Predictions on the impact of the budget cap on Formula 1 teams' performance

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Abstract

This study aims at quantifying the impact of the budget on the performance of Formula 1 teams. Until recently, the budgets of Formula 1 teams varied; thus, competitive advantage was provided to those that consistently had greater funds than others. Understanding how dominant the effect of the budget is in the performance of a team will provide significant findings since a cost cap that aims at balancing the financial field, has been recently introduced. Prediction models regarding the team that performed better on a relatively lower budget will provide insights regarding which of them may thrive in the future.

Keywords: Formula 1; Cost cap; Performance; Efficiency; Drivers' effect; Regression models

Abbreviations

RP: Relative performance
RB: Relative budget
DR: Drivers' effect
EF: Efficiency ratio

2010 AMS subject classification: 91-00 General reference works (handbooks, dictionaries, bibliographies, etc.) pertaining to game theory, economics, and finance.‡

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1. Introduction

Formula One (F1) is an international motorsport that is considered the most competitive in single-seat motor racing. It is the pinnacle of innovation in the automotive industry due to its radical technological advances, research and development (R&D) programs, drivers' capabilities and teams' expertise. Until 2021, no financial restrictions on the expenditures of F1 teams were imposed by the governing association of the sport (Fédération Internationale de l'Automobile, FIA). FIA proposed the implementation of a $70 million cost cap in 2010 to tackle the ramifications of the 2007-2009 economic crisis as three (3) constructors had withdrawn from the championship and the viability of F1 was at risk [Henderson et al., 2010]. Nonetheless, the endeavor did not thrive since the cap was considered very low and the subsequent F1 teams did not acquiesce to its application [Judde et al., 2013]. Instead, a Resource Restriction Agreement was established but it was not intended to operate as a budget cap [Straw, 2022]. For the first time in its history, the organizational structures and the F1 teams have agreed on implementing a budget cap beginning in 2021. The cap for 2021 and 2022 was set at $145 million and $140 million, respectively, and it is expected to be further reduced by $5 million in 2023 [FIA, 2021].

According to FIA [2021], the purpose of the budget cap enforcement is threefold:

1. Enhance the sporting fairness of the championship;
2. Promote competition and equal opportunities for all the participating teams; and
3. Ensure the long-term financial sustainability of the F1 teams.

The two former issues pertain to the competitive balance that each sport (or motorsport) should feature to a certain degree. Competitive balance is key to the success of sports because the outcome becomes more unpredictable. Unpredictability is an important factor that drives spectators into a sport and makes it more popular [Rottenberg, 1956]. Formula 1 is a hybrid motorsport in which the performance of the team and the driver determine the outcome. Throughout its history, teams with higher budgets were able to dedicate more funds to R&D, development of structural components, designing new performance packages, or hiring skillful professionals compared to the teams with lower budgets. This resulted in an unbalanced field in which the outcome of the championship was (more or less) predetermined. Nonetheless, the recently introduced budget cap will significantly affect the top teams and allow the rest of the field to be competitive (at least in financial terms).

An interesting feature that will potentially allow greater competition is that the cost cap is representative of the initial budget of a midfield team. Therefore, it aims to allow less wealthy firms to operate without significant changes and make those with higher budgets significantly reduce their expenditures. In recent years, three teams have (reportedly) significantly more funds than the others:

1. Scuderia Ferrari F1
2. Mercedes AMG
3. Red Bull Racing.

Therefore, the implications of the cap will primarily affect these three constructors. Nonetheless, the aforementioned teams will certainly experience a short-term advantage due to their existing facilities, staff and accumulated knowledge.

The budget cap involves all the operations of the F1 teams with some exceptions that are known as excluded costs. Those are reported in detail in the F1 Financial regulations [FIA, 2021] and the most prominent are summarized in **Table 1**. The budget cap's exemptions prove that its purpose is to impose financial restrictions that are solely associated with poor performance. It does not intend to affect the overall operations of an F1 team that are not associated with racing. A team can still spend any amount of money on non-F1 activities and promote its brand through marketing campaigns etc.

