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What It Takes To Be The Best: The Competitive Balance In Formula 1 Racing

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I dedicate this to my family whom I love dearly and who have shown unconditional love to me throughout this journey of my life.

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Introduction

Competitive balance is an essential aspect of sports that ensures every team or player has a fair chance of winning, which creates a level playing field. It refers to the degree of parity between teams or players in a particular sport, and it is a critical factor that contributes to the overall excitement and engagement of fans. A lack of competitive balance can lead to decrease fan engagement and interest, which can ultimately impact the financial viability of the sport.

Several factors can affect competitive balance. One of the most crucial factors is the distribution of talent among teams or players. If one team or player has a significant advantage, in terms of talent, it can make the competition less balanced and not as exciting for fans. Another element that can affect competitive balance is the distribution of financial resources between competitors. Some teams may be able to gain an advantage by investing in better equipment, facilities, or coaching. Other characteristics that can affect competitive balance include the rules and regulations of the sport, the level of competition among teams or players, and the overall structure of the league or competition.

Sports organizations and governing bodies have a responsibility to maintain competitive balance in their respective sports. This can be achieved through various measures, such as salary caps or budget caps, revenue sharing, draft systems, and regulations aimed at preventing monopolies or excessive dominance by a single team or player. While some degree of imbalance is inevitable in any sport, a lack of competitive balance can have negative consequences, such as decreased fan attentiveness. Thus, it is important for sports organizations and governing bodies to continuously monitor and address issues related to competitive balance in their sports.

The root of this empirical analysis stems from the global pandemic in 2020 when everyone was cooped up in their homes binge-watching whatever shows were out and popular. For me, that was watching Formula One's "Drive to Survive" docuseries on Netflix, which will be talked about later on. This sport was somewhat foreign to me. I kind of had an idea as to what it was but didn't realize the uniqueness of it. What stood out to me the most was the lavish lifestyle of each of the Formula One drivers. It is clear that this sport was made for the wealthy, however, the motorsport has evolved to be one of the most popular sports in the world, reaching people of all demographics.

With the existence of the lavish lifestyle, it is also evident that money and spending are big characteristics of the sport, in general. Formula One has been known for its high costs, with some teams spending significantly more than others, leading to uneven competition. For example, through the years, the top teams, such as Mercedes, Red Bull, and Ferrari have been estimated to spend upwards of $400 million per year, while some of the smaller teams have had spending budgets of less than $100 million. There is a large disparity between teams, resulting in a lack of competitive balance between the wealthier teams and the not-so-wealthy teams. Thus, with the recent addition of the spending cap (also referenced as the budget cap) in 2022 to Formula One, the introduction of it is a significant development, as it is aimed at reducing the financial disparity between teams and providing a more level playing field.

The topic of competitive balance in Formula One does not start with the writing of this paper, in fact, it has been something that many people have wondered about and have examined. Each author has a different outlook on the competitive balance in Formula One, thus, it is important to look at various works to gather a better understanding. Competitive balance within

Formula One has been a recurring theme because the sport is so different from many of the major sports like baseball, basketball, football, and soccer. Additionally, similar to Formula One, these major sports are looking at ways to make the sport more competitive, attract more viewers, and make the sport more entertaining. As a result, that is why year over year, different sports are making changes in the hopes that it will make the sport more fun to watch, while also maintaining competitive balance.

Furthermore, when writing this paper, it is important to acknowledge that there have been other people who have been interested in this topic. First, Paulo Mourão who wrote the book *The Economics of Motorsports* tries to answer this question of competitive balance in Formula One, providing data that illustrates the measurement of competitive balance using HHI over the years, starting from 1960 to 2014. Second, other authors Thomas Krauskopf, Martin Langen, and Björn Bünger who wrote "The Search for Optimal Competitive Balance in Formula One" focuses on the determinants of attractiveness in Formula One, more specifically how the maximization of attractiveness is connected to the optimal level of competitive balance. Third, a paper written by Oliver Budzinski and Arne Fedderson titled "Measuring competitive balance in Formula One Racing" aims to inform the reader based on two things: the economic analysis of Formula One and the literature on competitive balance in non-team sports.

Although all of these writings have to do with looking at the competitive balance in Formula One, each one talks about and looks at competitive balance differently. And because all of these works are different, this paper is deriving the various techniques that are used from these writings, as well as accounting for other factors that could play a major part in measuring competitive balance in Formula One Racing.

This paper will seek to explore the potential effects of the spending cap on competitive balance in Formula One. This includes factors that led to the introduction of the spending cap, the challenges and controversies associated with its implementation, and the potential impact of it on the sport. We will also examine the implications of the spending cap for teams, drivers, and fans, as well as the future of Formula One with this new regulation. Additionally, we will investigate the concept of competitive balance in Formula One, including factors that influence it and the result of competitive balance in the sport, as well as look at methods on how to measure competitive balance. Furthermore, the measurement that will be employed to calculate competitive balance is the Hirschman-Herfindahl Index (HHI), which will be provided later in this paper.

To achieve a better understanding of how effective the addition of the spending cap is on the competitive balance in Formula One, we gathered pertinent information from https://www.statsf1.com/en/saisons.aspx, looking at 60 years of data from 1960 to 2022. The data will help us analyze indicators such as the number of drivers, number of constructors (teams), number of circuits (races), and total points earned for both drivers and constructors in a given season that could all have potential impacts on competitive balance. In the empirical analysis, the aforementioned variables will be considered the potential control variables, the spending cap will be the dummy variable, we will also account for the evolution of technology which will be considered a time trend, and the HHI will be the dependent variable. These will all be introduced and further expanded on in the empirical work section.

The paper will be developed as followed: Chapter 1 will introduce essential background information on Formula One to set up the premise of the paper, Chapter 2 will provide a

literature review on the budgets as well as the use of technology in Formula One, Chapter 3 will develop the empirical work and econometrics used to study competitive balance in Formula One and considerations for next steps, and then the paper will conclude and speak about further implications as well as the limitations and future work to further understand the ever so prevalent topic of competitive balance.

Chapter 1: Formula One

Formula One Racing, Formula 1, F1. What is it? Many people have probably heard of it, including you, but may not know exactly what it is. To put it simply, imagine yourself go-karting, but the go-karts you are driving are a little bigger and can go upwards of 200 mph. In Formula One (F1), there are ten different constructors (teams) that compete, each team consisting of two drivers, totaling 20 drivers that race on a given weekend. However, the total number of drivers and teams has changed over time, with the sport starting with an extraordinary 81 drivers and 0 teams in 1950.

"Formula," refers to the set of rules by which all drivers' cars must abide. With the rules that have to be followed comes the uniqueness of the sport, such that teams have to be able to build their own distinct cars every year, conforming to the rules and regulations that are set in place by the Fédération Internationale de l'Automobile (FIA).

Launched in 1950, Formula 1, sanctioned by the FIA, is classified as the highest class of international racing for open-wheel single-seater formula racing cars. Each driver must hold a valid Super License, which is the highest class of racing license that is issued by the FIA. During a Formula One season, there are a series of races, known as Grand Prix. These races are done worldwide on closed public roads (or street circuits) as well as purpose-built circuits, which is quite different from NASCAR because they race on tracks. Additionally, the races must run on tracks that are Grade 1, which is the highest grade rating issued by the FIA. There are certain criteria that each circuit has to follow. This includes tracks conforming to different standards and facilities around the circuit following minimum requirements. There are currently 39 circuits and 49 layouts spanning 31 countries. A race lasts for 190 miles and usually takes about two

hours—but races can go on for longer. Throughout an F1 season, they race in places such as Belgium, Italy, Monaco, and the UK and have more recently added Azerbaijan, the Netherlands, Saudi Arabia, and Singapore.

In the course of a season, a point system is tallied. After each Grand Prix, points are added up over the length of the season to determine two annual World Championships: one for drivers and the other for constructors. In more recent times, points are awarded to the top ten finishers in the Grand Prix, although this has changed since the start of Formula One. The first-place winner receives the most amount of points which is 25, second place gets 18 points, and third place collects 15 points, and then the points drop to 12, 10, 8, 6, 4, 2, and 1.

In Formula One, winning is a huge indicator of the success of a driver and how talented of a driver the individual is. To win in Formula One, several components go into it. These include a driver with a great engineering team, having funding, being lucky, as well as driving talent. Skill and talent are two very important things for the driver to possess and can be measured. Measurable talents for drivers include handling skills, engineering knowledge, the ability to interact with a team, and driver popularity.

When steering a racecar, drivers are under tremendous pressure. The average temperature in an F1 cockpit is between 122 degrees Fahrenheit to 140 degrees Fahrenheit, and during a race, drivers lose around 2 to 4 kg (roughly 4 to 9 lbs) of their body weight. During braking and acceleration, the weight of a driver's head and helmet increases five times, and a driver feels an overload of 5 g, which means that the seat's downforce is equal to 400 kg. Additionally, in the event of a crash, this level increases several times. To put this into perspective, during a launch, astronauts undergo up to 3 to 4 g and while taking off, a passenger on an airplane feels 1.5 g.

Reflex is also a good indicator of how skillful a driver is. An average Formula One driver has a reaction time of 100 milliseconds (ms), compared to someone like us who has a reaction time of 300 ms. Consequently, it is important, and potentially life-saving, for Formula One drivers to be very skilled at what they do because of how taxing and dangerous the sport is.

Throughout its history, Formula 1 has been known to be a very dangerous sport, where drivers are constantly putting their lives on the line and one bad turn or one bad accident can turn into their last race. With the dangers that are present, over the recent decades, safety has become one of the main focuses as cars have been modified to be safer, such as the implementation of the halo over the cockpit to protect the drivers. Also, with time, Formula One cars have gotten faster, and are considered one of the fastest single-seater cars in the world—the first goes to IndyCar.[1] Now we will go on to talk about the car that is driven.

The Car

Many of us drive cars but not at the speeds that F1 drivers reach, and it is fascinating to see what distinguishes an everyday car on the street that you see from an F1 car. In technical terms, the answer is that the very high cornering speeds are attained by the generation of large amounts of aerodynamic downforce. Downforce is a negative force that pushes the vehicle down to the road.[2] When talking about lift (the direction), planes have a positive lift which is why they can fly, whereas for cars there is a negative lift. Thus, there is a downwards (negative) lift force that is created by the aerodynamic features of the vehicle.[3] This downforce is generated by front and rear wings, which have the side effect of causing extreme turbulence behind each car. The

[1] Duxbury, Anna, and Joe Holding. "How Fast Is an F1 Car? Top Speeds of F1, IndyCar, Motogp and More." Autosport, May 30, 2022. https://www.autosport.com/f1/news/how-fast-is-an-f1-car-top-speeds-of-f1-indycar-motogp-and-more-4980734/4980734/?nrt=54.
[2] Seas. Downforce. Accessed November 15, 2022. https://formula1-dictionary.net/downforce.html.
[3] Seas. Downforce. Accessed November 15, 2022. https://formula1-dictionary.net/downforce.html.

turbulence diminishes the downforce produced by a car directly behind it, making overtaking more challenging. In layman's terms, overtaking is when the attacking driver has managed to get their car into a position where they are on the side of the track where the defending driver needs to turn, which is alongside the right heading into a right-hander or alongside on the left heading into a left-hander.[4]

F1 cars are quite dependent on electronics, aerodynamics, suspension, and tires, and through time, concepts within the cars have been banned. In 1994, traction control (designed to prevent loss of traction of the driven road wheels), launch control (an electronic aid to assist drivers in accelerating from a standing start), and automatic shifting (a multi-speed transmission used in internal combustion engine-based motor vehicles that do not require any driver input to change forward gears under normal driving conditions) were first banned. Furthermore, these concepts were reintroduced in 2001 but were banned again in 2004 and 2008.

This paper is not only interested in the competitive balance in Formula One, but it is also interested in looking at the relationship between competitive balance and the spending cap. Such that if the spending cap does its job that Formula One hopes it does, creating a more level playing field for all of the teams, especially those at the bottom, then there should be an increase in competitive balance. History has shown, in Formula One, that the teams who have been able to spend the most amount of money, before any budget or spending cap that was implemented, the individual drivers—a part of the team—and the teams— in general—were more likely to win a championship. Accordingly, it is shown with Mercedes when they won seven consecutive years

[4] Editor. "F1 Overtaking Rules: What Are the Rules of Engagement?" Yahoo! Finance. Yahoo! Accessed November 15, 2022. https://uk.finance.yahoo.com/news/f1-overtaking-rules-rules-engagement-150400862.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAL1gR7iFDv1zoKJvpMO99UJ0_d7EEwjeqWqAaGUkGK1TX49gpQLd_eTiJBU_7ahsO6xN8x-uYx9A5h1K2hq9N28IW0-CdgjuYifVRcJuMAZiR4ZBxNLXJbVqtcGTeQyv926VCDLo876vDIQWsnBqyedD4f1dE4usNwi8IqSydIbu.

(2014-2020), and even in more recent years with Red Bull Racing. In any sport, winning is heavily influenced by spending, and Formula One is no different in that category. What makes F1 unique from other sports is the different equipment for the cars. For example, the engine, a pivotal component in making a fast car, can be quite expensive and can have a massive competitive advantage.

Although winning in Formula One can come with a multitude of reasons, such as driver talent (having the best driver), having the best people who work and run the team, having the best car, best engine, and more, all of these things have one thing in common, and that is the willingness to spend and having the funds to do it. To see if this is the case, and if there is a relationship between competitive balance and the spending cap, empirical research and analysis will be done.

The Driver

To become a Formula One driver, it takes a lot of time, effort, and money if one wants to participate in the motorsport. Formula One racing is like no other sport because there can only be 20 drivers in the entire world that participate in this sport, so it is very selective. These 20 drivers are the best of the best in the world, and you won't see a driver who isn't good at what they do.

To be an F1 driver, it is important to acknowledge that, unlike other sports, it is a lifestyle and not a profession or hobby. This means that one must always keep in mind that only hard work will lead to the dream goal. Formula One drivers are constantly training, whether it be racing, or mental or physical exercises—which are a crucial part of the practice. None of the drivers start practicing on expensive Formula One single-seats, but rather it starts with kart racing, and it often starts at very young ages (3-5 years old).

Kart racing allows one to practice the basic knowledge of driving on the racing track, which is almost like Formula One, except on a smaller scale. From an early age, drivers must master controlling the car at high speeds, while also maneuvering and avoiding collisions with opponents. At this riders stage, they learn tricks and build tactics, as well as discover what their strengths and weaknesses are. For prospective Formula One drivers who start at a very young age, karting is not only just practice, it is also a competitive motorsport with its championship and a resume booster to become a future Formula One driver. Therefore, it is a good thing to participate in these competitions, as it will have a major impact on your career if you participate in small motorsports, to help improve your racing skills as well as to compete for roughly 10 years.

It is almost impossible to jump from junior teams immediately to Formula One, to do this, one has to go through the lower tiers to get to the highest, such as Formula Ford, then Super GT, then F One. As soon as the racer achieves significant success, they have a chance to be noticed and can be taken into one of the Formula One teams. Additionally, due to the high cost of participation in motorsports, it is necessary to have a good sponsor—unless your father is Lawrence Stroll, who is the owner of the Aston Martin F1 team. Consequently, the better one drives and the more you participate in competitions, it is easier to get your name out there, and the more media coverage you will receive. This brings us to motorsport and the journey to reach Formula One being very expensive. Furthermore, motorsport is a business and if you want to drive a car, you have to own it, and you also have to have money on hand for mechanical problems as well as other things that go into the car.

Popularity

Popularity within Formula One has transcended the sport, as more heads have turned to watch how exciting and unique it is. And to keep on increasing the popularity of Formula One, the competitive aspect of it has to be thought about. Competitive balance, a measurement that looks at how evenly distributed the sport is (that is everyone has a relatively equal chance of winning), is a pertinent measure that will be looked at, as it can have an impact on the continuous popularity within the sport.

