potential of electric single-seaters, as well as obviously being a useful tool to add a competitive differentiating factor to the race, whose effect on the race can be likened to the choice of tyre mix during a pit stop in Formula 1.

The interview provided useful information both for a more in-depth analysis of the championship in the following chapter and for a better understanding of the actual impact of the competition in terms of technology transfer, highlighting several concrete areas in which Formula E has served as a platform for technological development with direct implications for series-production vehicles. In fact, despite the regulatory constraints typical of the championship, the competition fosters a continuous flow of innovation, in multiple areas.

First of all the championship has been a crucial source of innovation for road cars especially in terms of energy management and regenerative braking, as the advancement in regenerative capacity in road EVs has closely mirrored advances in road EVs the advancements of the race cars, especially regarding the complex software logic behind braking systems, which integrates hydraulic braking and regenerative motors across both axles. Moreover, the move to 800V architectures, already standard in Formula E, has influenced production EVs by improving system efficiency, power delivery, and charging speed. An lastly, one of the most transferable aspects of racing development has been the software, particularly in the areas of energy management, brake-by-wire, and active differential control, which have enabled precise control over vehicle behaviour and have been adapted to enhance drivability, safety, and energy efficiency in production vehicles. Furthermore, with regard to internal team dynamics and organisational integration, it was interesting to understand how the adoption of a matrix structure within the company fosters constant collaboration between the racing and production car departments, resulting in shared workspaces, daily interactions and joint development projects, which allow for the continuous evaluation of innovations developed in Formula E, for a possible adaptation and integration into road cars after an intermediate validation phase on prototypes.

In conclusion, we can therefore say that, although Formula E operates within a tightly regulated technical framework, it seems to remain an effective and active innovation platform for the automotive industry, where the technologies developed on the track are not only influencing the evolution of electric mobility, but also accelerating the industrialization of key solutions. However, the interview also highlighted how the particularly strict regulatory model adopted to date was appropriate at an early stage, when electric technology was still immature and had numerous technical limitations. Today, however, with the energy efficiency of the cars close to the theoretical maximum and with performance already very high, further developments would require extremely costly investments against marginal improvements, a situation that actually suggests the need for an evolution of the championship, both on a technical and regulatory level, progressively opening up the space for development in order to maintain the technological relevance of the competition and not risk losing the strategic interest of the manufacturers.

7. Innovation under constraint: modelling trade-offs in innovation-focused competitions

This last chapter proposes a synthesis of the contents discussed in the previous chapters and aims to do so through the construction of a model of causal relations aimed at describing and understanding in a more effective manner the internal dynamics, as well as the main variables and the interactions between them that characterised each of the three championships analysed within this paper. Therefore, the objective will be to identify the underlying structure of these competitions and to assess the possible existence of an optimal configuration for this type of format, in order to offer useful indications for the conscious and strategic orientation of innovation in the reference sector, that is, the automotive sector.

As a result of the analyses previously conducted, which included the historiographical reconstruction of the different championships, as well as their mutual evaluation in terms and the information gathered through an interview with representatives of a well-known Formula E team, it was therefore possible to identify fourteen variables considered significant for describing and interpreting the structure and interrelationships that characterize a motorsport championship. Furthermore, these variables were subsequently organised into four thematic macro-categories. The list of variables divided into each macro-category is presented below, accompanied by a brief explanatory description.

1. **Regulatory Structure & Governance**
    - **a.** Regulatory freedom
    - **b.** Collaboration between regulator and participants
    - **c.** Regulatory adjustments over time
    - **d.** Presence of technical standardization

These variables relate to the way the championship is managed and regulated and, in particular, concern the definition of the boundaries within which teams and the championship organisation can develop and pursue research and innovation activities.

2. **Technological Innovation & Industrial Integration**
    - **a.** Technical relevance for manufacturers
    - **b.** Sporting impact of innovation
    - **c.** Alignment with future industrial trends
    - **d.** Collaboration with external suppliers

In this case, the set of variables is aimed at defining the real industrial relevance of the innovation developed by the teams and its degree of connection with the automotive sector, with the aim of incentivising the search for solutions that are both significant from a purely sporting point of view and relevant for the industry as a whole.

3. **Economic Sustainability & Organizational Structure**
    - **a.** Cost containment measures
    - **b.** Economic return of the championship
    - **c.** Number of participating teams

These variables are associated with the economic aspects and the organisational structure of the championship, with the aim of ensuring the long-term sustainability of the competition, as well as favouring the entry of new teams and guaranteeing the continuity of existing ones.

4. **Sporting Value and Championship Attractiveness**
    - **a.** Competitive balance
    - **b.** Attractiveness for sponsors and audience
    - **c.** Frequency of competitions

Finally, this set of variables relates to the sporting value of the competition and its attractiveness to the public and sponsors, with the aim of configuring the championship not only as a technical test bed, but also as an effective and engaging sports entertainment product.

Once the main variables at the basis of the structure and existence of these motorsport championships have been defined, they will be used to construct three distinct causal diagrams, each one referring to one of the championships examined in the analysis, graphically representing the internal dynamics of each competition and explicitly highlighting how the variables identified interact with each other and contribute to the definition of the identity and effectiveness of the championship itself.

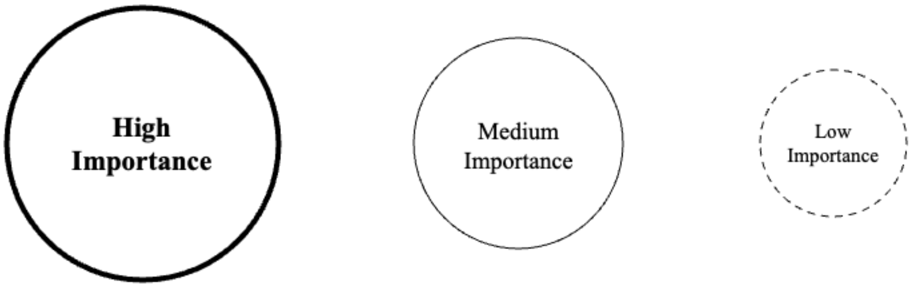
In particular, within these diagrams, both the causal relationships between the variables and the relative weight, or influence, that each of them exerts in the specific context will be mapped, therefore allowing to grasp the structural and strategic differences between the various leagues, as well as to highlight any recurring or particularly effective configurations. The analysis conducted will thus make it possible to return a systemic and comparative vision of the overall functioning of each competition, also allowing, in a more general perspective, to deduce the recurring dynamics that characterise a motorsports competition in a broad sense, identifying its fundamental structural elements and possible optimal configurations.