The present study aims at quantifying the historical relationship between the expenditures of the teams and the corresponding results in order to understand the actual impact of the budget on performance. The studied period will be 20 years, namely 2000-2019, and the accumulated data will refer to all the teams that participate in the current championship (2022). The initial goal of the study is to observe whether teams with higher budgets indeed performed better (as expected) than teams with lower budgets. However, a team's overall performance is also dependent on its staff efficiency and, eventually, on the performance of the drivers. Therefore, it is crucial to detect which of the teams participating in the championship were efficient, i.e., they achieved better results than teams with similar or even higher budgets. These teams are likely to thrive in the new era in which the budget cap will counterbalance the financial classes. The performance is assessed in terms of achievements in the sport and their budgets are derived via financial data.

F1 budget cap exemptions	
Travel and accommodation expenses	Marketing endeavors
F1 driver salaries	Property costs
Heritage activities	Corporate legal and taxation fees
Salaries of the highest-paid three (3) employees	All employees' bonuses and termination benefits
Depreciation or amortization losses due to revaluation of assets	Payables to FIA for entering the championship (new team) or for a driver's super license
Non-F1 activities	Any financial penalties
Power units' development, production and acquisition	Entertainment expenses for employees (max. expense $1 million)
Human resources activities	Exchange rates loss or gains

Table 1. The most important F1 budget cap exemptions (FIA, 2021)

2. F1 organizational framework and teams

The F1 championship takes place under the auspices of the FIA. The entire organization of F1 comprises two additional parts, the Formula One Group, the group that has the commercial rights of the sport and controls various of its aspects (management, licenses, marketing, broadcasting, etc.) and the F1 teams. The Formula One Group was purchased by Liberty Media Corporation in 2017 for the amount of $4.4 billion [BBC, 2016]. It is operated by the Formula One Management (FOM) which mainly controls the executive operations of the group. FOM also organizes the logistics, the traveling of staff and transport of equipment from one Grand Prix to the next.

There are currently ten (10) F1 teams that compete in the drivers and the constructors' championships which are listed below:

1. *Scuderia Ferrari (Ferrari)*
2. *Mercedes-AMG F1 (Mercedes)*
3. *Red Bull Racing (Red Bull)*
4. *McLaren Racing (McLaren)*
5. *Williams Racing (Williams)*
6. *Alpine BWT F1 (Alpine)*
7. *Alfa Romeo F1 (Alfa Romeo)*
8. *Scuderia Alpha Tauri (Alpha Tauri)*
9. *Aston Martin (Aston Martin)*
10. *Haas (Haas)*

The parentheses include the abbreviations that will be used for naming each team for the ease of the present study.

3. Data and methods

3.1 Methodology

Based on the theory of production functions [Heathfield, 1976], Duggal [2020] suggests that the performance of F1 teams (accumulation of points in the championship) is defined as a function of their budget, drivers' effect and team's fixed-effect. The latter will be referred to as the team's efficiency from now on. Therefore:

$$P = f(B, DR, EF) \quad (1)$$

Where P is the performance of each team and relates to the total points accumulated within a season, B is the annual budget, DR is the effect of the team's drivers and EF is the efficiency of the team.

To identify whether the performance of F1 teams can be approximated by the theoretical background, two regression models will be established for the corresponding data between 2000-2019. A hypothesis test on whether the budgets and performance are correlated will be conducted. This aims at establishing a direct correlation between performance and budgets. The analysis of variance (ANOVA) will be performed using the F-test to derive whether there is significant evidence that performance is impacted by the budgets. If this holds, a linear regression model between performance and budgets will be established:

$$P_{Y,j} = a + b \times B_{Y,j} + \varepsilon_{Y,j} \geq 0 \quad (2)$$

Where $P_{Y,j}$ is the performance of the team j at season Y, α is the performance intercept, $B_{Y,j}$ is the budget of the team j during season Y, b is the coefficient of a team's budget and $\varepsilon_{Y,j}$ is the residual of the team j in season Y.