As Formula 1 has become more and more popularized, some of the big questions are: What is so alluring about Formula 1? Is it the sexy-looking cars? The lightning-fast cars? The unique circuits? The danger within the sport? Or is it a combination of all of these things? This sport has shown that it is like no other. Formula 1 wasn't always this popular. It wasn't until recently that the motorsport gained a larger following among sports enthusiasts like me and many others. As such, six years ago (2016), worldwide viewership for Formula 1 was down an extraordinary $110 million compared to its pinnacle of $500 million in 2012.[5]

"In 2012, CVC Capital Partners sold $1.6 billion of F1 shares to funds managed by Waddell & Reed Investment Management and Ivy Investment Management, valuing them at about $9 billion. Liberty Media acquired F1 for $8 billion, which is about an 11% discount from the valuation in 2012."[6] Liberty Media established a focused campaign in the United States to potentially demonstrate some form of popularity as it sought to inject some much-needed branding and enthusiasm into the sport. One of the plans to increase popularity included a

[5] Killingstad, Written by Liam, Liam Killingstad, Edited by Peter Richman, and Peter Richman. "The Unstoppable Rise of Formula 1." Front Office Sports, July 10, 2022. https://frontofficesports.com/newsletter/the-unstoppable-rise-of-formula-1/.
[6] Killingstad, Written by Liam, Liam Killingstad, Edited by Peter Richman, and Peter Richman. "The Unstoppable Rise of Formula 1." Front Office Sports, July 10, 2022. https://frontofficesports.com/newsletter/the-unstoppable-rise-of-formula-1/.

docuseries titled “Drive to Survive”—which is something that people who may want to become more familiar with F1 should watch. The docuseries’ initial airing in 2019 contributed to a 40% boost in F1 viewership in the United States. Additionally, content has played a major role in the growth of Formula 1, as is evident with the Netflix docuseries “Drive to Survive.” However, it does not stop there as there are also upcoming Hulu and Apple projects that will continue to help the uproar of the exciting sport.

Formula 1’s renewed three-year deal with ESPN is reportedly in the annual range of $75-$90 million, which is a $5 million increase per year from the current agreement. Although the annual three-year deal may seem low in comparison to the NBA’s $2.6 billion annual agreement with Turner and ESPN, or the $2.6 billion ESPN paid for “Monday Night Football” alone, this deal depicts a step in the right direction.[7] Since 2018, Formula 1 has seen a continued increase in average viewership per race in the U.S.—going from half a million in 2018 to almost 1.5 million in 2022. In 2018, there were 547,722 viewers, 2019 there was a pretty big jump in viewership to 672,000, 2020 fell to 608,000 viewers, then in 2021 viewership jumped to 934,000, and in 2022 it exploded to a staggering 1.4 million viewers.[8] And the 47% rise that was present from 2021 has contributed heavily to the financial successes of F1.

Additionally, in the first quarter of 2022, the Formula One Group, a collection of businesses in charge of promoting the FIA Formula One World Championship, made a whopping $360 million in revenue. Formula 1 has transformed the idea of motorsports, and sports in general, and will continue to become more popular as more eyes steer towards it. As it becomes

[7] Killingstad, Written by Liam, Liam Killingstad, Edited by Peter Richman, and Peter Richman. “The Unstoppable Rise of Formula 1.” Front Office Sports, July 10, 2022. https://frontofficesports.com/newsletter/the-unstoppable-rise-of-formula-1/.
[8] Killingstad, Written by Liam, Liam Killingstad, Edited by Peter Richman, and Peter Richman. “The Unstoppable Rise of Formula 1.” Front Office Sports, July 10, 2022. https://frontofficesports.com/newsletter/the-unstoppable-rise-of-formula-1/.

more and more popular across the globe, it could potentially become the largest and most popularized sport in the world.

Team Spending

Just like in any sport, money is an essential thing to maintain and have access to—and Formula 1 is no exception. In Formula 1, teams need money to cover their expenses, and even low-cost teams need a good amount of money to cover a median season's expenses. Most of these revenues come from sponsors—the corporations whose names, brands, and logos give color to the paddock, to the various teams' equipment, to drivers' helmets, and to the cars.[9] Furthermore, a median Formula 1 team gets most of its budget revenues from commercial sponsorships (70%-90%), and the rest of the budget revenue comes from prize money, owners' investments, merchandising, and TV rights.[10] However, smaller teams usually depend more significantly on the generosity of the prize money and on the sponsors of the pay drivers—which are drivers financed by a sponsor. And from the years of 2010-2015, Formula 1 teams' revenues have increased. As a result of the revenue increase, this would indicate that the mean of all the teams' revenues has also gone up, from $135 million to a staggering $232 million.

If you are someone who has followed F1 for some time, a prime example of having money to spend leading to winning is the notorious Mercedes Team. Lewis Hamilton, a British F1 driver for Mercedes is without a doubt one of racing's all-time greats. Although his skill and abilities cannot be denied, his dominance is mainly due to unchecked spending that has greatly influenced his success. Much of Hamilton's on-track success has stemmed from the fact that

[9] MOURAO, PAULO. "Chapter 3." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economics of Motorsports (81)
[10] MOURAO, PAULO. "Chapter 3." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economics of Motorsports (81)

Mercedes is willing to outspend the competition—spending $430 million a year, which is more than double what most F1 teams are able to spend in a given season.[11] And this has made it difficult for teams to compete with Mercedes.

Mercedes has been able to continuously thrive because of its extraordinary amounts of spending in comparison to other teams, especially the ones that are less wealthy. It has been a recurring pattern that teams that are significantly less valuable are consistently left with fewer resources to work with and must fight to secure even the smallest advantages, all while trying to remain solvent. To put it into perspective, according to Forbes in 2019, the top three teams were valued at $1.35 billion (Ferrari), $1.015 billion (Mercedes), and $640 million (Red Bull Racing) pulling in revenue of $426 million, $451 million, and $327 million. On the other hand, the bottom three teams were valued at $130 million (Racing Point), $115 million (Haas F1), and $105 million (Alfa Romeo) pulling in revenue of $104 million, $95 million, and $84 million.[12] It is clear that there is indeed a massive wealth gap and that, in turn, has had an effect on on-track competition and success.

The good thing is that Liberty Media, F1's owner, prepared to implement a cost control measure—which will be talked more about later. Wealth has played an integral role in how successful top teams have been able to perform. Hopefully, by instituting this change, advantages that are seen by the wealthier teams will be less apparent and will inevitably create a more level playing field for mid-tier teams and teams that are closer to the bottom. Nevertheless, this is a jump in the right direction for Formula 1 as a sport, and it is important to keep in mind that it will

[11] Smith, Chris. "Formula One's Most Valuable Teams: Ferrari and Mercedes Gain Ground amid a Cost-Cutting Tug-of-War." Forbes. Forbes Magazine, November 26, 2019. https://www.forbes.com/sites/chrissmith/2019/11/26/formula-one-team-values-ferrari-mercedes/.
[12] Smith, Chris. "Formula One's Most Valuable Teams: Ferrari and Mercedes Gain Ground amid a Cost-Cutting Tug-of-War." Forbes. Forbes Magazine, November 26, 2019. https://www.forbes.com/sites/chrissmith/2019/11/26/formula-one-team-values-ferrari-mercedes/.

take some time for the spending cap to have an eventual impact to level the playing field, as the top three teams are still way ahead of the curve.

Spending Cap

In 2021, Formula 1 enforced a spending cap to create fair competition among the different teams, while also limiting the spending of richer teams.[13] The implementation of the cap means that Formula 1's biggest spenders—Mercedes, Red Bull, and Ferrari—have had to reduce their budgets and adapt their working practices to meet these limits. Thus, teams are no longer able to spend the copious amounts of money they were spending preceding the spending cap. Consequently, the technical regulations for 2022 were completely different, resulting in the first cars to be designed under the newly implemented spending cap.

The inevitable hope is that year over year, there will be a swap around who is having good results and who is having bad ones. This could also lead to having varying championship winners, however, all of these aspects will take time as the bigger teams still have an edge over other teams. Nonetheless, the spending differences have evolved from a $2-$300 million advantage to roughly a $10-$20 million advantage. These ranges are drastically different and will make teams have to consider where to put their money towards.

The discussions regarding this topic originated in 2019 with the reveal of the FIA Cost Cap regulations, which were included as a component of the provisional rules for 2021.[14] The Technical Regulations for the 2021 season were delayed to 2022 because of the pandemic, but the Financial Regulations would remain in place. The cap was set at $175 million for the 2021

[13] F1. "The 2021 F1 Cost Cap Explained – What Has Changed, and Why?: Formula 1®." Formula 1. Formula 1, May 28, 2020. https://www.formula1.com/en/latest/article.the-2021-f1-cost-cap-explained-what-has-changed-and-why.5O1Te8udKLmkUl4PyVZtUJ.html.
[14] Kanal, Samarth. "Timeline: How the FIA Cost Cap Story Unfolded as Red Bull and Aston Martin Enter Agreements over Breaches: Formula 1®." Formula 1. Formula 1, October 28, 2022. https://www.formula1.com/en/latest/article.timeline-how-the-fia-cost-cap-story-unfolded.6yAhD5hKoRuUTqhU1wYuGY.html#:~:text=The%2022%20FIA%20Cost%20Cap,rise%20in%20line%20with%20inflation.

season but was reduced to $145 million.[15] In 2022, the FIA set a spending cap of $140 million, which will be gradually decreased to $135 million over the years 2023 through 2025, accounting for inflation.

Additionally, the budget cap was enforced to make sure all teams could sustain themselves financially in the long term. The COVID-19 pandemic caused the postponement of the 2020 F1 season and, due to this, many F1 teams faced heavy financial losses. However, during the pandemic, the three wealthiest teams—Ferrari, Mercedes, and Red Bull—spent much more than other teams. With this happening, the FIA and F1 authorities were scared that Ferrari, Mercedes, and Red Bull were creating a monopoly over the World Championship because of their strong financial backup, and this led to the creation of a spending cap. Furthermore, some of the things that fall under the spending cap are all parts of the car (not the engine), all the elements to run the car, and most of the team personnel. Accordingly, the costs of things like marketing, driver salaries, and staff salaries are not included within the spending cap, and this is the case because they wanted to make sure that team drivers and staff were not affected by the spending cap.[16]

There has been controversy and backlash concerning the idea of the implementation of a salary cap coming from drivers and staff. Max Verstappen was someone particularly vocal about it, who is the reigning Formula One World Champion and drives for Red Bull Racing. Verstappen slammed the idea of capping driver salaries as a method for saving money in the sport saying, “it would have a negative impact on young drivers attempting to break into

[15] Asher, Richard. “F1 Cost Cap: What Is It and How Does It Work?” Motorsport.com. Motorsport.com - US, February 28, 2023. https://us.motorsport.com/f1/news/f1-cost-cap-what-is-it-how-it-works/10379800/.

[16] F1. “The 2021 F1 Cost Cap Explained – What Has Changed, and Why?: Formula 1®.” Formula 1. Formula 1, May 28, 2020. https://www.formula1.com/en/latest/article.the-2021-f1-cost-cap-explained-what-has-changed-and-why.5O1Te8udKLmkUl4PyVZtUJ.html.

motorsport's top category."[17] Additionally, he believes that the idea of a driver salary cap is wrong. Verstappen believes this because the drivers deserve to benefit from Formula One's increase in popularity over the recent years. Verstappen goes on to say, "Everyone is benefitting, so why should the drivers, with their IP rights and everything, be capped?"[18] The addition of a salary cap would make it more difficult for young drivers that hope to make it to Formula 1. This is because these young drivers are dependent on sponsors and financial support from backers to fund their advancement through junior racing, which would be done in exchange for a portion of their possible future F1 earnings. And as the sport is constantly growing and becoming more and more popular, teams are also earning more and more money, and drivers are the catalyst for the dramatic growth that is being seen.

As Max Verstappen and other drivers have voiced disgust with the spending cap, teams have also expressed warning signs about the spending cap and spending over the budget. For example, Ferrari "warned at the end of May [2022] there was 'no chance' it would stay within the budget cap for this year due to increasing costs, while Red Bull F1 chief Christian Horner warned of a 'catastrophe' over the crisis."[19] This is not only the case for the bigger teams like Ferrari, Red Bull, and Mercedes, as some of the smaller teams have revealed more reluctance to agree to a change in the regulations. One example is from the Alfa Romeo boss Frederic Vasseur who suggested "the bigger outfits simply develop their cars less to stay within the limit."[20]

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[17] Edmondson, Laurence. "Max Verstappen Says F1 Salary Cap Idea 'Completely Wrong'." ESPN. ESPN Internet Ventures, June 10, 2022. https://www.espn.com/f1/story/_/id/34067757/max-verstappen-says-f1-salary-cap-idea-completely-wrong.

[18] Edmondson, Laurence. "Max Verstappen Says F1 Salary Cap Idea 'Completely Wrong'." ESPN. ESPN Internet Ventures, June 10, 2022. https://www.espn.com/f1/story/_/id/34067757/max-verstappen-says-f1-salary-cap-idea-completely-wrong.

[19] Smith, Luke. "F1 Agrees to Budget Cap Increase for 2022 amid Inflation Pressure." Motorsport.com. Motorsport.com - US, July 9, 2022. https://us.motorsport.com/f1/news/f1-agrees-to-budget-cap-increase-for-2022-amid-inflation-pressure/10334849/#:~:text=F1%20introduced%20its%20first%20set,on%20the%20number%20of%20races.

[20] Smith, Luke. "F1 Agrees to Budget Cap Increase for 2022 amid Inflation Pressure." Motorsport.com. Motorsport.com - US, July 9, 2022. https://us.motorsport.com/f1/news/f1-agrees-to-budget-cap-increase-for-2022-amid-inflation-pressure/10334849/#:~:text=F1%20introduced%20its%20first%20set,on%20the%20number%20of%20races.

It is evident that teams have communicated negativity towards the implementation of the spending cap, and this has gone even further to Red Bull Racing breaking the rules in 2021. The FIA announced that Red Bull breached the spending cap of $145 million in October 2021 by overspending by 1.6 percent.[21] At the end of 2022, Red Bull was fined $7 million and will have a 10 percent reduction in its allowance for aerodynamic testing for the next 12 months.

Team Spending in Regards to Winning

In Formula 1, like any other sport, some teams are much wealthier than others. For example, in baseball, a team like the Los Angeles Dodgers—who had a total payroll of $274,825,514 in 2022—is going to be paying their players much more than a team like the Cleveland Guardians—who had a total payroll of $82,057,492.[22] Although there are baseball teams that have access to more funds than other teams, it doesn't necessarily lead to how well a team will perform. This is what distinguishes Formula 1 from other sports, but it does help to have more money to spend with. This is not to say that spending more doesn't lead to being more successful in the MLB, what is trying to be said is that money and spending are more important in Formula One, if a team wants to be successful. For example, if there is a great driver for a team that doesn't spend that much money and an average driver with a team that spends much more money, that average driver will win the majority of the races because they are driving the better car despite not being the better driver.

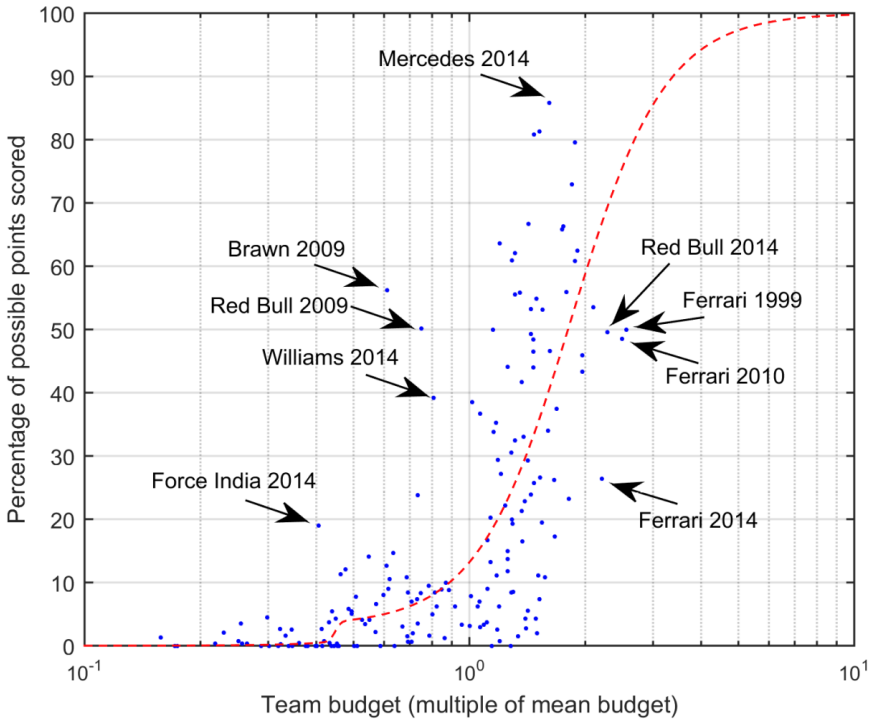
Historically, the championship has been dominated by a few teams: Ferrari, McLaren, Mercedes, Red Bull, and Williams. These are all teams that are willing to and have the funds to spend, and, as a result, teams with bigger budgets are more successful. Because of this, spending

[21] Edmondson, Laurence. "FIA Admits Red Bull Budget Cap Breach Investigation and Penalty Took Too Long." ESPN. ESPN Internet Ventures, November 18, 2022. https://www.espn.com/f1/story/_/id/35052867/fia-admits-red-bull-budget-cap-breach-investigation-penalty-took-too-long.
[22] "MLB 2023 Payroll Tracker." Spotrac.com. Accessed November 27, 2022. https://www.spotrac.com/mlb/payroll/.

priorities are very different for teams on opposite ends of the spectrum. For example, the three wealthiest teams, Ferrari, Mercedes, and Red Bull, have their spending priorities on calculating the optimal amount to invest in. There are also diminishing returns, and investing another $1 million may no longer return $1 million worth of value when it comes to performance, brand exposure, and prize money. Consequently, this determines an optimal spending point, and in economic terms, this point is when marginal revenue equals marginal cost. The consensus of top teams would suggest that this point is around an annual spending of $500 million—which includes money from sponsors and prize money.[23] In addition, lower-level teams' resources are frequently constrained by contributions from sponsors and pay drivers.