Within these diagrams, the relationships between the variables, as well as the relative importance of each of them within the specific competition, will be represented according to the following criteria:

- **Direction of the causal relationship**: arrows will indicate the direction of the influence between two variables, specifying which variable acts as cause and which as effect. The arrows may be either unidirectional, indicating a one-way causal influence from one variable to another, or bidirectional, representing mutual or reciprocal causality between the variable.

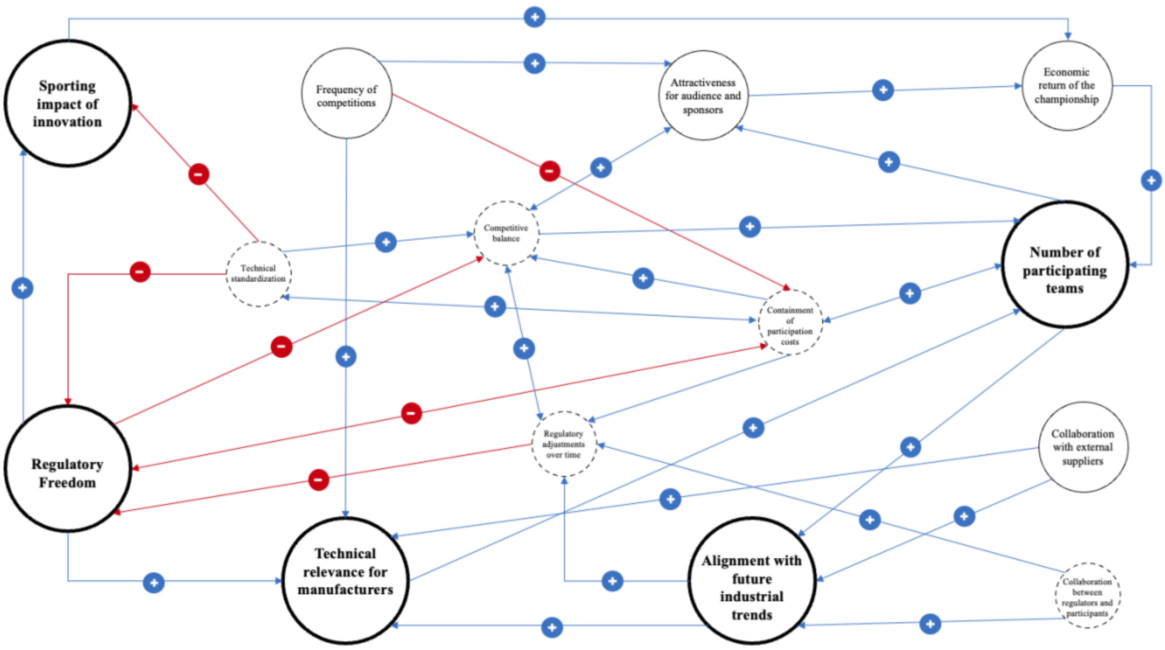
- **Polarity of the relationship**: it will be indicated whether the relationship is positive (increase in one variable leads to an increase in the other, and vice versa) or negative (increase in one variable leads to a decrease in the other).

- **Variable centrality**: the size of the node (variable) will reflect its degree of centrality within the system. This implies that as the size of a node increases, the variable it represents assumes a central and decisive role within the internal structure and dynamics of the league, while conversely, a small node indicates a variable with marginal influence in the overall championship configuration.



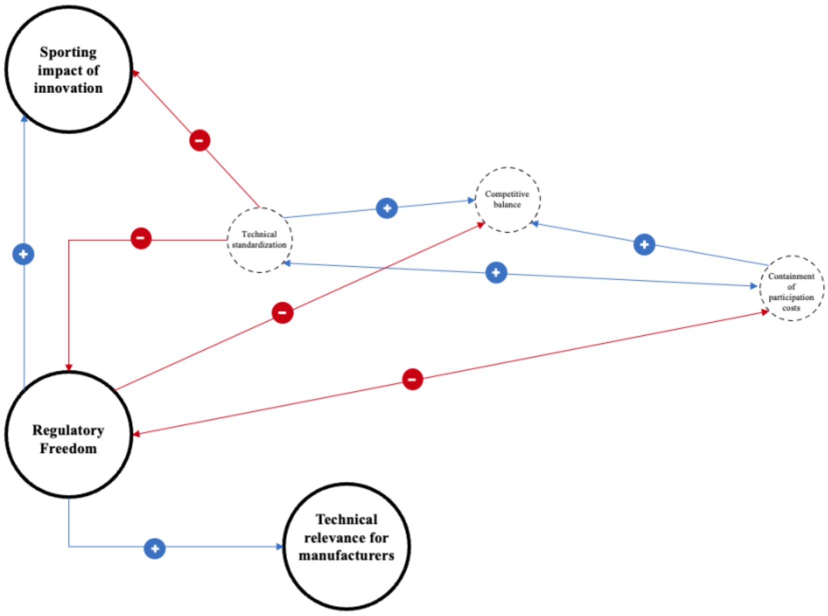
7.1 The early motorsport competitions adopted a model could not be sustainable today

Following the order adopted throughout the paper, the first competition to be mapped according to this causal pattern is that relating to the first motorsport competitions.