Afterwards, a multivariable regression model that will account for the drivers' effect will also be employed and Equation [2] will be transformed into:

$$P_{Y,j} = a + b_1 \times B_{Y,j} + b_2 \times DR_{Y,j} + \varepsilon_{Y,j} \geq 0 \quad (3)$$

Where $DR_{Y,j}$ is the ranking of the drivers employed in team j during season Y, b_1 is the coefficient of a team's budget and b_2 is the coefficient of drivers' effect.

The 2nd model will provide more accurate results in terms of pure performance by incorporating the drivers' effect. A residual analysis based on the results of this model will be performed to assess the efficiency of F1 teams and construct a final prediction model accounting for the three (3) independent variables (B, DR and EF). Note that if a team's residuals are constantly positive, it proves that it consistently performed better than the average team with a similar budget and drivers' rating and vice versa.

3.2 Historical budgets and monetary inflation

To establish the regression models, data on the budgets of each team per season must be accumulated. One would suggest that obtaining this data would be a straightforward procedure. On the contrary, this does not hold. Unlike other sport organizations, F1 teams do not reveal their financial data and frequently disclose information [Sylt, 2020]. Herein, numerous information from journal papers, magazines, online sources and hardcopies were used to determine the budget of each team per year. In order to be comparable, the budgets have to be adjusted for the inflation rates during the studied period. This adjustment was made using the Consumer Price Index (CPI) which refers to the weighted average change of prices for a basket of goods and services [data from the U.S. Department of Labor Bureau of Labor Statistics, 2022] and is a measure of the inflation rate. The year 2020 was selected as reference. It is assumed that the utilization of annual inflations for the US economy is justified, as the budgets and expenses in F1 are expressed in USD. The adjusted budgets are presented in **Table 2** and depicted in **Figure 1**.

The absence of budget values in certain seasons observed in **Figure 1** and **Table 2** indicates that the corresponding team did not exist (at least in its current form) at the time. For example, Mercedes entered the championship in 2010; therefore no data before that year is recorded. It is pointed out that some teams have undergone minor changes (including re-branding) throughout the years but the organization remains practically the same, therefore, it is considered a cohesive unit for the purposes of the present study. For example, Renault F1 implemented certain organizational structure alterations in 2021 and changed its name to Alpine aiming to re-brand the team. Apart from some substitutions in staff and subsequent minor changes, the organization remained the same therefore, there is no incentive to consider Alpine a different team than Renault.

F1 team/year	Team budgets (million $) adjusted for inflation rates (Reference year: 2020)																				
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
Ferrari	360	415	639	589	584	576	521	508	498	387	377	299	448	444	469	456	402	417	422	439	462
Mercedes	-	-	-	-	-	-	-	-	-	-	291	247	287	327	436	510	388	423	412	429	375
Red Bull	-	-	-	-	-	185	257	315	198	212	236	236	422	383	491	511	315	294	319	338	314
McLaren	338	402	438	506	492	559	515	503	520	466	346	247	287	311	387	507	271	239	227	253	390
Williams	215	282	508	506	486	479	251	245	200	182	141	144	161	167	213	203	154	164	155	152	250
Alfa-Romeo	108	120	173	219	200	214	454	444	440	345	118	104	161	155	120	112	139	144	139	157	203
Alpine	138	263	298	360	353	382	415	405	473	357	165	184	233	250	207	152	190	205	196	212	272
Alpha Tauri	-	-	-	-	-	-	84	100	154	157	165	121	125	94	196	150	146	150	155	157	140
Aston Martin	-	-	-	-	-	-	-	-	146	133	126	138	179	111	153	142	132	133	124	157	139
Haas	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	146	137	134	152	142