In an analysis done in 2015 to see how money predicts success in Formula 1, "teams with very low budgets, less than half the mean budget, are unlikely to score more than 10% of the available points."[24] There are numerous outliers in this range, but teams with budgets between half the mean budget and the mean budget indicate a modest improvement in winning. Although there is a lot of variation in this area, teams that spend more than the mean budget have the best chances of amassing a significant amount of points.[25]

[23] May 1, 2015 · by f1metrics · in Budgets. "How Money Predicts Success in Formula 1." f1metrics, September 3, 2015. https://f1metrics.wordpress.com/2015/05/01/how-money-predicts-success-in-formula-1/.
[24] May 1, 2015 · by f1metrics · in Budgets. "How Money Predicts Success in Formula 1." f1metrics, September 3, 2015. https://f1metrics.wordpress.com/2015/05/01/how-money-predicts-success-in-formula-1/.
[25] May 1, 2015 · by f1metrics · in Budgets. "How Money Predicts Success in Formula 1." f1metrics, September 3, 2015. https://f1metrics.wordpress.com/2015/05/01/how-money-predicts-success-in-formula-1/.



Source: F1 Metrics (2015)[26]

When looking at the scatterplot graph, it is important to note that most of the outliers are from either 2009 or 2014. This is the case because, in 2009 and 2014, Formula 1 saw big changes to the technical regulations. This demonstrated that during these periods, teams' success or failure depended more on how creatively they addressed the rules (aerodynamics in 2009 and engines in 2014) than on their sheer budgets.

Competitive Balance

Among sports, one of the main factors for the attractiveness of watching it is due to the competitive balance. Competitive balance relates to the relative strengths of the teams and individuals in a sporting event. The competitive balance is at its highest when all the teams and drivers have equivalent competitive strength. Furthermore, sports economic interest in

[26] May 1, 2015 · by f1metrics · in Budgets. "How Money Predicts Success in Formula 1." f1metrics, September 3, 2015. https://f1metrics.wordpress.com/2015/05/01/how-money-predicts-success-in-formula-1/.

competitive balance traces back to the uncertainty-of-outcome hypothesis, stating that fans want to see a close fight for the win.[27] Additionally, this is the thought that individuals are not as inclined to pay to watch sports on television or purchase tickets for events whose results can be easily predicted. This is the case because as humans, entertainment comes from the unpredictability of the sport, and without unpredictability, it essentially eliminates the primary reason why sporting events are exciting to watch and be a part of. And due to the low audience turnout, there is a terrible cycle of industry-wide poverty that results in low sponsorships and a sudden drop in revenue, and an increasing outcome uncertainty is then presumed to increase demand for watching sports.

"Outcome uncertainty relates to competitive balance as a high degree of competitive balance should, on average, increase outcome uncertainty, whereas a largely superior competitor will dominate the sport and make contest results ex-ante expectable."[28] When measuring competitive balance two popular measures can be used, the Hirschman-Herfindahl Index (HHI) and the Gini coefficient, which is a concentration index. A market with an HHI of less than 1,500 is considered a competitive marketplace, an HHI of 1,500-2,500 is moderately concentrated, and an HHI that is greater than 2,500 is highly concentrated.[29] Notably, this range is much different from mine. The way that they calculated the HHI in this article is not the same way I used to calculate HHI. Nonetheless, this shows that there is no consistent way to calculate HHI, as the method utilized in this article is merely one way. Alternatively, a high Gini coefficient is

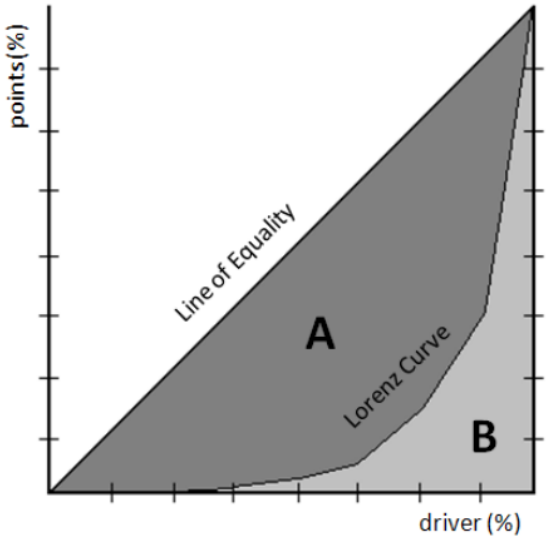
[27] Budzinski, Oliver; Feddersen, Arne (2019) : Measuring competitive balance in Formula One Racing, Ilmenau Economics Discussion Papers, No. 121, Technische Universität Ilmenau, Institut für Volkswirtschaftslehre, Ilmenau
[28] Budzinski, Oliver; Feddersen, Arne (2019) : Measuring competitive balance in Formula One Racing, Ilmenau Economics Discussion Papers, No. 121, Technische Universität Ilmenau, Institut für Volkswirtschaftslehre, Ilmenau
[29] Bromberg, Michael. "Herfindahl-Hirschman Index (HHI) Definition, Formula, and Example." Investopedia. Investopedia, November 22, 2022. https://www.investopedia.com/terms/h/hhi.asp#:~:text=How%20Is%20Market%20Concentration%20Defined,or%20greater%20is%20highly%20concentrated.

indicative of a high disparity which describes a small competitive balance, and vice versa. When looking at competitive balance, there will of course be differences and limitations in what the specific indexes measure, and, in this case, the Gini coefficient seems to be the best way of measurement.

The paper written by Thomas Krauskopf, Martin Langen, and Björn Bünger titled "The Search for Optimal Competitive Balance in Formula One" focuses on the point that there has to be an optimal level of competitive balance that maximizes the viewer's interest. The level of competitive balance is high if there are similar chances to win for all participants, such that there is somewhat of an even playing field amongst the drivers in Formula One, and vice versa for a low level of competitive balance.[30] It is also important to keep in mind that one has to take into account that there are different Formula One cars with different engines, which are driven by people of varying talents and skills. And to quantify competitive balance, the Gini coefficient could be used. The Gini coefficient index is often used when analyzing team sports such as baseball, basketball, and football. The utilization of this index is uncommon for individual sports such as Formula One, yet, it appears relevant as the Gini coefficient considers the varying points scored by drivers for their respective race finishes.

[30] Krauskopf, Thomas, Martin Langen, and Björn Bünger . "The Search for Optimal Competitive Balance in Formula One," September 2010.

Figure 1: Graphical illustration of the Gini coefficient



Source: Thomas Krauskopf, Martin Langen, and Björn Bünger (2010)[31]

Looking at the figure above, the axes are denominated in terms of the percentage of drivers and the percentage of points earned. We can see that the Line of Equality and the Lorenz Curve are illustrated. The Line of Equality represents the scenario where all drivers gain an equal amount of points, while the Lorenz Curve displays the actual distribution of the points scored.[32] If each driver accumulates points proportionally throughout the season, a perfectly balanced situation would occur. For example, 10% of all drivers gained 10% of all points and 50% of all drivers gained 50% of all points.[33] The Gini coefficient can be used to quantify the disparity when there is a situation where 50% of all drivers only have 10% of all points, indicating a smaller level of balance. Additionally, "The Gini coefficient is constructed by the ratio of area A to the sum of area A and B."[34]

[31] Krauskopf, Thomas, Martin Langen, and Björn Bünger. "The Search for Optimal Competitive Balance in Formula One," September 2010.
[32] Krauskopf, Thomas, Martin Langen, and Björn Bünger. "The Search for Optimal Competitive Balance in Formula One," September 2010.
[33] Krauskopf, Thomas, Martin Langen, and Björn Bünger. "The Search for Optimal Competitive Balance in Formula One," September 2010.
[34] Krauskopf, Thomas, Martin Langen, and Björn Bünger. "The Search for Optimal Competitive Balance in Formula One," September 2010.

As was mentioned earlier, a high Gini coefficient indicates a large disparity, which, in turn, reflects a low level of competitive balance. A high level of competitive balance may also mean that the number of TV viewers goes up because they want to see a competition that is not dominated by a single or small group of drivers. Consequently, if every competitor has an equal chance of winning, that might ensure some tension. This raises the assumption that Formula One interest is diminished by an excessively high level of competitive balance. To gauge the level of appeal, the levels of German TV viewership were utilized. The estimation of this approach involved using an Ordinary Least Squares (OLS) regression with estimators that are consistent in the presence of heteroscedasticity. The OLS regression analysis demonstrated that viewers do not have a strong and clear preference for a particular level of competitive balance. As a result, viewers have conflicted preferences when it comes to competitive balance. They desire an exciting battle at the top, but an excessive level of balance may not be appealing. Thus, finding a sweet spot between having an exciting race and not having too high of a level of competitive balance is ideal when it comes to audience viewership, according to this study. Now, we will go on to talk about Paulo Mourão and the application of the Hirschman-Herfindahl Index.

In *The Economics of Motorsports* by Paulo Mourão, when writing about the Hirschman-Herfindahl Index (HHI), he mentions how there are always weaknesses in every indicator. For instance, the HHI depends on the number of competitors. Although it is not linear, more competitors tend to produce a lower HHI, which is linked to a championship that is more fiercely contested. "However, the use of different measures (as alternative independent variables—employed here) minimizes the individual bias of resorting to only one indicator."[35]

[35] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (119)

Furthermore, "the HHI oscillates in the range [1/n;1], such that when the HHI score is 1, a single driver gets all the points, and an HHI score of 1/n means that all competing drivers had the same number of final points."[36] In motorsports, a score of 1 is extremely unlikely to occur because it requires the same racer to cross the finish line alone. A high degree of concentration being used by a few top drivers can be inferred from a very high value of the HHI, which shows a lack of competitive balance. A low HHI value is related to a more competitive championship. The equation that is applied to calculate HHI is:

$$HH = \sum_{i=1}^{n} S^2_i$$

In this equation, S^2_i represents the squared percentage of points scored by a driver *i* at the end of a season.

Table 4.1 Hirshman-Herfindahl Index (HHI) for a selection of Formula One seasons

Season	HHI (drivers)	HHI (constructors)
1960	0.084	0.278
1965	0.122	0.197
1970	0.081	0.155
1975	0.105	0.165
1980	0.110	0.195
1985	0.096	0.195
1990	0.114	0.221
1995	0.121	0.214
2000	0.155	0.292
2005	0.093	0.174
2010	0.098	0.188
2014	0.109	0.211

Source: My own calculus based on official data.

Source: Mourão (2018)[37]

[36] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (120)

[37] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (121)

Table 4.1 indicates that there is a high Pearson correlation coefficient (0.513) between the values in the column that pertains to the HHI of drivers and the column that pertains to the HHI of constructors.[38] This is the outcome of, or highly connected with, the outcome of the total points accrued by the drivers during each season for each team. It is significant to remember that a team's points were not simply the aggregate of those of its drivers throughout the seasons of the early races (1950–1979). In addition, for some seasons, for classification, only the top five results from the first half of the season and the top five results from the second half of the season were totaled. In certain seasons, only the best-placed car from each manufacturer was eligible to collect points.

Some rare circumstances can occur that would support a lower correlation. Suppose that the drivers who won had teammates who finished towards the bottom (a teammate of the winning driver finishing in the tenth position), while the teams that ranked in the middle had rivers with more balance performances (finishing in the third or fourth positions). In such a scenario, the HHI of both constructors and drivers could oscillate in non-parallel ways.[39] Table 4.1 also indicates an increasing trend between the 1960s and the 2000s, during which the HHI (drivers and conductors) exhibit high values, suggesting a significant degree of competitive imbalance (a high concentration of the points in a small group of drivers and teams). After 2000, both for drivers and conductors, the levels of this competitive imbalance indicator decreased.

[38] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (121)
[39] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (121)

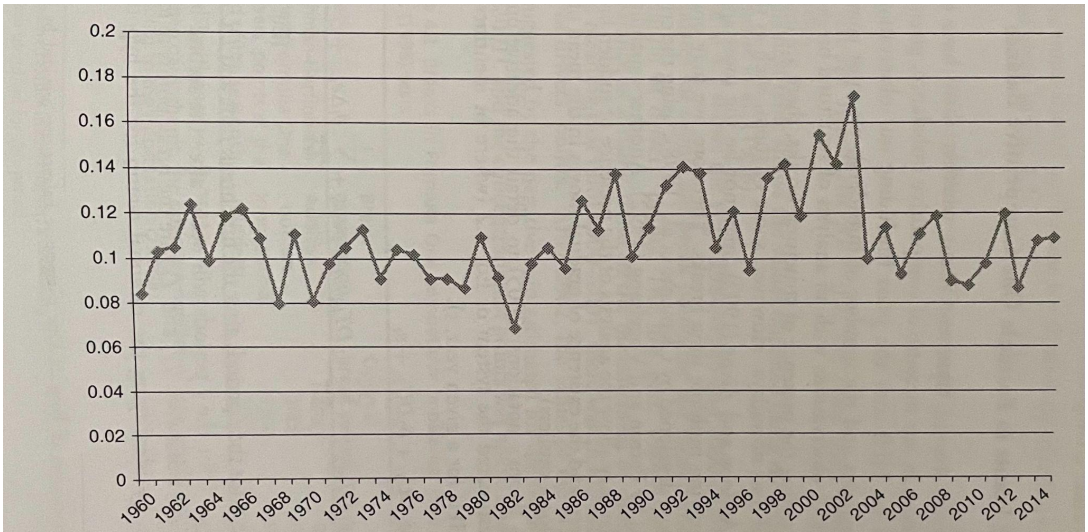


Fig. 4.3 Hirschman- Herfindahl Index for Formula One drivers' points (1960–2014)
Source: Own calculus based on official data

Source: Mourão (2018)[40]

Figure 4.3 makes all of this much easier to understand and visualize. Initially, there were consistent values between the years 1960 to 1980. Subsequently, there was an increase in values between 1980 and 2002, with the highest HHI value recorded in 2002 which was at 0.172. In 1982, the minimum HHI value was recorded at 0.069. During that season, the difference in points between the champion (Keke Rosberg) and the driver in sixth place (René Arnoux) was only sixteen points. Additionally, at the end of the season, twenty-six different drivers had earned at least one point.[41]

The high level of competitive balance during the seasons of 1981 and 1982 is evident from several other indicators. In 1981 and 1982, a total of thirty-one races took place, during which fifteen different drivers emerged as race winners. On the other hand, in 2002, this year was notable for being one of the most boring seasons because Michael Schumacher triumphed

[40] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (123)
[41] MOURAO, PAULO. "Chapter 4." Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (122)

with 144 points, securing the championship in the eleventh of the season's seventeen races. Furthermore, after the 2002 season, the HHI decreased to much more balanced values—around 0.08—which is more in-tuned with the previous patterns that were seen.