As can be clearly seen from the diagram, the structure of these competitions is strongly unbalanced, since, as already highlighted previously, there is a marked predominance of the variables related to free technological development, mainly oriented towards direct industrial innovation, while conversely, variables associated with cost containment and the search for competitive balance are marginal.

Notably, the core variable of the diagram, and thus the foundation of the overall structure of the competitions as well as their internal and organisational dynamics, is regulatory freedom, which, by exerting a significant influence on numerous other variables, is the one that contributes decisively to shape the very essence of these competitions. In fact, the pursuit of innovation coupled with a broad regulatory freedom inevitably has repercussions on the overall balance of the championship, for while such an approach incentivises design freedom and maximises the sporting impact of innovation while enhancing the technical relevance for the manufacturers involved, it tends to undermine the importance of cost control, reduce the competitive balance between participants and oppose technical standardisation.



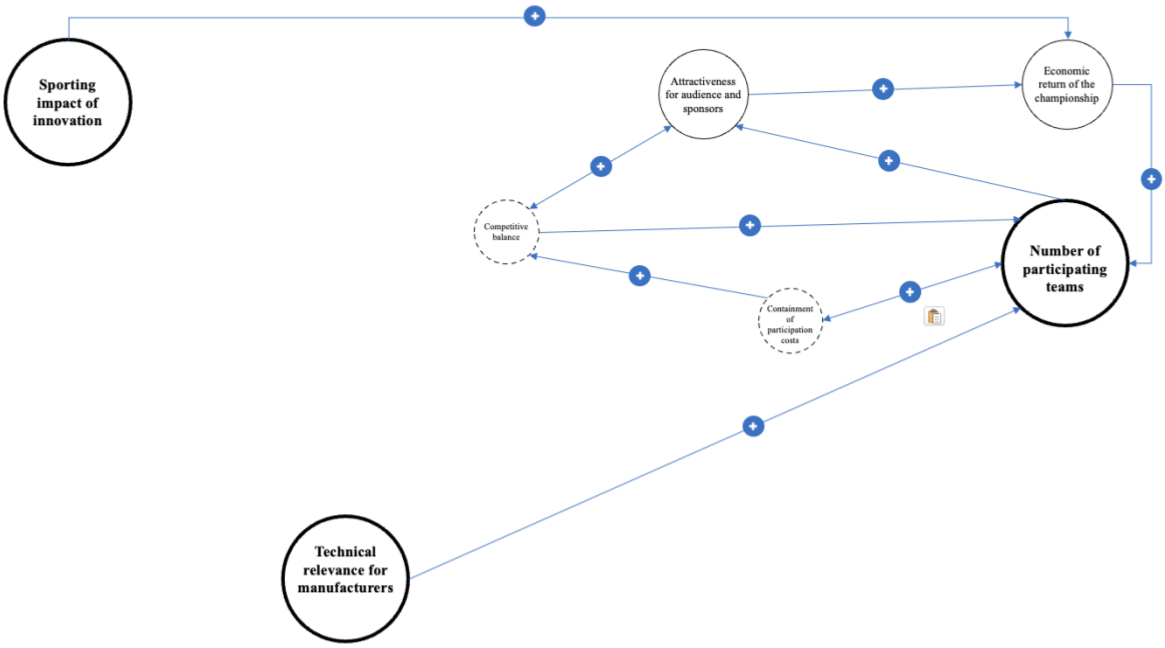
The extreme regulatory freedom that characterised these competitions immediately resulted in a rapid proliferation of radical innovations. Given the relative technological simplicity of the time, when the car was still an emerging innovation, these developments were, for the most part, relatively inexpensive, a factor that, combined with the fact that the environment was mainly populated by wealthy individuals, meant that neither the teams nor the organisers perceived cost containment as a priority, except, as mentioned above, at certain historical moments with particular socio-economic impact, such as the outbreak of the two world wars or the economic crisis of the late 1920s.

Precisely because of the unlimited freedom of design, coupled with almost no control over costs, the first teams and manufacturers interpreted these competitions as a concrete opportunity to directly test and develop any innovation that might prove useful for series production, making this type of competition, in fact, an extension of the research and development department of the manufacturers of the time, achieving a perfect alignment between the needs of the competitive world and those of the industrial sector.

Moreover, the first car manufacturers benefited from these competitions both in terms of technical development, which was favoured by the broad freedom of construction, and in terms of sport, since this freedom resulted in a direct impact of innovation on the race results, as the decisive element for victory was often not so much the skill of the driver as the technical superiority of the vehicle. All this translated into a significant return on image for the manufacturers, who could demonstrate the superiority of their cars over those of the competition, with the aim of strengthening their reputation and increasing sales. In fact, although these early competitions were not particularly remunerative in terms of economic rewards, their economic value lay in their effectiveness as a marketing tool, increasing the appeal of the winning cars and, consequently, the commercial competitiveness of the brand.

That said, at first glance, this type of competition would appear to be an optimal structure in terms of promoting innovative development, however, it also presents a number of critical issues and major compromises that, in the current context, would no longer make the adoption of such a competitive model sustainable.

A first somewhat paradoxical element can be found in the relationship between the high number of teams participating in competitions and the absence of cost containment measures. It is indeed surprising that, despite the total freedom of design and the lack of economic regulation, these competitions recorded a large and constant participation, with new teams and manufacturers constantly being born. This was made possible by the relatively low cost of the technology available at the time which, being still in an embryonic phase, allowed even teams with extremely limited resources to design and build competitive vehicles, sometimes without an immediate industrial purpose. Moreover, despite the absence of a competitive balance, dictated by the extreme freedom of radical innovative solutions, which in fact made these competitions less engaging from a purely sporting point of view, they still managed to arouse strong public interest thanks to the significant emotional and symbolic involvement that such events were able to generate, often fuelled by feelings of national pride and a marked connotation of national identity linked to the origin of the constructors and drivers. Precisely this strong attraction generated by the sense of national belonging that characterised these competitions, combined with the high sporting impact of the innovation, capable of guaranteeing a significant return in terms of image and, consequently, economic benefits in terms of sales, as well as the high technical relevance recognised by the manufacturers, was a determining factor in sustaining the continued participation of the teams, effectively compensating for the absence of structured cost control and competitive balancing mechanisms, guaranteeing the survival and development of the competitions in the long term.