Seasons 2000-2001: Business F1, March and April 2003, Credit Suisse Formula 1 Office (hardcopy)
Season 2002: F1 Racing Magazine 2003a (hardcopy)
Season 2003: F1 Racing Magazine 2003b (hardcopy)
Season 2004: F1 Racing Magazine 2004 (hardcopy)
Season 2005: F1 Racing Magazine 2005 (hardcopy)
Season 2006: F1 Racing Magazine 2006 (hardcopy)
Season 2007: Wood (2008) in Bleacherreport.com
Season 2008: Collantine (2008) in Racefans.net
Season 2009: Forbes.com (2010)
Season 2010: Autosport.com (2010)

Season 2011: Forbes.com (2012)
Season 2012: Boxall-Legge (2019) in Autosport.com
Season 2013: Forbes.com (2014)
Season 2014: Forbes.com (2015)
Season 2015: Mourão (2017)
Season 2016: Rencken (2016) in Autosport.com
Season 2017: Cooper (2018) in Motorsport.com & Rencken (2017) in Autosport.com
Season 2018: Rencken (2018a) in Racefans.net & Rencken (2018b) in Racefans.net
Season 2019: Rencken (2019) & Rencken (2020) in Racefans.net

Table 2. Budgets for the ten (10) F1 teams participating in the 2022 championship during 2000-2019 adjusted for inflation in 2020 (reference year).

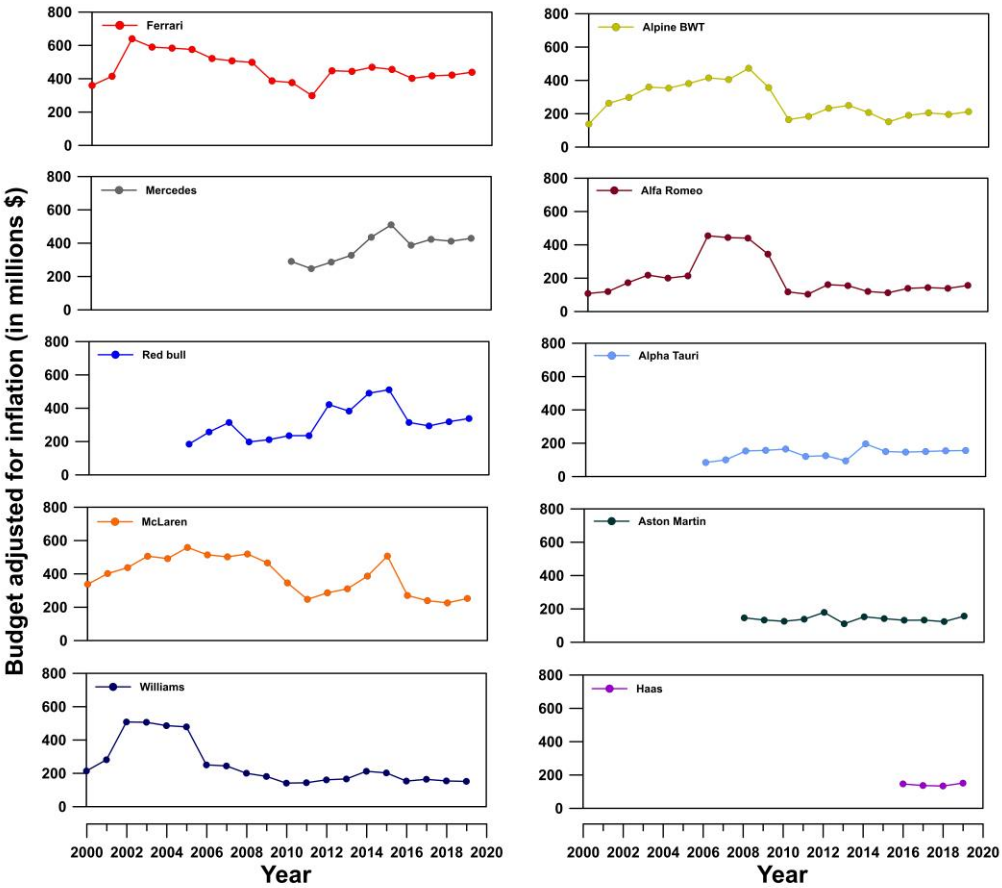


Figure 1. The budgets (adjusted for 2020 cumulative inflation rates) of each team participating in the 2022 championship from 2000-2019.