Competitive balance in Formula One is something that should be looked more into. As the sport is continually progressing, fans want to see the sport become more competitive. Formula One is, without a doubt, one of the most entertaining sports to watch, and it would be beneficial for the motorsport to find more ways to help level the playing field for teams, despite it taking some time.

Chapter 2: Literature Review

During the examination of the competitive balance in Formula One, we have come across a series of papers that have asked questions, similar to the question that is trying to be answered here, in this paper. Provided here will be a literature review to further our understanding on spending, as well as look at other factors such as technology that could have potential influences on this idea of competitive balance in Formula One.

In Formula One, constructors are spending greatly on cars and engines, and that, in essence, has had an impact on the production of winning and capital expenditures. In a paper written in 2020 titled "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry" Raghav Nitankumar Duggal writes, "Abramovitz and later Solow's discovery of technical change in the aggregate production function suggests that if Q is the output produced by a firm or an individual, then K and L represent the units of capital and labour respectively, needed to produce the Q units of output."[42] The performance of the teams, in the context of Formula One constructors, can be viewed as the outcome they generate, with the necessary factors of production taking the form of performance inputs derived from the car and human capital. However, when technology advances and educational standards rise, a shift in the production function is brought about by changes in the marginal productivity of these elements of production. "Solow uses the term 'technical change' to describe these shifts and proposes the aggregate production function as Q = F (K, L, t)."[43]

[42] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.
[43] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.

"Technical change" is the driver of the functioning of the sport. Such that the evolution of technology and competition is the result of changes in sponsorship and business within Formula One. The adoption of new technology, such as the shift toward turbo-hybrid engines and significant developments in aerodynamics and manufacturing techniques, is one illustration of this seeming evolution. Because of this, the level of expenditures per team has increased significantly since the 1970s as sponsorship money has increased. Additionally, since more established automakers like Mercedes or Ferrari are under additional pressure to outperform privately owned F1 constructors for brand image reasons, some of them spend up to twice as much annually relative to privately owned constructors. Accordingly, new technology for the development of cars, along with drivers and staff to oversee commercial operations, are the main areas of budget spending for F1 constructors.

There are also other areas of expenditure spending. Constructors in F1, such as Ferrari and Renault, have been involved in the development and production of their own components. It is worth noting that not all F1 constructors manufacture every component of their car. For example, Force India (a former team), Haas, Sauber Alfa Romeo, and a few other F1 teams outsource major components. These components consist of the engine, gearbox, and more. Moreover, teams can accomplish this by either sourcing components from their competitors, such as Ferrari, Mercedes, and Renault, or from a third-party constructor like Honda, who is not involved in competing.

It is obvious that R&D spending varies amongst constructors, despite the fact that seasonally specific regulations for outsourcing and in-house production can change over the seasons. "An analysis by Formula Money (n.d.) reveals that approximately 25% of a

constructor's budget can be utilised on R&D spending, comprising mainly of facilities like wind tunnel and track testing."[44] Everdingen et al. (2019) discovered that F1 constructors that possess these facilities tend to have higher R&D spending compared to those without them. Consequently, these teams resort to outsourcing components. They also demonstrate that constructors who allocate a significant portion of their budget to R&D tend to reduce their spending on branding activities, such as advertisements and social events. Additionally, while their research shows that branding activities do produce a positive return on investment, constructors that spend a lot on R&D typically outperform their rivals who do not spend as much.

"As described by Ployhart and Moliterno (2011), managerial skills, abilities and experiences are considered as human capital."[45] The analysis conducted by Formula Money (n.d.) also indicates that approximately 25% of a constructor's budget is allocated to salaries for the team, drivers, and director salaries.[46] Thus, human capital constitutes the foundation for innovation and the operation of the team in Formula One. Firms that are highly innovative and efficient can save both time and money, thereby gaining a competitive advantage over their rivals and improving performance. Furthermore, F1 teams put a lot of trust and effort into different parts of the team. These include relying on the skills and expertise of engineers to build the cars, on team principles for making strategic decisions, on drivers to perform well on the track, and on the pit crew to construct and fix the cars. It is apparent that technology and human capital play a considerable role in the performance of an F1 team. It is also evident that investments in R&D

[44] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.
[45] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.
[46] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.

and skilled staff demands high-budget investments. Just as teams were spending a lot of money on cars and engines, the implementation of a budget cap limits the ability of teams to spend as much money as they can on their cars.

As we have seen how teams like Mercedes have had the ability to spend much more money compared to the smaller-tiered teams, a budget will help reduce the spending on cars and engines. Looking at "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," a panel dataset was created utilizing a variety of Formula One driver and constructor performance metrics in order to examine the effects of the budget on the performance of F1 teams.

The data was compiled during a 20-year span from 2000 to 2019. It involves all driver and constructor data that was taken from the official FIA website. The data includes performance indicators for every driver per season. It uses metrics such as points scored, podiums attained (top-three finish), number of pole positions during race qualifications (the fastest car during qualification), total race wins, number of fastest laps, number of races the driver did not fully finish (DNFs), and number of disqualifications (DSQs). "For constructor's budget data, numerous sources were used such as journal articles, reports, and news articles like CNN recognised motorsport magazines like Racefans, Autosport, F1technical, and Team Liquid."[47] The empirical evidence in this work examines the driver, team, and fixed budget effects on team performance in order to investigate the impact of budget on team performance. Additionally, "the average budget spent per season for constructors has constantly increased from 2000 to 2019. A

[47] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.

reason for the increase can be associated with the rapid developments in automobile technology, and increased sponsorship money."[48]

Several models were presented to calculate the impact of budget on team performance in this paper. In this model, the variable 'c_relbudget' is treated as a constant across all teams. As a result, while the model does not produce a coefficient for budget, it does not have an impact on the explanatory ability of the driver and fixed effects. Because the points system has undergone multiple changes over the years, it is challenging to compare the performance of teams based on the absolute number of points scored per season. Therefore, the variable 'c_relpoints' (relative points) is calculated by dividing the actual points scored by a team in a season by the average points scored per season.

Table 5: Regression results

Dependent Variable: c_relpoints	Model 1 (No FEs)	Model 2 (Team FE)	Model 3 (Driver FE)	Model 4 (All FEs)	Model 5 (Constant budget)
c_relbudget	1.63*** (0.08)	1.44*** (0.16)	1.34*** (0.12)	1.32*** (0.16)	-
Constant	-0.60*** (0.06)	0.22 (0.35)	0.82 (0.61)	-	2.67
Observations	494	494	494	-	-
F-test	375.95***	83.36***	130.93***	2.25***	5.81***
R-squared	0.51	0.66	0.67	-	-

*** Denotes significance at the 1% level and parenthesis denote standard error

Source: Duggal (2020)[49]

[48] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.
[49] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.

As it stands, the budget coefficient is 1.63, which means that if the budget is raised by 1%, points should rise by 1.63%. Model 2 incorporates team-fixed effects to track the effect team personnel have on their team's performance. When team fixed effects are taken into account, the budget coefficient decreased from 1.63 to 1.44, which suggests that a 1% increase in budget resulted in a 1.44% rise in points.[50] The budget influence on the anticipated points earned by a team per season is lessened when team fixed effects are taken into account, which accounts for the decrease in coefficient. This is clearly demonstrated by the rise in R-squared from 0.51 to 0.66, which shows that the second model fits the budget effect on team performance more closely. In Model 3, the team fixed effects are excluded, and the driver fixed effects are included instead, as the resulting coefficient is 1.34. Additionally, the fact that Model 3's coefficient is lower than Model 2's shows that driver effects outweigh team effects.

In Model 4, both driver and team-fixed effects are included. The results demonstrate that adding driver and team fixed effects minimize the impact of budget on points achieved, as the coefficient of model 4 declines to 1.32. By including the driver and team fixed effects, it makes sense to anticipate that the coefficient will fall. The coefficient dropping from model 1 to model 4 is consistent with the hypothesis that stronger human capital positively affects team performance. The models given during the investigation show that driver and team-fixed effects have a significant impact on a team's success. This shows that teams with the biggest budgets are typically teams that do better than those who do not have strong financial power as employing skilled human capital demands financial investments. Additionally, it has been observed that talented drivers who win world championships do, in fact, have a favorable impact on their

[50] Duggal, Raghav Nitankumar. "Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry," 2020.

performance, so it is not unexpected that the FIA has set bans and changed the rules to include budget limitations. The spending cap of 2022 is intended to restrict R&D expenditures and eliminate the financial advantage certain teams currently enjoy over others, hence, enhancing the competitiveness of underfunded teams.

In the world of Formula One, there is a continual contest between the utilization of technology to improve performance and the application of raw driving ability. This brings up the topic of increased strategies leading to competitive balance, looking at strategy, skill, human capital, and experience of the drivers. The paper titled "Formula One Racing: Driver vs. Technology" written by Stephanie Young, brings up a couple of important questions including "At what point does such an advance of technology diminish the role of the driver?"[51] and "At what point does regulating technology impede the development of technology for consumer cars?"[52] Made available in 2009, Formula One instituted the possibility of using a mechanical kinetic energy recovery system, which can harvest energy from the car's deceleration and store it for later use. The advent of the mechanical kinetic energy recovery system has sparked discussion about whether these technologies diminish driver talent and have a negative impact on the integrity of Formula One. This is but one illustration and is fairly insignificant in comparison to computer-aided braking systems, which prevent the display of driver talent.

Competition between drivers, who control the car, and constructors, who create, produce, test, and race the car, has always been encouraged in Formula One, but there have been a lot of worries that advanced technology is essentially taking the place of the driver as the driving force. The FIA has also banned various technologies on the grounds that they substitute driver talent,

[51] Young, Stephanie. "Formula One Racing: Driver vs. Technology." *Intersect* 5 (2012).
[52] Young, Stephanie. "Formula One Racing: Driver vs. Technology." *Intersect* 5 (2012).

and that technology has shifted to be secondary to the driver in order to challenge the dominance of technologies. One example of a technology that was banned was traction control. This "is an electronic system that works with the traction circle of the tires in order to deliver the 'maximum mixture of acceleration and cornering grip.'"[53] Another example of a technology that was banned was the anti-locking braking system. "The brakes work by squeezing a rotor, moving kinetic energy, and slowing the car down through friction, releasing heat and light as byproducts."[54] "Anti-lock braking systems (ABS) are electronic systems that control force input into each of the four brakes at the four wheels of the car, eliminating brake lock regardless of driver input into the brake pedal."[55] According to the FIA, some of the bans have resulted in Formula One cars being less advanced technologically than regular cars, and this has emphasized the skills of the drivers.

As there are technologies that can limit a driver's talents, there are also technologies that can highlight skilled drivers. A couple of examples is a drag reduction system (DRS) and an adjustable rear wing. Consequently, these technologies can distinguish outstanding drivers from modest drivers. "Both the DRS and the adjustable rear wing actually improve performance and speed, but only when used at the right speed, at the right part of the track, and with the correct combination of circumstances."[56] DRS and the adjustable rear wing cannot be controlled remotely by the team and must be activated and deactivated by the driver. Thus, these tools are used to distinguish quick and adaptable drivers from those who are deemed as less talented. There are certainly good and bad things about technological advancements and the FIA and

[53] Young, Stephanie. "Formula One Racing: Driver vs. Technology." *Intersect* 5 (2012).
[54] Young, Stephanie. "Formula One Racing: Driver vs. Technology." *Intersect* 5 (2012).
[55] Young, Stephanie. "Formula One Racing: Driver vs. Technology." *Intersect* 5 (2012).
[56] Young, Stephanie. "Formula One Racing: Driver vs. Technology." *Intersect* 5 (2012).

Formula One want to make sure that technology does not hinder the driver while retaining technological progress.

Chapter 3: Empirical Work and Analysis

Methodology

The data on Formula One was collected (via databases, websites, and articles). Then the data was put into Excel spreadsheets (to make it look more presentable), and with the data that had been accumulated, it was moved into STATA to run regression analysis to test the hypothesis. Through running an empirical analysis, it aided in determining if spending has had an influence on competitive balance, as well as if there were other possible factors that could have potentially affected competitive balance in Formula One, more specifically if the addition of the spending cap would have a positive or negative effect on competitive balance.

The main data source was compiled from https://www.statsf1.com/en/saisons.aspx. This website had information on Formula One Racing from 1950-2023. The website provided all sorts of data, which included drivers, constructors, engines, tires, Grand Prix, circuits, and more; but this paper primarily focused on driver and team statistics, which was useful to some extent.

The primary data included total points won (from 1960-2022) for both drivers and constructors (teams), as well as providing names of different drivers and teams for the specific year, all of this going to help formulate data to run with STATA. From 1960-2022, it involved a wide range of data. This is the case because since the start of Formula One racing, the number of drivers, constructors, and Grand Prix has fluctuated, and the points system has changed throughout its time. As a result, the points distribution, for both drivers and teams, was not consistent throughout the years, as there may have been years where teams and drivers had substantially more points compared to other years.

Although this website was very helpful in providing statistics on Formula One to help test the hypothesis, the difficult part was finding data on spending. The compilation of data was difficult because there was no database that contained all of the necessary information. This empirical analysis would have run a lot smoother if Formula One had a public database that provided all of its data from the start of it. And because of this, it was difficult to find historical data on team spending, as there was no public database.

The process of gathering data involved continuous searching to find the information and data that was desired. It was a frustrating experience because there was no public database that provided everything such as team spending, budgets, teams and drivers who won in a given year, total points (drivers and teams) in a given year, amount of drivers and teams for that year, the total number of circuits, engine, and car, which made it difficult, thus, the information is being pulled from multiple sources.

All of this data and information was gathered to help the empirical analysis by deciding on what variables and what data we would want to be added when running the regression analysis. This meant that all of the data that was compiled had to be documented in Excel. This involved tedious work having to input the information by hand, and constantly copying and pasting data into Excel.

The information that the analysis ended up using was focused from 1960 to 2022. I found info on the number of drivers, the number of constructors, the total points, and the number of circuits. With this information, regression analysis was run to test the hypothesis that the spending cap, first implemented in the 2022 season, will have a positive effect on the competitive

balance in Formula One, thus creating a more level playing field between the top-tier and lower-tier teams.

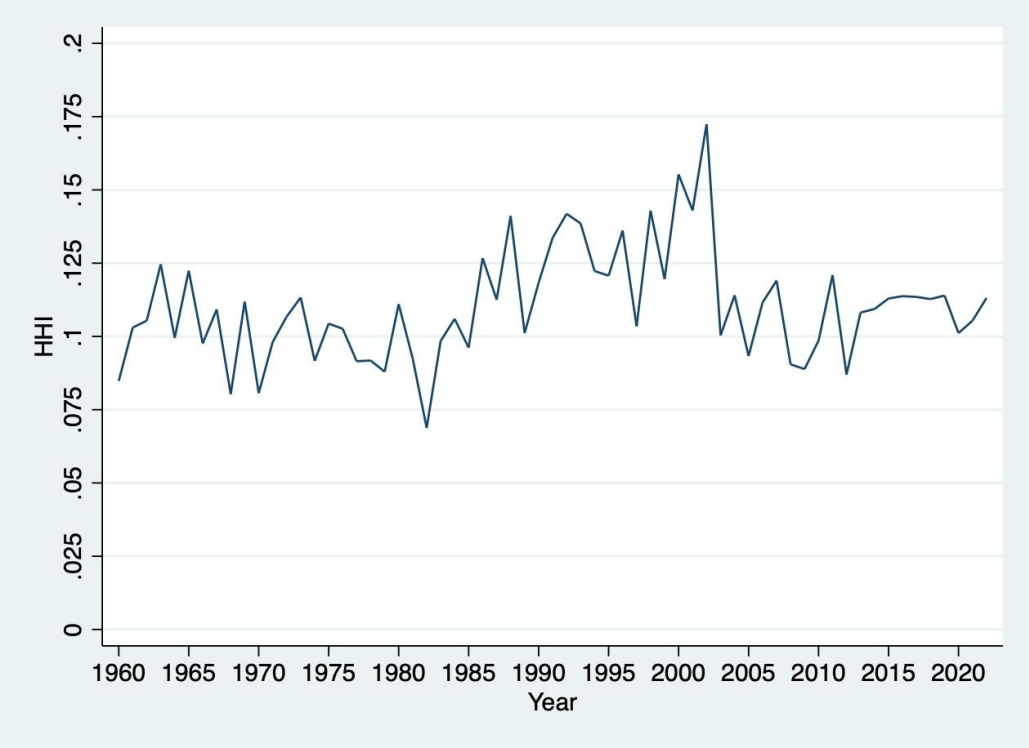
On average (looking at Table 1), the HHI over the 62 years of data is .1101322, and there are approximately 36 drivers. In order to better interpret this data, we can use Paolo Mourão's equation regarding the measurement of HHI. The range of possible HHIs is from X to 1, in which X would be considered a low HHI value which is related to a more competitive championship.