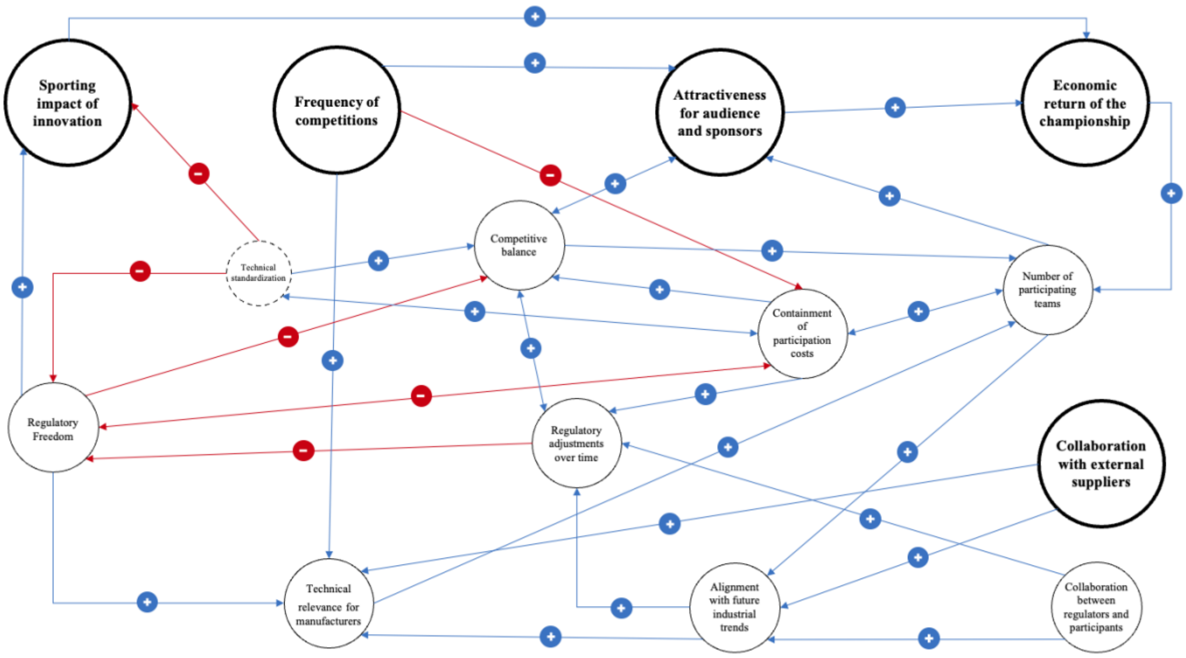


It is therefore evident that, nowadays, the combination of extreme regulatory freedom, total absence of cost control, high number of participating teams, low level of competitive balance and, at the same time, high attractiveness to the public represents a configuration that is difficult to replicate and sustainable. In fact, the high complexity of the technologies currently involved in these competitions necessarily imposes a careful control of costs, in order to encourage the participation of a large number of teams, so as to have a greater impact at industry level and not limit access to a few large manufacturers with almost unlimited economic resources. At the same time, the public's interest has progressively shifted towards aspects linked to spectacle, entertainment and the valorisation of the driver's technical gesture, rather than a factor of nationalistic pride. In particular, this change was favoured by a greater level of competitive balance between the cars, which, however, necessarily entails some sort of reduction in design freedom for the teams, as the need to search for this balance has made it necessary to introduce elements of standardisation in design and components, which also contributed at the same time to cost containment.

Thus, what emerges from the structure of this type of historic competition is a marked technical relevance for manufacturers, determined by a strong alignment with industry trends and needs, made possible by extreme design freedom and a high number of participating teams. However, this configuration presents trade-offs that, in the current context, would no longer be sustainable. In particular, the absence of cost containment mechanisms is problematic considering the high technological complexity of modern cars and would result in limited participation in the competition. Furthermore, in the same way, the lack of a competitive balance between the cars, although it favours the regulatory freedom and therefore the technical relevance of the competition, compromises the sporting attractiveness of the event, which is fundamental to guarantee a reasonable level of participation, as well as a greater involvement of the public, which in turn is crucial to obtain a higher economic and image return for the teams participating in the competition, and consequently, to favour the participation of a larger and more diversified number of teams.

7.2 Thanks to its strong tradition and hype, Formula 1 retains its technical relevance and economic strength

We will now proceed with the analysis of the Formula One World Championship. As discussed above, it is a competition characterised by an extremely long and prestigious history, which has undergone profound changes from its origin to the present day, and consequently, the following section will offer observations and reflections at a broader level of abstraction, with the aim of providing a representative overview of the overall evolution of the championship. However, given the numerous changes that Formula One has undergone over the course of its more than seventy-year history, the analysis will focus on the recent period, with particular emphasis on the last ten to twenty years, a period that is particularly significant for understanding the current structure, priorities and characteristics of the competition, as it reflects the most relevant transformations in terms of regulatory approach, technological development and commercial positioning.