According to the data provided in **Table 2**, the teams can be classified based on their average adjusted annual budget as follows:

1. Ferrari;
2. McLaren;
3. Mercedes;
4. Red Bull;
5. Alpine;
6. Williams;
7. Alfa Romeo;
8. Alpha Tauri;
9. Aston Martin;
10. Haas

Nonetheless, the effect of the budget on the performance of an F1 team is a relative term meaning that a high or a low budget is always dependent on the corresponding budgets of subsequent teams. Hence, it was decided to use a relative measure of the teams' budget (RB), i.e.:

$$Relative\ Budget_{j,Y}(RB) = Budget_{j,Y} - Min(Budget_Y) \quad (4)$$

Where j represents the team and Y the season.

3.3 Performance evaluation

The performance of each F1 team is purely evaluated by its racing results, i.e., the collected points at the end of the season. The performance assessment would be a straightforward task if the reward system was constant throughout the period of interest (2000-2019). However, the point system has changed several times over the past two decades. In particular, the systems used between 2000-2002, 2003-2009, 2010-2018 and 2019 are different. Moreover, the number of races held each season has changed over the years. To overcome these difficulties in comparing the performance of F1 teams throughout the studied period, it was decided to acquire a relative measure, namely the ratio between the points scored to the maximum available points per season:

$$Relative\ Performance\ (RP) = \frac{TP_{j,Y}}{MAP_{j,Y}} \quad (5)$$

Where $TP_{j,Y}$ and $MAP_{j,Y}$ are the collected points of team j and the maximum available points in season Y, respectively. The relative performances per season for all the F1 teams are presented in **Table 3**. Note that any penalties imposed on F1 teams, that were irrelevant to performance, are not applied in this assessment.

During the studied period (2000-2019), 19 out of 20 constructors' championships were won by the teams that participate in the 2022 season. Ferrari has claimed 7 championships with a winning rate of 33.3%, Mercedes, participating in F1 since 2010, has won 6 championships and has the highest winning rate (63.3%), Red Bull has won 4 championships with a winning rate of 25% and Alpine has won 2 championships (winning rate of 9.5%). The average relative performance yields the following pecking order in terms of success:

1. Mercedes
2. Ferrari
3. Red Bull
4. McLaren
5. Alpine
6. Williams
7. Aston Martin
8. Alfa Romeo
9. Alpha Tauri
10. Haas

Boxplots with the finishing positions of each F1 team in the studied period are illustrated in **Figure 2**.

Season	Scuderia Ferrari	Mercedes	Red Bull	McLaren	Williams	Alfa-Romeo	Alpine	Alpha Tauri	Aston Martin	Haas
2000	38	-	-	34	8	1	5	-	-	-
2001	40	-	-	23	18	5	2	-	-	-
2002	50	-	-	15	21	2	5	-	-	-
2003	25	-	-	23	23	3	14	-	-	-
2004	37	-	-	10	13	5	15	-	-	-
2005	13	-	5	25	9	3	26	-	-	-
2006	29	-	2	16	2	5	29	0	-	-
2007	31	-	4	33	5	15	8	1	-	-
2008	25	-	4	22	4	19	11	6	0	-
2009	11	-	24	11	5	6	4	1	2	-
2010	21	11	26	24	4	2	8	1	4	-
2011	20	9	34	26	0	2	4	2	4	-
2012	20	7	23	19	4	6	15	1	5	-
2013	18	19	31	6	0	3	16	2	4	-
2014	11	35	20	9	16	0	0	1	8	-
2015	22	37	10	1	13	2	4	3	7	-
2016	19	36	22	4	7	0	0	3	8	1
2017	26	33	18	2	4	0	3	3	9	2
2018	27	31	20	3	0	2	6	2	5	4
2019	24	35	19	7	0	3	4	4	3	1
Mean	***24***	***26***	***17***	***15***	***7***	***4***	***9***	***2***	***5***	***2***

Table 3. The relative performance (%) for each F1 team per season.