It is difficult to interpret this number in isolation. If we have a perfect balance, the HHI would be X: If we were to apply Mourão's equation, the HHI measurement would be .0007635 = $1/(36.19048)^2$. Although this number is quite different from the mean HHI that is presented in the table, this value (.1101322) is closer to 1/36 than it is to 1. Thus, one could say that this is reasonably competitive because an HHI of 1 would indicate that a single driver is winning all of the points, hence 1/1 = 1, which is highly improbable in motorsports and a complete lack of balance. The total amount of circuits has also increased substantially, as well as the number of constructors and drivers, which is meaningful for the increase in the total amount of points.

Trends in HHI Over Time

It would be in our best interest to look at the trends in HHI over time to see how similar or different the one we got is to Paulo Mourão's, which is represented in his book *The Economics of Motorsports*.

Figure 1: HHI Trend (1960-2022)



Source: Author's Calculations

The graph above shows the HHI trend from 1960 to 2022. Looking at the graph, there are a few peaks and troughs, but overall, it is relatively the same throughout. From 1960 to 1985 the trend appears to be relatively flat with not that much movement staying around .075-1.25. Then between the years of roughly 1985 to roughly 2005, there is a sudden uptick in the Hirschman Herfindahl Index. Towards the latter half of the increase in HHI, it skyrocketed to almost a staggering 1.75, the highest that it has ever been. Between the years 2000 to 2005, the HHI trend fell dramatically to near levels that were previously seen and eventually flattened out, but the levels were slightly higher than before, prior to 1985.

Looking at the years between 1985 to 2005, it is clear that the HHI trend is much higher than both the preceding years and the following years. A question could be asked here on what

could have possibly impacted this upward trend. After some research, what potentially could have been some key factors were the major improvements in technology during this span of time, as well as the new rules and regulations that were put in place. These improvements in technology and regulatory changes may have affected particular teams both positively and negatively, thus, that is why the HHI trend is much higher.

Although the technology was improving prior to these years, it wasn't until the late 70s and early 80s that new technologies and innovation, such as the turbo engine was introduced by Renault and Lotus. It was mainly manufacturer-supported teams (Renault, Ferrari, and Alfa Romeo) that used this engine, which caused some controversy with the other teams. On the other hand, many of the other teams used the Ford-Cosworth DFV engine, which was introduced a decade before. These two groups were represented by the Fédération Internationale du Sport Automobile (FISA), at the time an autonomous subcommittee of the FIA, and the Formula One Constructors Association (FOCA). One group advocated for a strict limitation on ground effect, which refers to a set of techniques used to create downforce. Furthermore, there were financial factors to consider, with larger constructors enjoying unrestricted budgets, while smaller teams sought after a greater share of Formula One's earnings to maintain their competitiveness.

Nelson Piquet's championship win in 1983 marked the first time a turbocharged engine was victorious. And in 1979 and 1980, Renault demonstrated the superior efficiency of turbocharged engines.[57] The cars equipped with turbocharged engines were quicker on almost all of the high-speed and high-altitude tracks. And by 1982, it was clear that turbocharged engines were the best on the market when it came to on-track competition. By the 1983 season, almost all of the teams used the engine except for one team, Tyrrell.

[57] "History of Formula One." Wikipedia. Wikimedia Foundation, April 28, 2023. https://en.wikipedia.org/wiki/History_of_Formula_One.

In 1989, turbo-charged engines were banned and new regulations were put in place. In the early 90s, the world started seeing the introduction of electronic driver-aids. The active suspension (pioneered by Lotus in 1987), semi-automatic gearboxes (Ferrari in 1989), and traction control (Ferrari 1990) all enabled cars to reach higher speeds, provided that teams were willing to spend the money.[58] In due time, many of these aids were banned in the 1994 season because it was impeding true driver talent and skill. The year 1994 was a hectic one. It involved crashes that were so bad that drivers ended up dying on the tracks. Due to this, it made the FIA more diligent in coming up with important changes. These changes were made to ensure the safety of the driver, despite the chaos that was happening in the sport during this period of time.

As the 1998 season approached and beyond, all teams had a V10 engine, as it became the most popular engine used. In the early 2000s, several prominent automobile manufacturers entered the world of Formula One, while technical regulations underwent changes that included the banning of two electronic driver assistance systems. Additionally, at the end of the 2004 season, Ford Motor decided to pull out which exposed some vulnerabilities with some of the smaller teams, as they were put in a poor situation.

Comparing the HHI trend to that of Paulo Mourão's, both trend lines appear to be comparable. This indicates that the findings in this empirical analysis paper and in Mourão's book when examining the HHI trend, are consistent and replicable. This would be helpful for people who would want to progress on this very idea of competitive balance in Formula One. While the sport becomes more and more popular, popularity can only do so much, thus, finding ways to make the sport more competitive would be in the best interest of the motorsport.

[58] "History of Formula One." Wikipedia. Wikimedia Foundation, April 28, 2023. https://en.wikipedia.org/wiki/History_of_Formula_One.

Additionally, as we can see, around the time the budget cap was implemented the HHI trend spiked down but then there is a sharp increase. However, looking at the graph, it does not tell the whole story. Examining the graph is not merely enough because it can only reveal certain trends, as there could potentially be other aspects that the graph, itself, cannot visually depict or explain to us.

When looking at the HHI trend, there could be several reasons why the graph looks that way. In statistics, there is a variable called a "confounding" variable, which influences the dependent and independent variables. And because there are confounders, the trend is not causal. Potential confounding variables within this measurement that could have an effect could be the total number of drivers or the total amount of constructors in a given season. This could have an effect on the HHI because more drivers and more teams could mean that it is harder to win as many points comparatively speaking to lesser amounts of drivers and constructors. As a result, drivers are tallying up similar amounts of total points in a season because the probability of winning is lower. With differing amounts of constructors, this could lead to teams acting differently when it comes to tactics, which could impact the place that the driver will come in and, subsequently, the number of points that a driver on a specific team could win.

Another confounding variable could be the number of races in a given season. Over the past years, the number of circuits has constantly changed, and this could possibly have an effect on the HHI trend. This could be the case because, similar to having more drivers and more constructors, having more circuits or fewer circuits means that drivers can accrue more or fewer points that season. Due to this, there could be years where the points distribution could be more

equal throughout drivers because there were higher amounts of drivers, and the case could be where the points distribution is less equal throughout.

An additional confounding variable could be the points system used in the given season. Like everything else in Formula One, since the years it started, the points system has changed. There have been years where it has been more difficult to get points because there were fewer spots for drivers to win points and vice versa where there were more spots for drivers to have a chance of accumulating points. For example, up until 2002, only the top 6 drivers received points and between 2000 to 2009, a maximum of 10 points was given to the winning driver. After 2002, the top 8 drivers were now able to receive points, and this was done to encourage mid-tier teams to make the competition closer. From 2010 on, the race winner won 25 points with the top 10 drivers being able to score points, and additional changes were made that further created points gaps between drivers and teams.

One last confounding variable could be technology. Throughout the years, technology has gotten more complex, and with the complexities, it has become more advanced. As a result, technology could possibly have an impact on the HHI trend because advancements in the sport mean that vehicles and the design of vehicles have changed throughout time. Cars have gotten faster, and due to cars getting faster, that could be conducive to particular drivers and teams progressing more than others. Initially, to quantitatively measure technology from the years 1960 to 2022, the data had technology starting with a 0 in the year 1960, then went up by one in the following year. And by doing this, this numbering system indicates that with time, technology has improved. However, we thought that a better way to represent technology was to square the

term. Squaring the term meant that it goes up exponentially, which is a more useful way to show improvement in technology, as with time technological progress increases exponentially.

Due to these confounding variables, what the HHI trend illustrates may not paint the full picture. Within the dataset, there were potential confounds that made the HHI trend look that way. These confounders could consist of differing amounts of drivers, differing amounts of teams, differing amounts of races, as well as the changing of the points system.

Descriptive Statistics

We will now go on to talk about the descriptive statistics as shown in the table below.

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
HHI	63	.1101322	.0190132	.0687747	.1724064
totalcircu~s	63	15.79365	3.327106	8	22
totalconst~s	63	13.36508	3.597946	9	23
totaldrivers	63	36.19048	14.05044	20	91
Total	63	737.7063	679.2341	196	2350
trend	63	31	18.3303	0	62
BudgetCap	63	.031746	.1767314	0	1

Source: Author's Calculations

Illustrated in the table is the median for HHI, total circuits, total constructors, and total drivers, which are all close to the mean. Since the HHI median (.1092058) is smaller than the mean (.1101322) that means that the distribution is skewed to the right. For total circuits, the median (16) is greater than the mean (15.79365), which indicates that the distribution is negatively skewed or skewed to the left. The total constructors' median (12) is less than the mean (13.36508), and the total drivers' median (35) is also less than the mean (36.19048). On

the other hand, the total points median is considerably different from the mean. The median (416) is much smaller than the mean (737.7063), which reveals that it is heavily skewed. This shows that the total amount of points has a strong influence on HHI, which will be talked more about later.

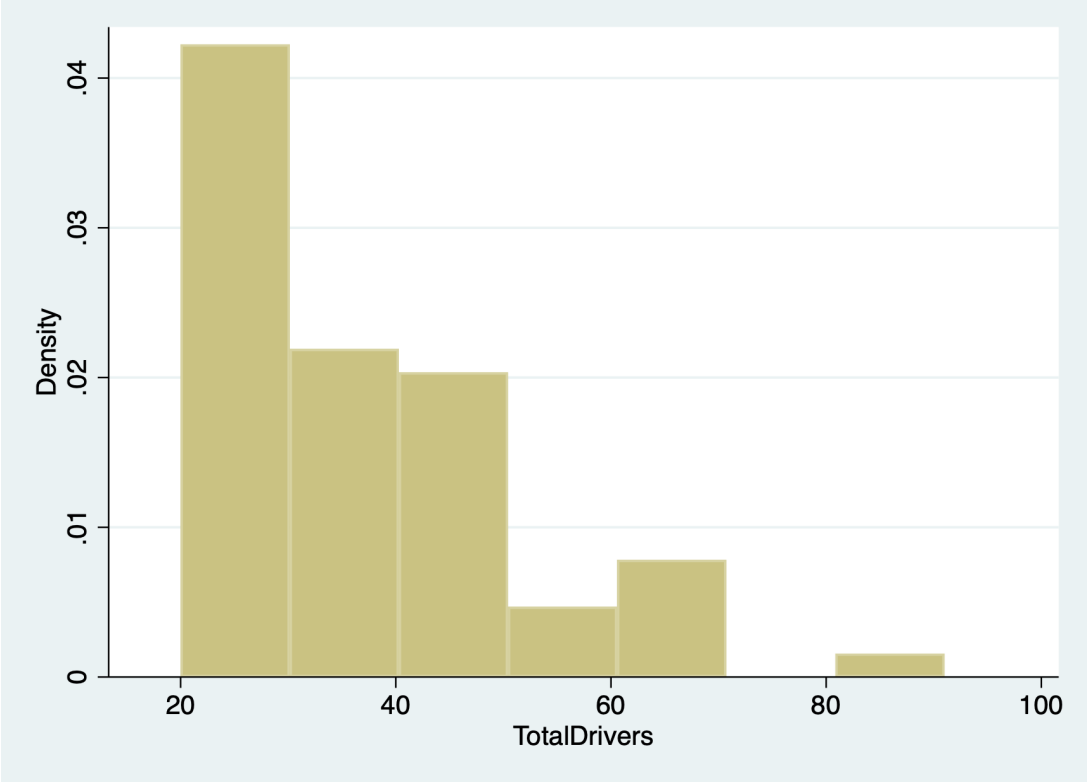
We can also look at the standard deviation for all variables that are used. Two notable variables to talk about are HHI and total points. The standard deviation for HHI, as shown in the table, is .0190132. Because the standard deviation is low, almost zero, this tells us that the data points are clustered around the mean. Whereas, we can look at the standard deviation of total points (679.2341) and relate it to the mean (737.7063) and see that there is a large difference between the two, which suggests that the data points are spread out and that there are outliers affecting the data. Total circuits have a standard deviation of 3.327106, total constructors have a standard deviation of 3.597946, and total drivers have a standard deviation of 14.05044. This is to say that HHI has decreased with time. A more competitive balance is better than a less competitive balance, which means that the optimal level would be 1/n, n being the total number of drivers in a given year. It is also important to note that since 1960, the total number of drivers and constructors has gone down, however, the total amount of points has gone up. This could be conducive to the change in the points system over the years. As we have discussed the descriptive statistics of the variables, next we will incorporate regression analysis to further examine this empirical study.

Distributions

Before moving on to the regression, I investigated the characteristics of the data. Here, we will be examining the effects of using the logarithm of various variables that are used in the

analysis. Logging variables improves the fit of the model by transforming the distribution of the features into a normal curve. It can make skewed data more normally distributed. Below we can see the influence that logging variables have, and it can help us with considering which variables to keep the same and which to log.

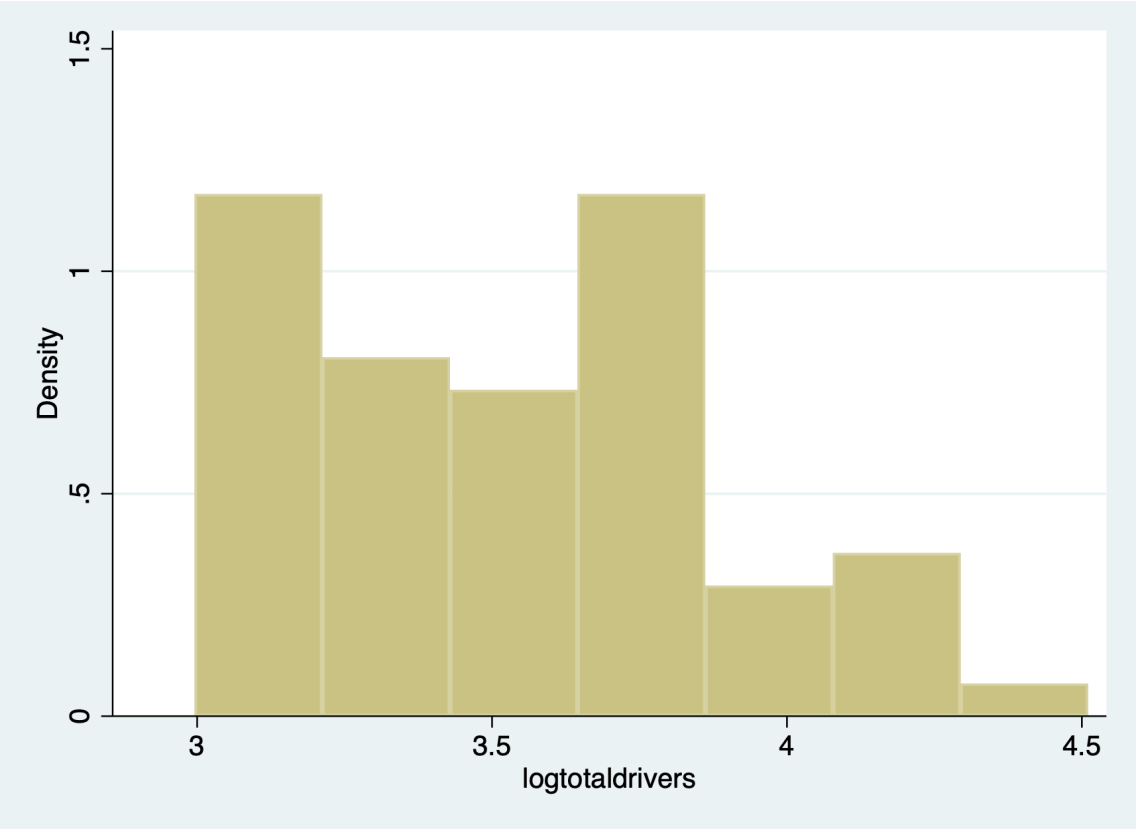
Figure 2: Histogram of Total Drivers



Source: Author's Calculations

Here, the distribution for total drivers is not optimal. We can see that the distributions are left skewed, and we would like to see a normal curve distribution, however, that is not illustrated here. Since it does not show a good distribution, we thought that it would be good to log the variable to see if the distribution is better behaved after.