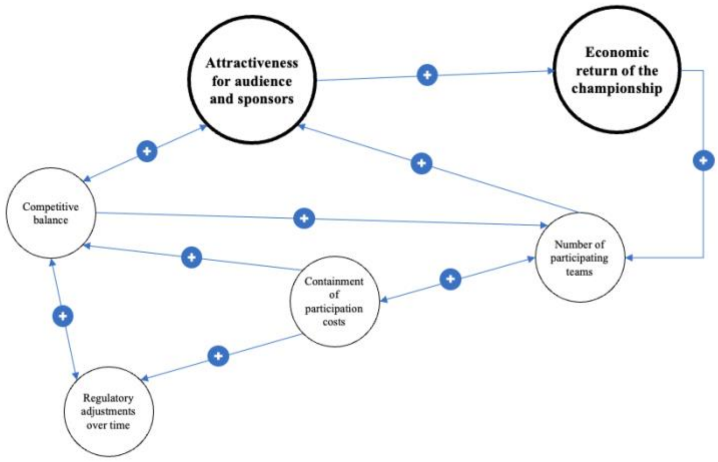


As can be seen from an initial observation of the causal diagram, the Formula One championship presents a decidedly more balanced structure than the competitions analysed above. In this case, a particularly important role is attributed to the media attractiveness and economic return of the competition, which exert a significant influence on many of the most relevant variables within the competition. In fact, Formula 1 is no longer just a motor racing competition, but has progressively turned into a real global industry, extremely profitable, able to generate more than 2.4 billion euros in annual turnover and reach a total audience of around 1.5 billion spectators per season. By way of comparison, Formula E has an annual turnover of around €170 million and a total audience of around 13 million viewers, which puts the championship in a still fragile economic situation, characterised by recurring operating losses that limit its long-term sustainability (Formula 1 da 2,4 miliardi, la Formula E in crescita ma resta ancora lontana, 2023).

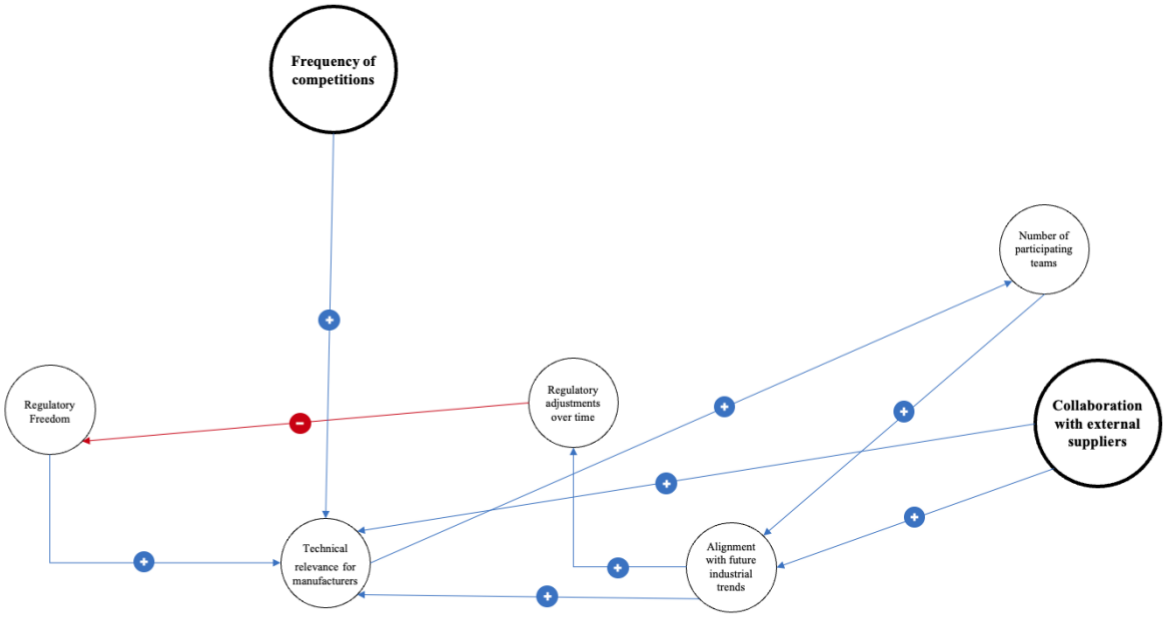
In order to achieve this status as a global sports industry, the Formula One championship has over the years made continuous changes to the technical regulations that have progressively shaped the competition, according to a process driven primarily by two objectives, the first of which is to be attributed to the desire, more pronounced than in pioneering competitions, to pursue a greater competitive balance, in order to increase the media interest of the public and, above all, of sponsors, who, since the 1970s, have become an integral and fundamental part of the championship, bringing profound changes in the dynamics of the series that have led to an enormous increase in the economic return, transforming the competition into a true sports product to be promoted and enhanced. The second objective, on the other hand, has been to maintain the relevance of the championship for the automotive industry, through constant dialogue between teams, external suppliers and regulatory authorities, which allows technical evolution to be geared towards industrial needs as well.

Thus, in the first case, the desire to pursue a greater competitive balance has historically translated into a progressive limitation of regulatory freedom and the introduction of cost-containment measures, including, on the one hand, some historical technological bans, such as the abolition of turbo engines, the stricter regulation of private testing and the introduction of the budget cap, all instruments adopted with the aim of ensuring greater fairness between teams, limiting the competitive advantage derived from superior economic resources. While on the other hand, as far as the relevance of the championship for the automotive industry is concerned, it has historically manifested itself, as analysed above, mainly in the area of engine development and in the transfer of radical technical solutions that have emerged in racing due to the presence of regulatory gaps, the most significant examples of which include advances in aerodynamics, the introduction of active suspension, traction control systems, the use of composite materials and so on. A central role has also always been played by collaboration with external suppliers, involved in the development of key components such as tyres, fuels, lubricants, software and mechanical parts (especially engines). In recent years, however, in response to the new challenges posed by the automotive industry, particularly those related to environmental sustainability and emission reduction, Formula One has progressively adapted its regulatory framework to encourage the adoption of hybrid technologies and synthetic fuels, an orientation that will be further reinforced from 2026 onwards, with the introduction of a new generation of hybrid engines, which aim to take this technology to its extreme, and will lead to the entry of three new relevant players in the championship, Audi, General Motors and Ford, a sign that the championship is still highly relevant from a technical industrial point of view.

Therefore, in order to fully understand the dynamics characterising the current structure of the Formula 1 championship, it is essential to highlight how its exceptional media attractiveness, combined with the growing profitability achieved over the years, has allowed the competition to assume an extremely balanced configuration. In particular, a championship that is highly profitable for the teams from every point of view, economic, sporting and image, naturally stimulates participation, without the need to introduce particularly rigid cost control measures, as long as, through constant and targeted adaptation of technical and sporting regulations, a discrete amount of competitive balance is maintained which is sufficient to obtain a sports and entertainment product capable of generating media interest to support the competition.