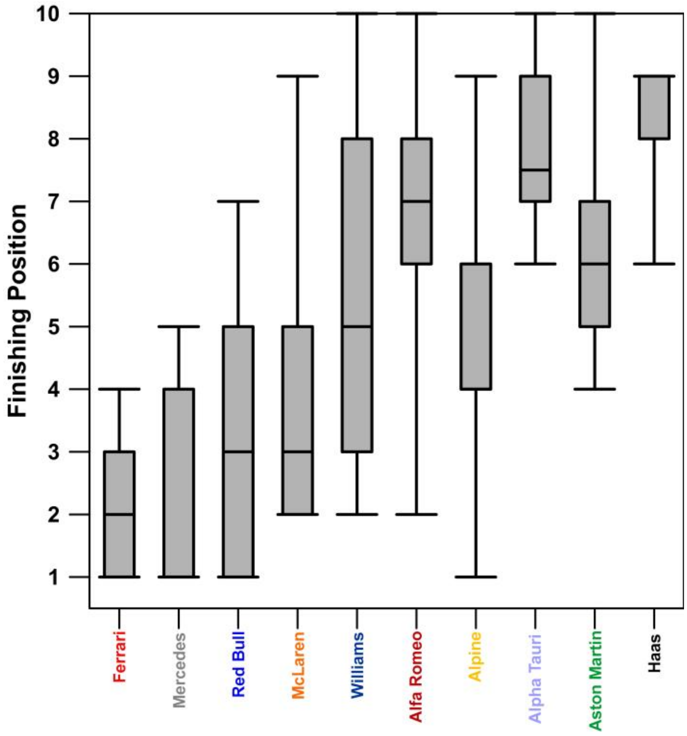


Figure 2. Boxplots of finishing position in the constructors' championship for each F1 team (2000-2019).

3.4 Quantification of the driver's effect on performance

F1 is a complex sport that involves the competition of both drivers and teams. The overall performance of a constructor is dependent on the performance of the team but also on the skills of the 2 drivers who participate in the championship. The most important component of winning lies in the performance of the car, but the extent of the driver effect is highly disputable [Bell et al., 2016]. Herein, the driver effect will be isolated since the purpose of the thesis is to study the performance of each F1 team. The rationale behind this lies in the fact that drivers are not a constant parameter when it comes to future performance predictions.

The quantification of the driver effect is a challenging task with limited studies found in the literature [Phillips, 2014; Bell et al., 2016; Duggal, 2020]. This is due to many parameters that must be taken under consideration in order to assess the performance of a driver and are summarized below:

1. A driver's performance is intercorrelated with the F1 car provided. For example, a driver in a winning car that finishes 5^{th} performs worse than a driver in a non-competitive car that finishes 8^{th} despite the former scoring more points.
2. There are certain parameters that affect the performance of a driver during the race but cannot be controlled by him. For instance, if a driver is involved in a crash that has no responsibility, his performance is unfairly devalued. The same applies when the team makes a strategic error.
3. The comparison of drivers' performance in different cars is inexpedient therefore, drivers are frequently compared to their teammates that drive the same car. Unfortunately, this approach also presents certain issues since the skills of the teammate are not always representative of the entire field.
4. There are non-racing parameters that affect the performance of the driver and cannot be readily quantified. These include his relationships with the team, communication with the staff and his motive to perform in the team's environment.

To overcome these issues herein, a database on F1 drivers' skills that utilizes data from 1950-2019 will be used to quantify the drivers' effect. This database was developed based on the TrueSkill ranking system [Herbrich et al., 2007], a Bayesian skill system established by Microsoft to assess the performance of video game players and distinguish the individual from team effects. According to the TrueSkill algorithm, a player's skills are represented by a normal distribution and characterized by a mean value and a variance based on their past performance. The algorithm also considers the corresponding effects of the teams participating in a game. The concept of separating individual and team effects is similar to the conditions found in F1; therefore, the TrueSkill system can be applied to quantify the skills of the F1 drivers. A detailed analysis of the mathematical formulas behind TrueSkill can be found in [Herbrich et al., 2007].