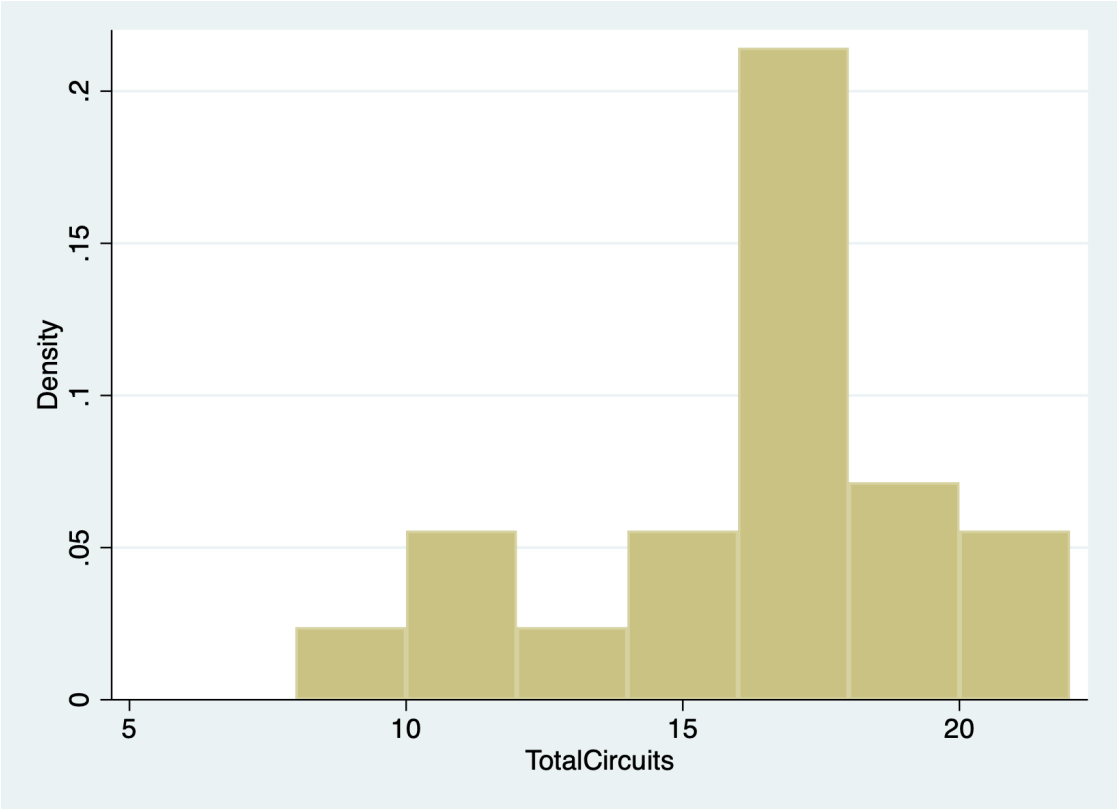
Figure 3: Histogram of Logged Total Drivers



Source: Author's Calculations

We can see that by logging total drivers, the distribution appears to look a little nicer. The distribution is less skewed to the left which is a better indicator. Thus, we will consider using this logged variable when running for regressions.

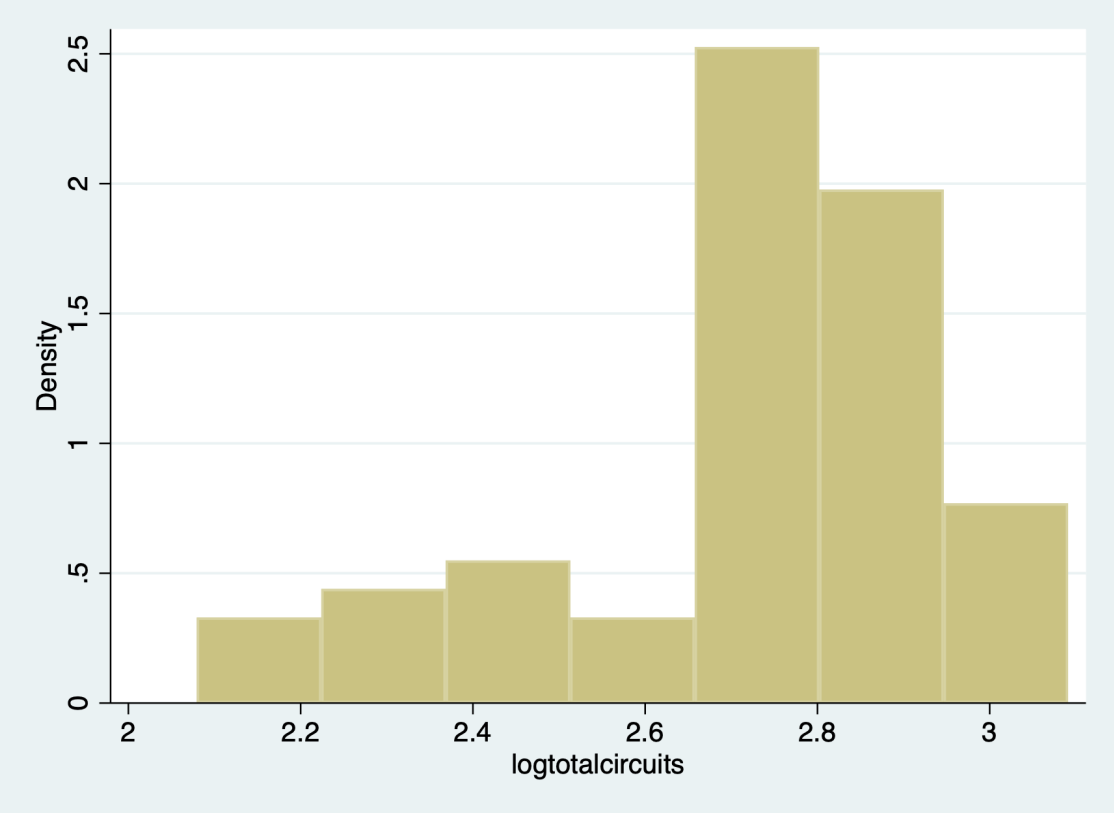
Figure 4: Histogram of Total Circuits



Source: Author's Calculations

The distribution for total circuits looks well-behaved, it is decently distributed, but it would still be good to see if logging this variable creates a more pleasing distribution.

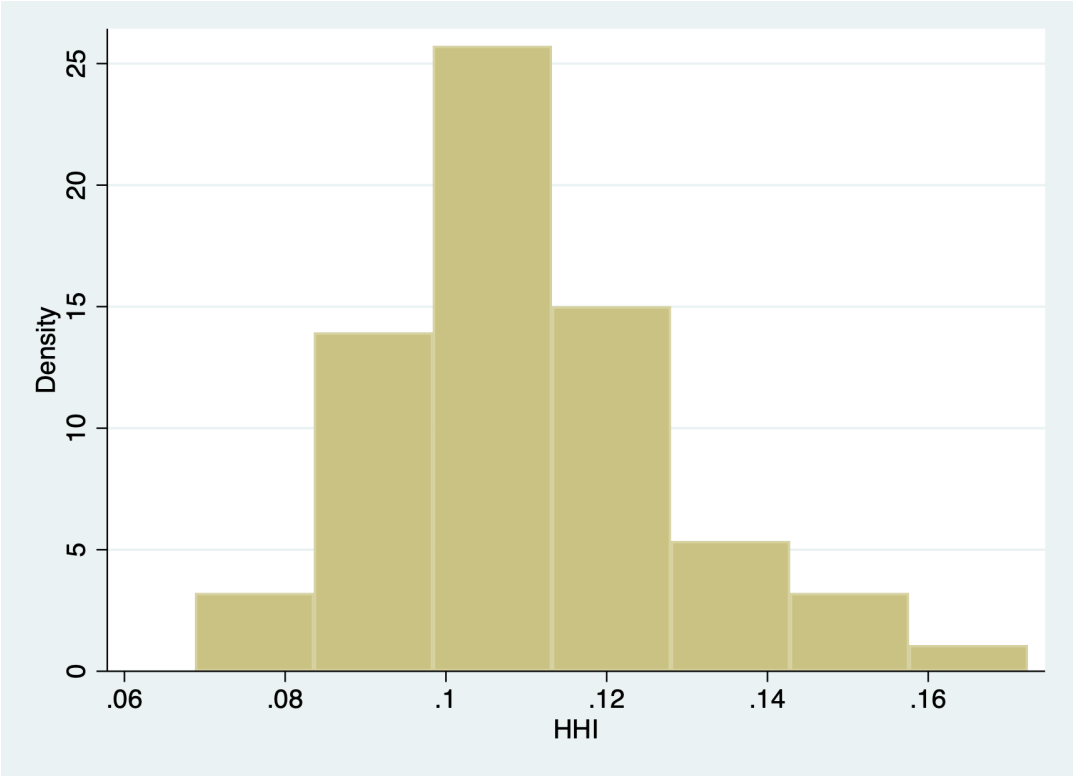
Figure 5: Histogram of Logged Total Circuits



Source: Author's Calculations

As shown above, logging the variable total circuits has a slightly better-behaved distribution. Because this indicates a slightly better distribution, the logged variable could potentially be used for the regression.

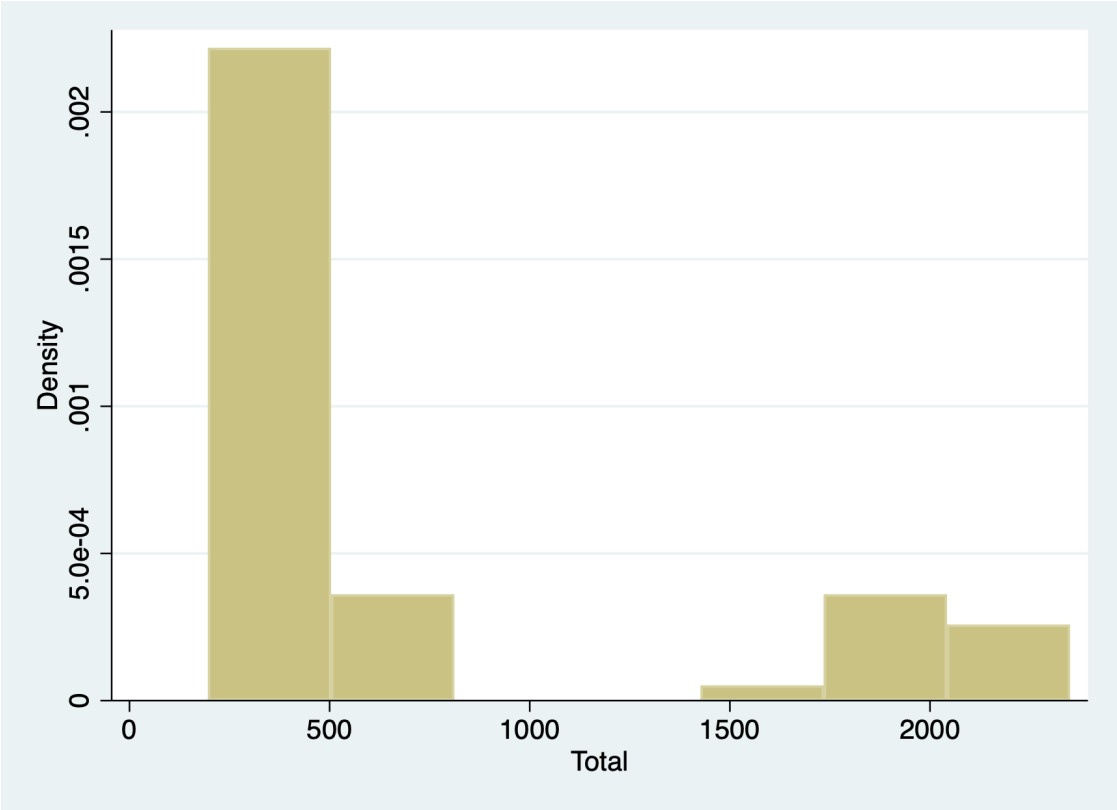
Figure 6: Histogram of HHI



Source: Author's Calculations

The distribution for the variable HHI is ideal. We can see the very defined normal curve, which indicates that there is a good distribution between the points. Since the distribution looks like this, we do not have to log the HHI variable.

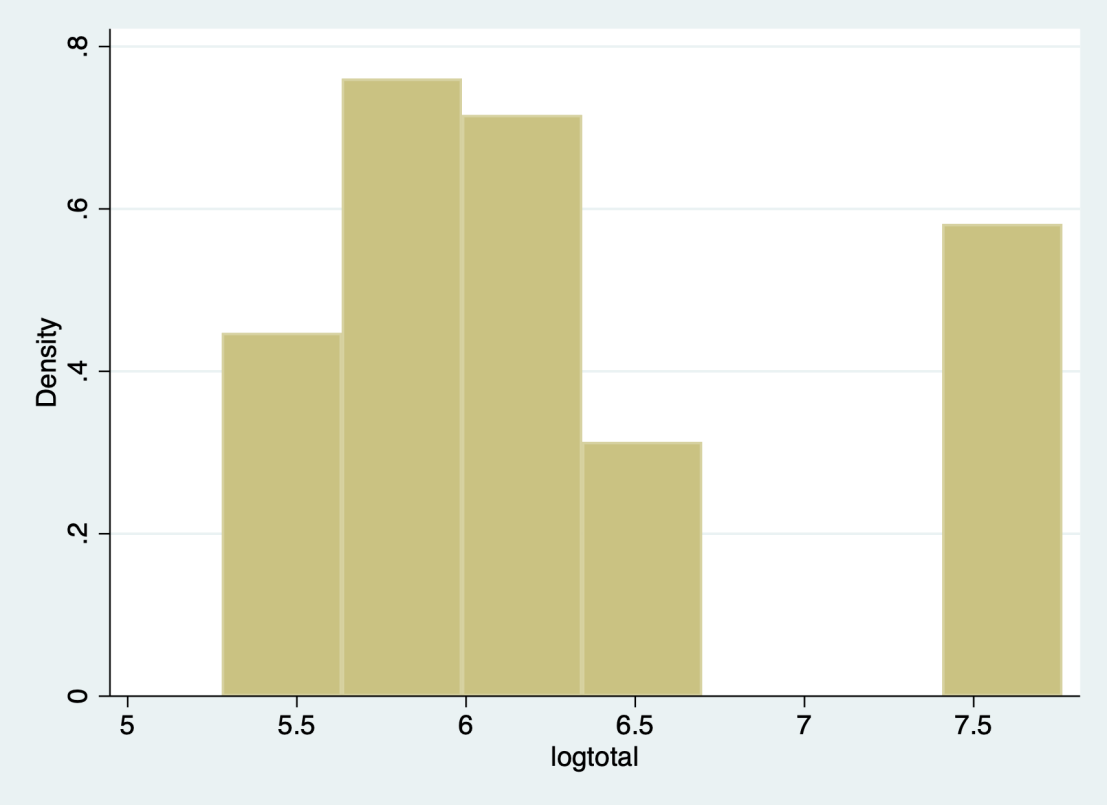
Figure 7: Histogram of Total Points



Source: Author's Calculations

The distribution for total points is not optimal, however, it does make sense why it looks like this. There have been quite a few amounts of years where the total possible points were quite low, which was due to the points system. It wasn't until recently, due to the change in the points system, that made it easier and more likely for teams to be able to get more points because there were more opportunities.