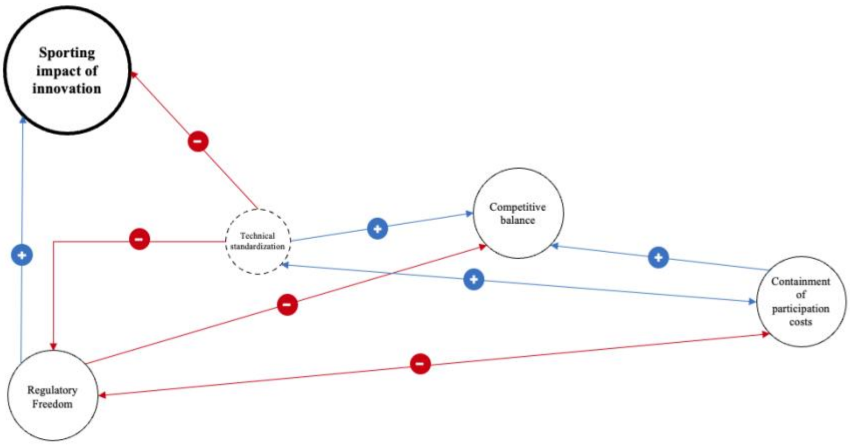


Furthermore, having a solid base of participating teams, coupled with a dense network of collaborations with external suppliers and partners, ensures that the championship continues to be aligned with future industrial trends, as both payers have an interest in pushing the competition towards the development of technologies directly applicable or transferable to industrial contexts. Moreover, this strong push for convergence between competition and industry needs, while often leading to regulatory adjustments that steer development towards certain areas, and thus limit regulatory freedom to a greater or lesser extent, it however helps, particularly in combination with the high frequency of races, to maintain the technical relevance of the championship at a significant level, promoting at the same time, a virtuous circle that encourages the entry of new teams and supports the innovation and competitiveness of the sport in the long run.



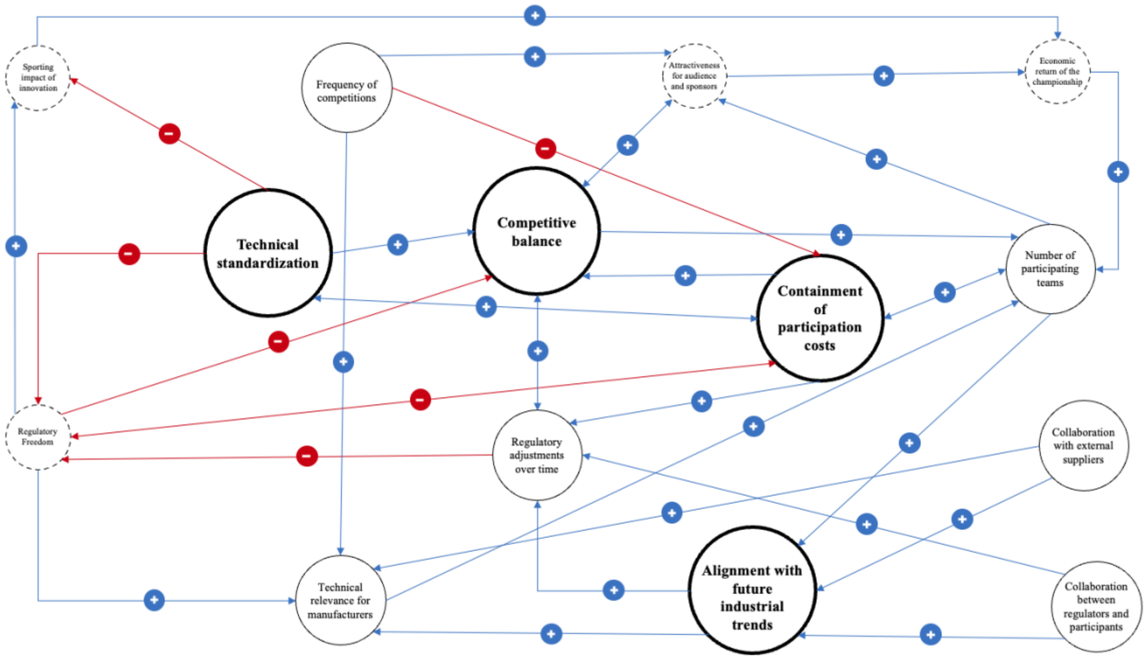
In summary, the Formula One championship has managed, over the years, to develop and consolidate a very strong media attraction, which was fuelled by the presence of champions of great renown, sponsors willing to invest huge sums and highly prestigious teams and personalities. The combined contribution of all these factors has led to an exponential growth in the economic return generated by the competition, stimulating the entry of numerous manufacturers, both as official teams and as technical partners, and encouraging the involvement of external suppliers. All these players were driven by the prospect of obtaining a return not only in terms of technology, but also economics and image. Consequently, the success of this competition probably lies in the solid media dimension that Formula One has managed to build over time. Indeed, as emerged also from the interview with representatives of a well-known Formula E team, the economic return and public involvement are key factors in guaranteeing, on the one hand, the long-term sustainability of the competition and, on the other hand, the presence of a sufficient number of teams willing to participate and who also have the necessary resources to invest in research and development, a crucial aspect considering the high participation costs required by competitions at this level.

Thus, Formula One, thanks to a strong media attractiveness combined with targeted and strategic regulatory adjustments, has managed over time to build a competition in which the sporting impact of innovation has been, and continues to be, extremely relevant, although the focus has gradually shifted from the radical technical innovations that characterised the pioneering phase of the championship towards more incremental and specialised forms of innovation of today, where the small details are the ones that make the difference. In fact, while operating within more restricted regulatory frameworks than in the past, the championship retains a fair degree of design freedom, with a very low level of technical standardization, that allows teams to develop their single seaters in their entirety, sometimes even with significant technical solutions, without altering in an excessive way the competitive balance of the championship, or by imposing cost containment measures that are too excessive to be undermine the technical and construction freedom of the participating teams.