The drivers that participated in the championships during the studied period were classified according to their TrueSkill rating in 6 categories (Rank 1 represents the best drivers and Rank 6 the worst-performing ones), as presented in **Table 4**. An arbitrary point system is also established based on the ranking class of each driver with class I providing +5 points and class VI -5 points. Note that the ranking classes represent the average performance of the examined drivers and not their current form.

The overall drivers' effect is the cumulative ranking of the team's drivers that participated in the season. If a team changed a driver during the year, a weighted average ranking is obtained based on the number of races that each of the corresponding drivers participated in. The maximum number of changes documented from one team in the studied period was 2, i.e., the maximum number of drivers for one chassis was 3. Therefore:

$$\overline{DR} = \frac{n_1}{N} \times DR_1 + \frac{n_2}{N} \times DR_2 + \frac{n_3}{N} \times DR_3 \qquad (6)$$

Where $\overline{DR}$ is the weighted average driver effect, DR_1, DR_2, DR_3 the driver ranking of the 3 drivers that participated in the season; n_1, n_2, n_3 the races that each one drove; and N the total races.

Drivers	Ranking Class	Ranking Points
Schumacher M., Hamilton L.	**I**	**+5**
Vettel. S., Rosberg N., Alonso, F., Raikkonen K., Verstappen M., Button J., Hakkinen M.	**II**	**+3**
Webber M., Barrichello R., Ricciardo D., Bottas V., Coulthard D., Massa F., Villeneuve J., Montoya J.P., Schumacher R.	**III**	**+1**
Fisichella G., Frentzen H-H., Kubica R., Perez S., Heidfeld N., Leclerc Ch., Kovalainen H., Trulli G., Hulkenberg N., di Resta P., Grosjean R., Sainz C., Magnussen K., Kvyat D., Gasly P., Ocon E., Albon A.	**IV**	**-1**
Wurz A., Salo M., Kobayashi K. Petrov V., Sutil A., Norris L., Nasr F. Stroll L., Alguersuari J., Buemi S., Nakajima K., Vergne J.E., Klien C., Senna B., Vandoorne S., De la Rosa P., Liuzzi V., Maldonado P., Piquet N. Jr., Pizzonia A., Speed S., Gutierrez E.	**V**	**-3**
Diniz P., Bourdais S., Giovinazzi A., Palmer J., Ericsson M., Wehrlein P., Hartley B., Russell G., Sirotkin S., Latifi N.. Doornbos R.	**VI**	**-5**

Table 4. F1 drivers' skill ranking based on the TrueSkill ranking system (developed by Microsoft).

4. Results

4.1 Correlation of relative performance and relative budgets

Before taking into consideration the drivers' effect, a correlation between the relative budgets and the relative performance of F1 teams will be established using a linear regression model like the one presented in Equation (2). The simple linear regression model yields an F-statistic of 165.9, meaning that the regression is statistically significant at any tested level. Therefore, it is confirmed that relative budgets and relative performance are correlated. The linear regression equation yields:

$$RP_{Y,j} = 2.76 + 0.059 \times RB_{Y,j} + \varepsilon_{Y,j}\ , R^2 = 0.52 \quad (7)$$

This correlation indicates that:

1. A team will the lowest budget during the season is expected to collect 2.76% of the available points and
2. The relative performance will increase by 0.059 (%) for every additional million $ spent during the season.

The coefficient of determination indicates that 52% of the variation in RP can be explained by the variability of the RB in F1 for the studied period. The strength of the correlation is considered moderate. This proves that budgets affect the overall performance but the efficiency of the F1 teams and the drivers' effect also play important roles. In fact, having a correlation with a high R^2 would mean the performance only depends on the budget and that efficiency does not impact the outcome. The RP-RB data plot is illustrated in **Figure 3**.