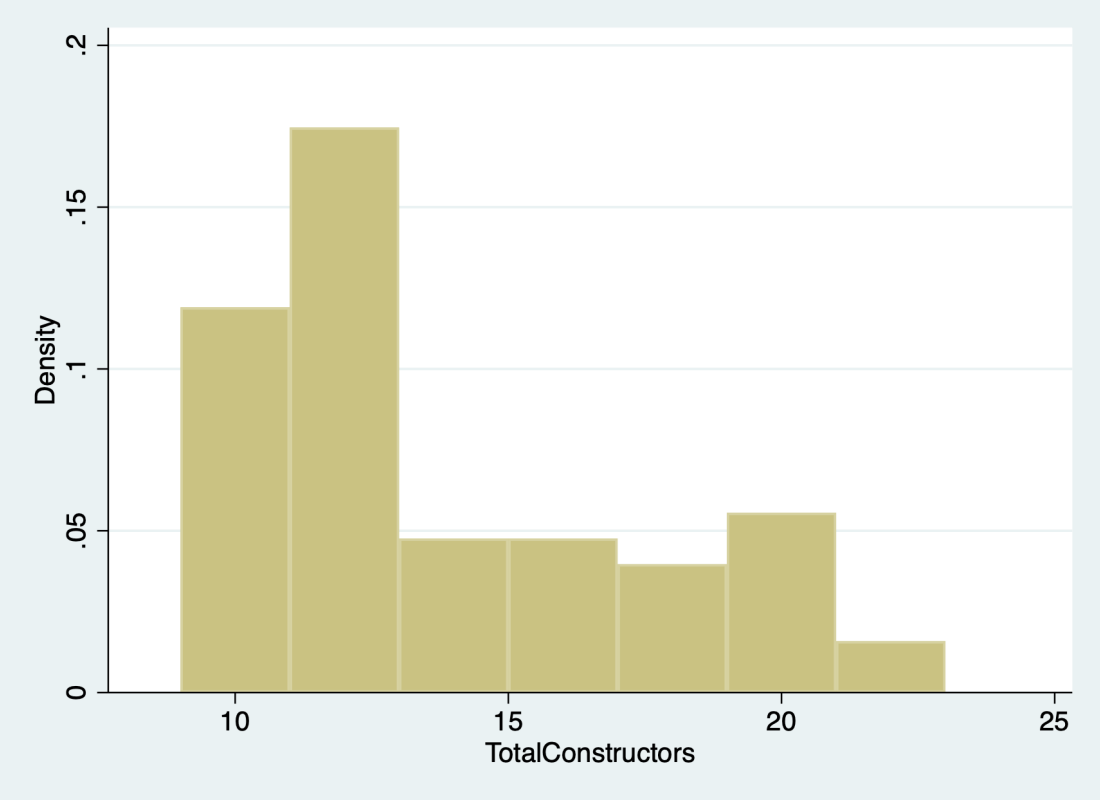
Figure 8: Histogram of Logged Total Points



Source: Author's Calculations

Here, by logging total points it appears that there is a more normal distribution. Since the distribution shows more of a normal curve, we will use the logarithm of total points in our regression analysis.

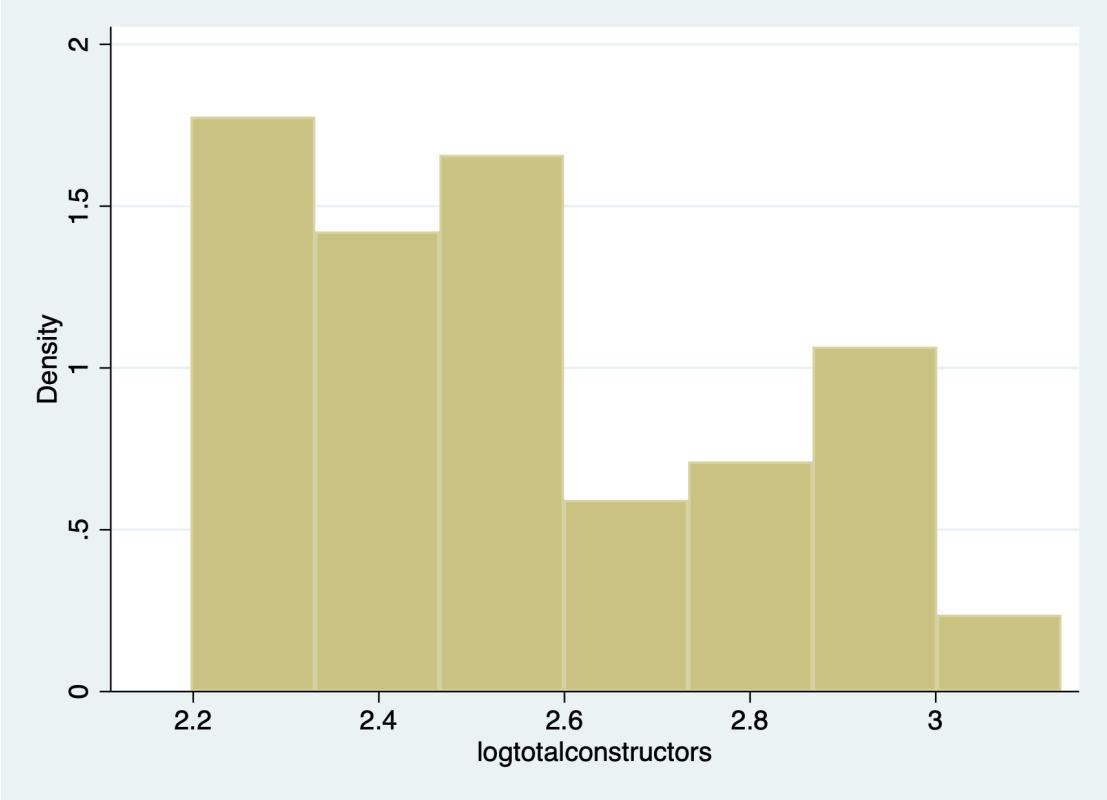
Figure 9: Histogram of Total Constructors



Source: Author's Calculations

The distribution for the variable total constructors looks admirable, as the points are distributed rather evenly. Nevertheless, it would be helpful to log the variable to see if the distribution looks more normal.

Figure 10: Histogram of Logged Total Constructors



Source: Author's Calculations

Logging the variable does little to the distribution, so we will not need to log total constructors. Nevertheless, it was still good to see if logging the variable total constructors would present a more normal distribution.

Multicollinearity

As we looked at the distributions for all of the potential variables, we saw how logging particular variables made the distributions appear more normal. Consequently, it would be beneficial to check for multicollinearity between the variables to see if there are any variables that we could exclude because they are highly correlated.

Table 2: Pairwise Correlation

	HHI	total~ts	tota~ors	totald~s	logtotal	trend	Budget~p
HHI	**1.0000**						
totalcircu~s	**0.1454**	**1.0000**					
totalconst~s	**-0.1979**	**-0.1661**	**1.0000**				
totaldrivers	**-0.2845**	**-0.7189**	**0.6297**	**1.0000**			
logtotal	**0.0047**	**0.8616**	**-0.3796**	**-0.6625**	**1.0000**		
trend	**0.2355**	**0.9174**	**-0.4231**	**-0.8248**	**0.8988**	**1.0000**	
BudgetCap	**-0.0086**	**0.3405**	**-0.1707**	**-0.1908**	**0.3557**	**0.3037**	**1.0000**

Source: Author's Calculations

The pairwise correlations show us how correlated the variables are. To better contextualize this table, an absolute value between 0 to 0.3 are considered weak correlation, 0.4 to 0.5 are considered moderate, and anything between 0.6 to 1 is strongly correlated.[59] Accordingly, a correlation of 1 means that there is a PERFECT positive correlation and -1 means that there is a PERFECT negative correlation.

We wanted to see if the characteristics of the data might meet the assumptions of Ordinary Least Squares (OLS) regression. The main focus was to see if there is multicollinearity between the independent variables. Looking at the table, total drivers and total circuits have a correlation of -0.7189 which makes sense because with time the number of drivers has decreased and the number of circuits has increased. We can say the same with the trend (technology) and total circuits with a correlation of 0.9174 because as technology improves, the total amount of circuits has also increased. Total drivers and total points have a correlation of -0.5606, which is moderate, but this makes sense because as the number of drivers has decreased, the total amount of points has increased. Also, trend and total points have a correlation of 0.8010 which is

[59] TheDataHall. "Correlation Analysis in Stata (Pearson, Spearman, Listwise, Casewise, Pairwise)." The Data Hall, March 18, 2023. https://thedatahall.com/correlation-analysis-in-stata-pearson-spearman-listwise-casewise-pairwise/#:~:text=The%20higher%20the%20absolute%20value,treated%20as%20a%20strong%20correlation.

sufficient because better technology can lead to an easier chance of winning points. What was interesting to see was total drivers and total constructors having a correlation of 0.6297 because both the total number of drivers and the total number of constructors have decreased over time. This indicates that there is a strong correlation between the two variables, thus, there is multicollinearity.

I dealt with concerns of multicollinearity between other variables by removing the total drivers and the total circuits from my regression framework. Total drivers and total circuits will have stronger effects because they are too similar. It is important to keep in mind that multicollinearity between independent variables will result in less reliable statistical inferences. This is so because it can make it difficult to determine the individual effects of each independent variable on the dependent variable. It can also result in unstable estimates of the regression coefficients. Additionally, it can lead to inflated standard errors of the regression coefficients, and it can cause incorrect inferences about the statistical significance of the independent variables. Thus, since total drivers and total circuits were too closely related that is why they were taken out of the regression model and will be talked about soon.

Regression Specifications

The subsequent equation that will be used in this paper represents the multivariate regression. After transferring and omitting collinear variables, I estimated:

$$HHI_t = \alpha_0 + \boldsymbol{\beta}_1 S_t + \boldsymbol{\beta}_2 X_2 + \boldsymbol{\beta}_3 X_2 * X_2 + \boldsymbol{\beta}_4 \boldsymbol{\gamma} + \varepsilon_t$$

The dependent variable is the Hirschman Herfindahl Index (HHI) which represents the competitive balance measure and t denotes the Formula One season (year); S denotes the budget cap set in place (which equals 0 in years 1960-2021 and 1 in years 2022 and after); X_2 represents

the time trend (0-62); γ refers to the number of drivers in a given year. The coefficient of interest is β_1. β_1 is the marginal effect of the Spending Cap on the Hirschman-Herfindahl Index. The squared term in the equation (X_2*X_2) is the technology time trend variable. The idea is that with time, technological progress improves nonlinearly, thus, that is why X_2 is squared. The controls include the total circuits in a year, total drivers in a year, total constructors in a year, and total points in a year.

The equation further addresses the confounding variables that are presented through the HHI trend graph. The goal is to see if these confounding variables have any sort of effect on the competitive measure, which can help figure out if the implementation of a budget cap helps create, in any way, a more level playing field among the drivers and different teams.

Expected Results

Intuitively speaking, the coefficients on Budget Cap should be negative and Time Trend to be positive, and that of Budget Cap and Time Trend to be statistically significant. I expect the coefficient on total circuits to be negative. I expect the coefficient on total constructors to be negative. I expect the coefficient on total points to be negative and statistically significant as the transformation of the points system has made it easier to accrue points, potentially closing the massive gap in points across all drivers and teams.

Regression Results

Looking at the regression model, the log of total points is significant ($p < 0.05$), and technology (trend) are both significant ($p< 0.05$), whereas total circuits and budget cap are not significant (greater than 0.05). Thus, total points and technology have a significant association with HHI.

Table 3: Multivariate Regression

Linear regression

Number of obs	63
F(6, 56)	2.94
Prob > F	0.0146
R-squared	0.2937
Root MSE	.01681

HHI	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
totalconstr~s	-.000568	.0006055	-0.94	0.352	-.001781	.0006449
logtotal	-.0251899	.0120066	-2.10	0.040	-.049242	-.0011378
trend	.0004876	.0009636	0.51	0.615	-.0014427	.0024178
c.trend# c.trend	.0000281	.000038	0.74	0.463	-.0000481	.0001043
c.trend# c.trend# c.trend	-3.26e-07	4.37e-07	-0.75	0.459	-1.20e-06	5.50e-07
BudgetCap	.0048754	.008973	0.54	0.589	-.0130997	.0228504
_cons	.2442564	.0634579	3.85	0.000	.1171349	.3713778

Source: Author's Calculations

Looking at the regression model, the log of total points is significant ($p < 0.05$), and technology (trend) are both significant ($p< 0.05$), whereas total circuits and budget cap are not significant (greater than 0.05). Thus, total points and technology have a significant association with HHI.

The coefficient tells us how much the dependent variable changes for every one-unit increase in the independent variable.[60] Now looking at the budget cap, which is the dummy variable, has a coefficient value of .0048754. This is the association between the budget cap and HHI, which describes the marginal effects on HHI. Looking at the table, we can use the variable of total constructors as our first example. We can see that the coefficient value is -.000568 which

[60] Frost, Jim. "How to Interpret p-Values and Coefficients in Regression Analysis." Statistics By Jim, March 21, 2023. https://statisticsbyjim.com/regression/interpret-coefficients-p-values-regression/.

indicates that when total constructors increase by one unit, the HHI will decrease by .000568. Looking at the coefficient value for the log of total points (-.0251899), the same idea can be utilized.

We can also look at the R-squared in the table which is 0.2937. This is a statistical measure that tells us how well the variation in the independent variables explains the variation in the dependent variable.[61] R-squared ranges from 0 to 1. A value of 0 indicates that none of the variations in the dependent variable is explained by the independent variables, whereas a value of 1 indicates that all of the variations in the dependent variable are explained by the independent variables. A higher R-squared indicates that the independent variables are better at explaining the variation in the dependent variable. An R-squared value of 0.2937 means that variation in the independent variables in the regression model explains 29.37% of the variation in the dependent variable, and 70.63% of the variance in the dependent variable is still unexplained by the independent variables included in the model. This indicates that the model may not be a very good fit for the data, and there may be other factors that are influencing the dependent variable that is not accounted for in the model.

Looking at the Root MSE, or the Root Mean Square Error, it is a statistical measure that tells us how much the predicted values from a model differ from the actual values in the current dataset.[62] A lower Root MSE indicates that the model is better at predicting the actual values in the dataset, while a higher Root MSE indicates that the model is less accurate. A Root MSE of 0.01681 means that, on average, the predicted values from the regression model differ from the

[61] Fernando, Jason. "R-Squared: Definition, Calculation Formula, Uses, and Limitations." Investopedia. Investopedia, April 15, 2023. https://www.investopedia.com/terms/r/r-squared.asp#:~:text=R%2Dsquared%20is%20a%20statistical,variable%20in%20a%20regression%20model.

[62] Zach. "How to Interpret Root Mean Square Error (RMSE)." Statology, May 10, 2021. https://www.statology.org/how-to-interpret-rmse/.

actual values in the dataset by 0.01681 units. Additionally, Root MSE can be used to compare the performance of different models or to assess the improvement in model performance after making changes to the model.

I estimated that the budget cap had no effect on competitive balance. This empirical analysis is a preliminary finding and future work would be needed to better interpret the influence of the budget cap.

Considerations For Next Steps

Since this paper is a preliminary study, it could potentially help future researchers grasp a better understanding of the topic of competitive balance in Formula One, and it could even assist in shedding some light on competitive balance in sports in general. This is just the beginning of this vast topic, and it would be awesome to see other researchers expand on this. By continuously developing on this topic, it could be beneficial and help Formula One achieve a more competitive playing field between the constructors and drivers, which is something that the sport has not done well consistently throughout its existence.

When assessing the next steps, an important concept to consider is time. The current data that is presented is limited due to the amount of time because the budget cap was just recently introduced. This means that if we want to see if there is an actual effect of the implementation of the budget cap on competitive balance, more time would be needed to see the possible impact of it. In an ideal world, we would want 5-10 years of data to see if there are eventual effects and not the 2 years of data that is used in this paper. Thus, as time progresses with the enforcement of the budget cap, we can gain a better understanding concerning if the budget cap is helpful in creating a more level playing field, or if the budget cap does not have a positive effect on competitive

balance. Nonetheless, only time will tell, and the hope is that in due time, the budget cap will reveal an effect on the ever-so-daunting competitive balance in Formula One.

Additionally, when pondering the next steps, future work will hopefully have the ability to gain easier access to constructor spending in Formula One, which would eliminate the problem of not having enough data. By having easy access, further research could help with noticing the impact of spending, if there is one, in Formula One. Accordingly, by having access to spending budgets over the years, further studies will have a more straightforward way of controlling spending budgets, which was a problem in this current study.

It was also not possible to control for disparities in budgets, as it is clear that each team does not spend the same amount of money. If there was a public database that provided this necessary information, then it would be much easier to see the impact on spending through the years. Thus, having easier access to a database that presents the total spending budgets for each team, on a yearly basis, would be beneficial for future work as this is a key indicator to see if spending has any effect on competitive balance.