7.3 The growth paradigm of Formula E may be holding back innovation that was meant to accelerate

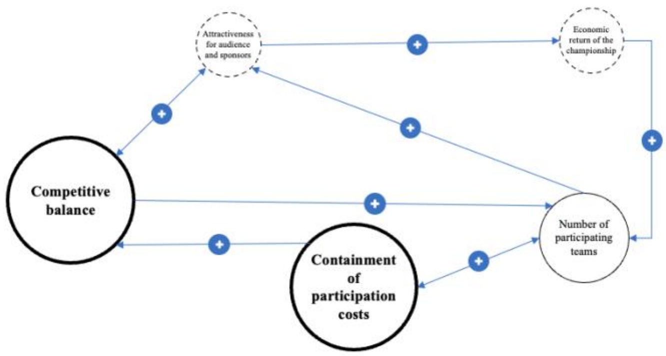
Finally, a causal analysis of the Formula E championship is proposed, the most recent of the competitions considered, since, as highlighted several times throughout this paper, it is the only one to have been expressly conceived with the objective of promoting innovation within the electric automotive sector.



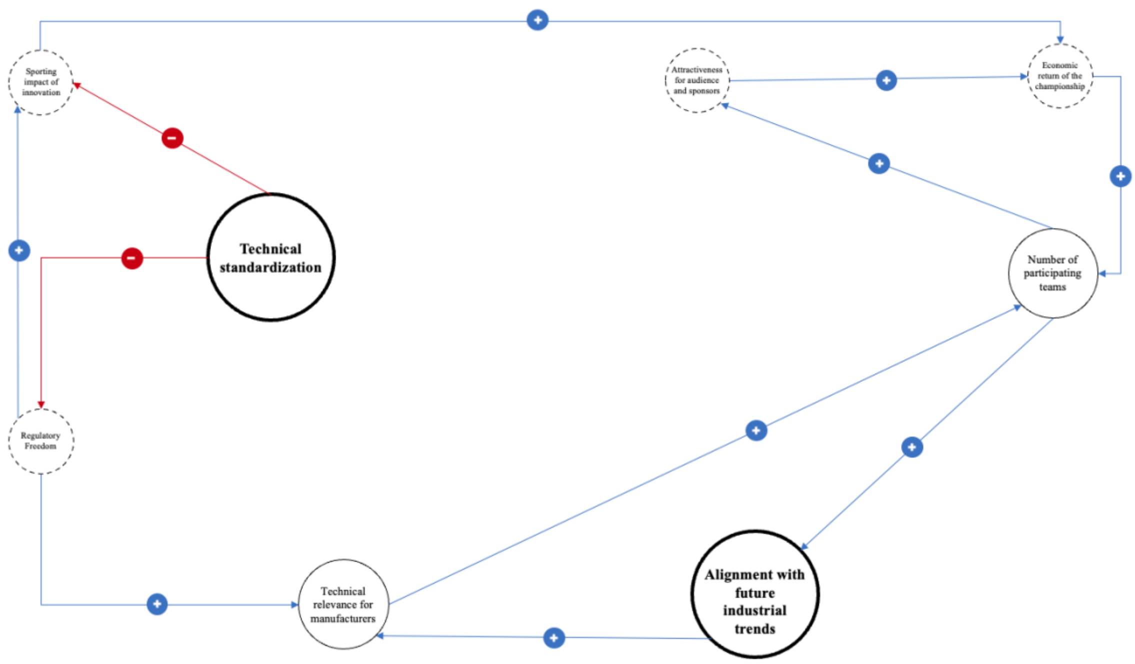
Again, it is possible to clearly discern from the diagram the central variables at the heart of the competition. In particular, a strong alignment with future industry trends and a strong focus on cost containment and competitive balancing emerge as predominant elements.

The interview conducted with representatives of a well-known Formula E team proved particularly useful in highlighting the main dynamics behind this specific configuration of the championship, which was created with the ambition of presenting itself as an accelerating platform for the development and dissemination of new technologies in the electric sector, but which nevertheless has to deal with a still limited level of media interest and economic return compared to other established motorsport series, a conflict that has so far limited the true innovative potential of the series.

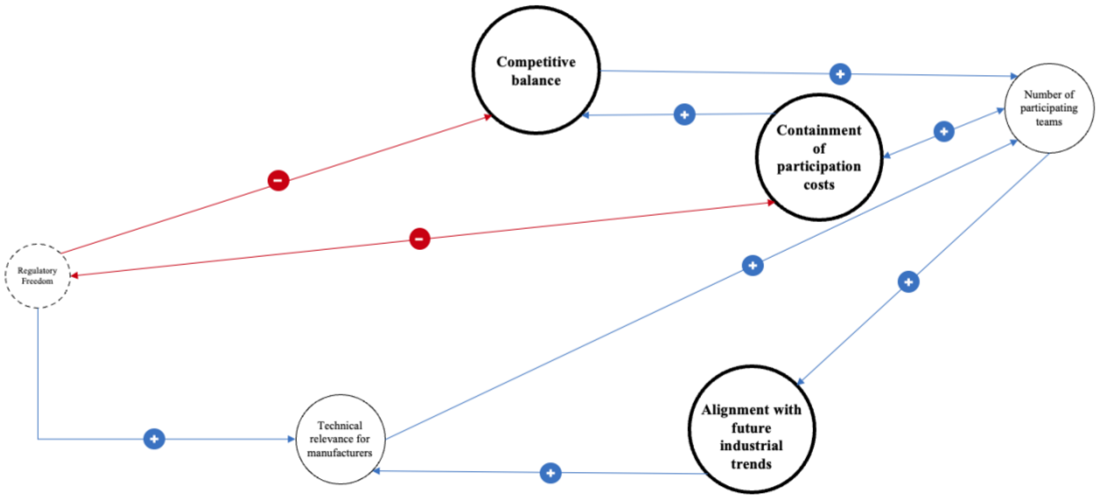
In fact, the extreme attention to cost containment is aimed at stimulating the entry of new teams and ensuring their permanence over time, thus contributing to the economic sustainability of the championship. At the same time, the constant search for a competitive balance aims to generate media interest around the competition and to build an engaging sports product, capable of attracting the public and increasing its visibility.