Conclusion

The results of this study have provided valuable insights into the concept of competitive balance in Formula One. Maintaining competitive balance is crucial for the long-term sustainability and growth of the sport, as it keeps fans engaged and invested in the competition. My findings suggest that the budget cap did not affect competitive balance. This was contrary to my expectations and should be viewed as preliminary. Even though it is a preliminary result, the study remains informative for future research.

Empirically modeling competitive balance is difficult. The only statistically significant variable in this study was the log of total points (0.040) with a p-value of less than 0.05, which indicates that the total amount of points is important to evaluate when measuring the Hirschman-Herfindahl Index (HHI). The constant changing of the points system since the beginning of Formula One has had a perpetual effect on HHI, as it has made it easier to accumulate points, which, in turn, could possibly cause the closing of the gap between drivers and constructors considerably easier.

Exploring technology as a time trend, there are many nuances as the measured variable is not telling the complete story. Although exponentially increasing technology has a lower p-value than keeping technology as a linear trend, making it increase exponentially is more realistic. However, there are indeed limitations, which will be talked about shortly.

When examining the spending cap, it did not display the significance that this study was hoping to see, however, it is understandable why it was not significant. The lack of years since when the spending cap was instituted made it difficult to fully comprehend the data.

Accordingly, in order to see the possible effects of the spending cap, more years would need to be looked upon, which is another limitation that will be talked about very soon.

Additionally, throughout this empirical analysis, multicollinearity was an ensuing problem. There were variables that were highly correlated with each other and, due to this, the variable for total drivers had to be removed because it was exceptionally similar to total circuits. It is always important to be aware of multicollinearity because it can affect the reliability and validity of the results of regression analysis, and it can lead to incorrect conclusions about the relationship between the independent variables and the dependent variable. Nonetheless, this study highlights the importance of continued attention and monitoring of competitive balance in Formula One, and the ongoing efforts to promote fairness, equality, and transparency in competitions.

As we have come to learn, Formula One is a highly competitive sport where every team strives to gain an edge over its competitors. Over the years, Formula One has experienced several changes in the rules and regulations aimed at ensuring a level playing field for all teams. Despite these efforts, there have been occasions where certain teams have dominated the sport for extended periods of time. For example, Ferrari was dominant in the early 2000s, while Mercedes and Red Bull Racing have been the teams to beat in recent years.

Due to this, as of recently there has been growing concern among Formula One fans and stakeholders about the lack of competitive balance in the sport, with a few teams dominating the championships due to their massive spending power. In order to address this issue, the Formula One governing body introduced the spending cap which limits the amount of money a team can spend on their car's development and performance. Additionally, the expectation is that it will

reduce the financial advantage of the bigger teams and create more opportunities for smaller teams to be competitive.

However, the success of the spending cap will ultimately depend on its effective implementation and enforcement, as, for example, Red Bull Racing failed to comply with the spending cap. Formula One will need to be vigilant in ensuring that teams are not finding ways to circumvent the rules or engage in financial doping. Additionally, it is important to note that the spending cap will not solve all the issues of competitive balance in Formula One. There are other factors such as engine regulations, aerodynamics, and driver talent that will continue to play a significant role in determining a team's success. Nevertheless, the implementation of the spending cap is a step in the right direction to help with fixing the forever problem of endless spending for the wealthier teams.

Further Implications

The implications of competitive balance in Formula One are significant. One could say that when it comes to competitive balance, Formula One is behind the curve compared to the other major sports, however, that is not a fair statement. Formula One is unique in that each team has to develop its own car, which means that all cars are not standardized. Someone could say that this is a blessing and a curse. Since there is a lack of standardized rules and regulations this means that it does not fully ensure competitive balance, yet, at the same time, this is what separates Formula One from other sports.

For example, we can look at a sport like the NBA, in which it has employed rules such as the draft, free agency, and the salary cap to improve competitive balance. Although these rules primarily have long-term effects on the competition by adjusting the distribution of talent and

players that come in and come out of the league, these are standardized rules that have been shown to work in the NBA. I am not sure if Formula One would be able to realistically implement a draft into the motorsport, but it would definitely be interesting to see how something like this would work out. Thus, when it comes to concepts that Formula One should think about adding to increase competitive balance, not only monitoring the spending cap and ensuring it is being followed but also standardizing the sport, which will be talked about in the next section.

Limitations/Future Work

It is important to note that this study is just the beginning, as the implementation of the budget cap has recently been enforced. Thus, the data does not paint the whole picture regarding how effective the spending cap is. As more and more years go on with the spending cap in effect, this will provide a better understanding of how influential it truly is.

It was a difficult process to be able to find all of the relevant data. The approach of gathering data involved continuous searching to find the information and data that was needed. It was a frustrating experience because there is/are no public database(s) that provides everything such as team spending budgets, teams and drivers who won in a given year, total points (drivers and teams) in a given year, amount of drivers and teams for that year, the total number of circuits and races, the type of engine used for each car, as well as the specifics of the car, made it difficult. Also, there is a database that is called statista.com to gain access to the data, however, you need to pay money to obtain and use the data. As a result, the information is being pulled from multiple sources. All of this data and information was gathered to help the empirical

analysis with deciding on what variables and data were wanted to be added when running the regression analysis.

Another limitation was access to general data. Due to there not being a public database at hand, testing the hypothesis was difficult. It was difficult because there was no downloadable data. This meant that all of the data that was compiled had to be entered into Excel. This involved tedious work having to input the information by hand, and constantly copying and pasting data into an Excel spreadsheet. The information that the analysis ended up using was focused from 1960 to 2022. With the information that was compiled, regression analysis was run to test the hypothesis that the spending cap, first implemented in the 2021 season, would have a positive effect on the competitive balance in Formula One, thus creating a more level playing field between the top-tier and lower-tier teams. Furthermore, by having the raw data for spending budgets, future research can paint a better picture than what this empirical study is trying to illustrate.

One other limitation is the time trend variable that we used to measure technology through the years. It can be said that since 1960 technology has improved substantially, however, there are of course limitations to this thinking. In this data, we have squared technology which means that it goes up exponentially. This is more realistic than what was previously used—looking at technology as a linear concept. This meant that with time, technology improved linearly every year. Although squaring technology, as a time trend, is a more telling way of measuring it, as technology does progress exponentially, there are still limitations. This paper does not account for years when technology could have been slowed down or even when technology remained stagnant. It is also not accounting for years when technological progress

could have increased considerably compared to other years. Although this is a substantial way to measure technology, a better run study would try to measure technology in a way that more accurately depicts it for that specific year. This would help show a better relationship, overall, with technology when attempting to extrapolate the competitive balance in a given year.

Through the years, Formula One has taken various steps to increase competitive balance, whether that be the introduction of the spending cap or introducing technical regulations that involve banning certain components of the car, however, there are certainly opportunities for further improvements. As was mentioned earlier I think the best way to ensure competitive balance is 1. To make sure that teams are following the rules of the spending cap and 2. Formula One should look for options to standardize the sport more. I believe that by further standardizing the sport, competitive balance will increase, but it is important to keep in mind that this is a long-term thing. The expectation shouldn't be that the immediate implementation of a spending cap, or the standardization of the motorsport, will create a more level playing field right away. This process will take time.

Here are some ideas that Formula One could think about accomplishing when it comes to making the sport more competitive. As was mentioned earlier with the draft, such that all of the major sports in North America have a drafting system, Formula One could possibly implement something like this. I know that season over season the drivers do not vary that much, so instituting a draft would be a little difficult because there is a specific amount of spots for drivers to race and be on a team. I do think that drafting drivers who are driving in F2 or lower could be feasible, and, thus, would be a future investment for a team. This would be the same as what many of the organizations that participate in these major sports currently do. Drafting can help

produce more capital for a team, which is something that some of the smaller teams do wish they had more of.

Although driver talent and skill are both essential in the sport, one could say that they are not the number one things on the minds of teams. Evidently, the car is a large indicator of a team's success, as an average driver can look exceptional in a very fast car compared to a considerably better driver in a slower and less expensive car. Formula One could allow smaller teams to purchase cars from larger teams, or even rent them, to reduce the cost of manufacturing and development. However, this idea eliminates the very uniqueness of the sport such that each team individually develops their own car. This would mean that there are teams that would be driving the exact same car in a race.

To culminate all of these aforementioned ideas means that Formula One should be more standardized, which could help create a more competitive balance between drivers and teams. As someone who is immersed in sports, many of the sports that are standardized have been more appealing to me as a fan. And as someone who is interested in Formula One because of how unique of a sport it is, going into a season, you pretty much have a good idea as to what team and what driver will win this year. This is the major problem in Formula One in that people know and expect a specific driver and team to be on top (Max Verstappen and Red Bull Racing), which makes the sport less entertaining to watch, despite the dangerous aspect of it helping elevate the sport.

Increasing competitive balance in Formula One is a complex issue that requires a multifaceted approach. The motorsport should consider implementing a combination of the previously mentioned measures and continually monitor their effectiveness, to ensure a fair and

level playing field for all teams. Furthermore, with the implementation of the spending cap and the possible additions of these measures above, it will take some time for us, fans, to see a change in who is constantly winning and losing. Only time will tell to see if the goal of the spending cap fulfills the wishes of Formula One.

Bibliography

Asher, Richard. “F1 Cost Cap: What Is It and How Does It Work?” Motorsport.com. Motorsport.com - US, February 28, 2023. https://us.motorsport.com/f1/news/f1-cost-cap-what-is-it-how-it-works/10379800/.

Bromberg, Michael. “Herfindahl-Hirschman Index (HHI) Definition, Formula, and Example.” Investopedia. Investopedia, November 22, 2022. https://www.investopedia.com/terms/h/hhi.asp#:~:text=How%20Is%20Market%20Concentration%20Defined,or%20greater%20is%20highly%20concentrated.

Budzinski, Oliver; Feddersen, Arne (2019) : Measuring competitive balance in Formula One Racing, Ilmenau Economics Discussion Papers, No. 121, Technische Universität Ilmenau, Institut für Volkswirtschaftslehre, Ilmenau

Duggal, Raghav Nitankumar. “Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry,” 2020.

Duxbury, Anna, and Joe Holding. “How Fast Is an F1 Car? Top Speeds of F1, IndyCar, Motogp and More.” Autosport, May 30, 2022. https://www.autosport.com/f1/news/how-fast-is-an-f1-car-top-speeds-of-f1-indycar-motogp-and-more-4980734/4980734/?nrt=54.

Editor. “F1 Overtaking Rules: What Are the Rules of Engagement?” Yahoo! Finance. Yahoo! Accessed November 15, 2022. https://uk.finance.yahoo.com/news/f1-overtaking-rules-rules-engagement-150400862.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAL1gR7iFDv1zoKJvpMO99UJ0_d7EEwjeqWqAaGUkGK1TX49gpQLd_eTiJBU_7ahsO6xN8x-uYx9A5h1K2hq9N28IW0-CdgjuYifVRcJuMAZiR4ZBxNLXJbVqtcGTeQyv926VCDLo876vDIQWsnBqyedD4f1dE4usNwi8IqSydIbu.

Edmondson, Laurence. “FIA Admits Red Bull Budget Cap Breach Investigation and Penalty Took Too Long.” ESPN. ESPN Internet Ventures, November 18, 2022. https://www.espn.com/f1/story/_/id/35052867/fia-admits-red-bull-budget-cap-breach-investigation-penalty-took-too-long.

Edmondson, Laurence. “Max Verstappen Says F1 Salary Cap Idea 'Completely Wrong'.” ESPN. ESPN Internet Ventures, June 10, 2022. https://www.espn.com/f1/story/_/id/34067757/max-verstappen-says-f1-salary-cap-idea-completely-wrong.

Fernando, Jason. “R-Squared: Definition, Calculation Formula, Uses, and Limitations.” Investopedia. Investopedia, April 15, 2023. https://www.investopedia.com/terms/r/r-squared.asp#:~:text=R%2Dsquared%20is%20a%20statistical,variable%20in%20a%20regression%20model.

Frost, Jim. “How to Interpret p-Values and Coefficients in Regression Analysis.” Statistics By Jim, March 21, 2023. https://statisticsbyjim.com/regression/interpret-coefficients-p-values-regression/.

F1. “2021 F1 Financial Rules and Regulations: What Is the Cost Cap and How Will It Be Enforced?: Formula 1®.” Formula 1. Formula 1, January 4, 2021. https://www.formula1.com/en/latest/article.what-is-the-2021-f1-cost-cap-and-how-will-it-be-enforced.4l0LPbfFgBhDxjccMseCHO.html.

F1. “The 2021 F1 Cost Cap Explained – What Has Changed, and Why?: Formula 1®.” Formula 1. Formula 1, May 28, 2020. https://www.formula1.com/en/latest/article.the-2021-f1-cost-cap-explained-what-has-changed-and-why.5O1Te8udKLmkUl4PyVZtUJ.html.

“History of Formula One.” Wikipedia. Wikimedia Foundation, April 28, 2023. https://en.wikipedia.org/wiki/History_of_Formula_One.

Kanal, Samarth. “Timeline: How the FIA Cost Cap Story Unfolded as Red Bull and Aston Martin Enter Agreements over Breaches: Formula 1®.” Formula 1. Formula 1, October 28, 2022. https://www.formula1.com/en/latest/article.timeline-how-the-fia-cost-cap-story-unfolded.6yAhD5hKoRuUTqhU1wYuGY.html#:~:text=The%202022%20FIA%20Cost%20Cap,rise%20in%20line%20with%20inflation.

Killingstad, Written by Liam, Liam Killingstad, Edited by Peter Richman, and Peter Richman. “The Unstoppable Rise of Formula 1.” Front Office Sports, July 10, 2022. https://frontofficesports.com/newsletter/the-unstoppable-rise-of-formula-1/.

Krauskopf, Thomas, Martin Langen, and Björn Bünger . “The Search for Optimal Competitive Balance in Formula One,” September 2010.

MOURAO, PAULO. “Chapter 3.” Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economics of Motorsports (81)

MOURAO, PAULO. “Chapter 4.” Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (119)

MOURAO, PAULO. “Chapter 4.” Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (120)

MOURAO, PAULO. “Chapter 4.” Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (121)

MOURAO, PAULO. “Chapter 4.” Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (122)

MOURAO, PAULO. “Chapter 4.” Essay. In *Economics of Motorsports: The Case of Formula One*. PALGRAVE MACMILLAN, 2018. The Economic of Motorsports (123)

“MLB 2023 Payroll Tracker.” Spotrac.com. Accessed November 27, 2022. https://www.spotrac.com/mlb/payroll/.

May 1, 2015 · by f1metrics · in Budgets. “How Money Predicts Success in Formula 1.” f1metrics, September 3, 2015. https://f1metrics.wordpress.com/2015/05/01/how-money-predicts-success-in-formula-1/.

Smith, Chris. “Formula One's Most Valuable Teams: Ferrari and Mercedes Gain Ground amid a Cost-Cutting Tug-of-War.” Forbes. Forbes Magazine, November 26, 2019. https://www.forbes.com/sites/chrissmith/2019/11/26/formula-one-team-values-ferrari-mercedes/.

Smith, Luke. “F1 Agrees to Budget Cap Increase for 2022 amid Inflation Pressure.” Motorsport.com. Motorsport.com - US, July 9, 2022. https://us.motorsport.com/f1/news/f1-agrees-to-budget-cap-increase-for-2022-amid-inflation-pressure/10334849/#:~:text=F1%20introduced%20its%20first%20set,on%20the%20number%20of%20races.

Seas. Downforce. Accessed November 15, 2022. https://formula1-dictionary.net/downforce.html.

TheDataHall. “Correlation Analysis in Stata (Pearson, Spearman, Listwise, Casewise, Pairwise).” The Data Hall, March 18, 2023. https://thedatahall.com/correlation-analysis-in-stata-pearson-spearman-listwise-casewise-pairwise/#:~:text=The%20higher%20the%20absolute%20value,treated%20as%20a%20strong%20correlation.

Young, Stephanie. “Formula One Racing: Driver vs. Technology.” *Intersect* 5 (2012).

Zach. “How to Interpret Root Mean Square Error (RMSE).” Statology, May 10, 2021. https://www.statology.org/how-to-interpret-rmse/.