However, while such measures are useful and necessary to promote and grow the series, they can also be counterproductive, as the resulting high degree of technical standardisation leads to a significant reduction in the regulatory freedom granted to the teams, thereby also limiting the sporting impact of innovation and reducing the technical relevance of the competition for the manufacturers, with negative effects both on the number of participating teams and, indirectly, on the media interest and the overall economic return of the championship itself.



This represents the great trade-off, or, in a certain sense, the main contradiction on which the championship is based, in other words, the need to ensure competitiveness and economic equilibrium on the one hand, while on the other, the need to broaden the possibilities of technical experimentation in order to maintain high industrial relevance and attract new investments. Precisely this vicious circle, as detailed above, has been highlighted by the abandonment of important German manufacturer teams, such as Audi, BMW and Mercedes, which have progressively lost technical interest in the championship within the space of a few editions, reflecting the difficulty for high-profile industrial realities to continue to invest in a competition perceived as limited in its ability to generate technological innovation that is truly transferable to the production sector.



Nevertheless, from the interview it has emerged that the championship intrinsically possesses a strong innovative value for the automotive sector, since, unlike in other championships, such as Formula One, almost all technologies developed in Formula E are subsequently adapted and applied to road vehicles. The problem, therefore, would not lie so much in the technical relevance of the competition, but rather in the speed with which innovation is actually achieved, the extent of possible exploration of such technologies, and the real need for such an advanced and expensive platform to develop them.

Consequently, also according to the interview, the structure underpinning the championship proved effective at an early stage, when the flurry of technological novelty introduced by the series, combined with the technical limitations still present in the technologies used at its inception, made it possible to reconcile development and experimentation with strict cost control in a way that was stimulating for manufacturers. However, this particular model, that has worked in the past, now needs to evolve, firstly in order to attract new participants and also because the further scope for development in the current areas of interest, in particular energy efficiency and energy management, is now limited in light of the excellent results already achieved in the ten years of the competition's existence, making it therefore necessary to broaden the area of technical experimentation to include components and areas that were initially excluded from development due to technological limitations at the time, but which could now be the subject of advanced research. Such an opening, however, would inevitably entail a revision of the current pillars on which the competition is based, namely competitive balance and cost control.

8. Conclusions

This thesis tried to investigate the role of motor racing championships as instruments to stimulate and disseminate technological innovation in the automotive sector, analysing in particular three distinct models of competition: early motorsport, Formula 1 and Formula E. Through the theoretical framing of the concept of staged competition and the analysis of the main variables influencing its effectiveness, such as regulation, competitive pressure, design freedom, economic sustainability and openness to innovation, it was therefore possible to construct an interpretative framework useful for assessing the technological potential of motor racing.

The historical analysis conducted in the first chapters showed how each championship responded to different logics in terms of technological development and industrial transferability. In fact, early motorsport acted as a spontaneous catalyst for innovation, thanks to the absence of regulatory constraints and the strong interaction between pioneers, manufacturers and industrial territory. Formula 1, on the other hand, has represented a model of innovation driven by extreme performance, where technology transfer has historically occurred more selectively, influenced by the increasing degree of specialisation and technical complexity. Formula E, finally, has embodied a more direct and oriented form of innovation, where the explicit goal of accelerating the transition to electric mobility has produced a competitive environment that is functional to the development of immediately applicable technologies. Moreover, the contribution provided by this analysis, integrated with the bibliographical research on the concept of staged competition, made it possible to identify the most relevant types of systemic variables to be included in the causal model, which emerged clearly thanks to the joint analysis of historical and theoretical sources.

Finally, the comparison of the three models, obtained through the creation of a causal model of the interrelationships between the systemic variables of motor racing championships, made it possible to highlight the strengths and weaknesses of each approach, revealing that there is no single optimal championship, but rather different arrangements responding to different priorities and contexts.

Historically speaking, pioneering motorsport has proved to be an extremely fertile context for technological innovation, thanks to the almost unlimited freedom of construction, the absence of stringent regulatory constraints and the close integration of competition and industry. However, such a model, based on radical experimentation and the absence of regulatory control, would be difficult to sustain today, since on the one hand, the absence of limits would imply high and unpredictable costs, incompatible with contemporary economic logics; on the other hand, the lack of sporting balance would strongly reduce its value as an entertainment product, compromising its attractiveness for sponsors, manufacturers and the public, which, in a context in which financial sustainability and media engagement are central elements, would make a return to such an anarchic model no longer possible.

Formula E, on the contrary, is an example of a competition which was designed specifically with a strong orientation towards technology transfer, and in this perspective, the championship has been able to create a direct link between sports innovation and industrial application. However, strict technical regulations, which severely limit the design freedom of teams, are progressively reducing the evolutionary potential of the competition, a factor which, combined with the relative youth of the championship and its limited international notoriety, also compromises its ability to attract investment on a global scale, making any regulatory opening complex without risking compromising its stability.

Finally, Formula 1 has emerged as the model that best balances the needs for innovation, economic sustainability and entertainment. Its high media visibility and long sporting tradition have enabled it to attract leading constructors, significant economic resources and a global fan base. The technical regulations, while constrained by safety and cost containment requirements, leave room for considerable design freedom, making advanced technological experimentation possible. Therefore, precisely this balance between engineering freedom, economic sustainability and commercial appeal makes Formula One a championship that is still relevant and influential in the automotive innovation scene today.

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