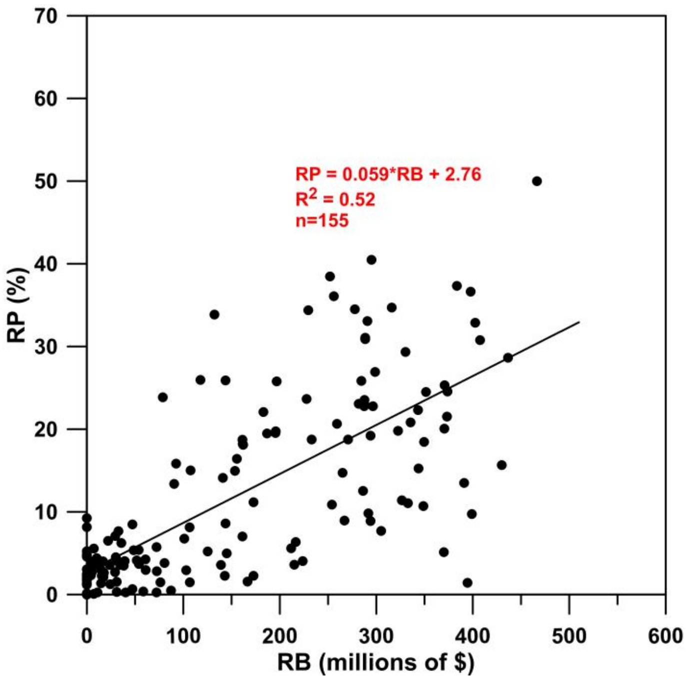


Figure 3. Correlation of relative performance (RP) and relative budgets (RB) for the 2000-2019 data using the simple linear regression model.

4.2 Correlation of relative performance, relative budgets and drivers' effect

To incorporate the drivers' effect (DR), a multivariable linear regression model is established. The constructed model yields an F-statistic of 123.4 and, therefore, the regression is statistically significant at any level. However, in order to observe whether this applies to both independent variables, the T-statistic is used. The T_{stats} for the DR and the RB variables are 6.27 and 5.86, respectively. The corresponding marginal levels of significance using the T_{stat} (p-values) are practically 0 ($p_{DR} = 3.6 * 10^{-9}$ & $p_{RB} = 2.8 \times 10^{-8}$), hence there is strong evidence proving that both RB and DR are correlated with the RP. The multivariable linear regression model yields:

$$RP_{Y,j} = 5.981 + 0.0338 \times RB_{Y,j} + 1.136 \times DR_{Y,j} + \varepsilon_{Y,j} \geq 0, R^2_{adj} = 0.61 \quad (8)$$

Where R^2_{adj} is the adjusted coefficient of determination.

The derived model suggests that:

1. The predicted relative performance of a team with the lowest budget of the season (RB=0) that has a net driver effect (DR=0) is 5.981%;
2. An increase in the RB by one million $ will increase the expected RP by 0.0338%
3. An increase/decrease in the team's drivers ranking by one will increase/decrease the overall relative performance by 1.136%.

The data plots between RP-RB and RP-DR given the multivariable regression model are depicted in **Figure 4**. A 3D plot of Equation [8] is depicted in **Figure 5**.

The relative budgets and drivers' effect were also examined in terms of collinearity using the variance inflationary factor [Marquardt, 1970]:

$$VIF = \frac{1}{1 - R_j} \quad (9)$$

Where R_j is the coefficient of determination between RB and DR (or DR and RB). VIF exceeding 5-10 indicates collinearity issues and the corresponding regression model should be used with caution [Berenson et al., 2020]. The corresponding VIF is equal to 1.92. This indicates that DR and RB are low-moderately correlated but not to an extent that makes the model unreliable.

The partial coefficients of determination $R_{DR/RB}$ and $R_{RB/DR}$ were 21% and 18%. Therefore:

1. An additional 21% of the variation in an F1 team performance is explained by the variation of the DR after the RB effect has been considered and;
2. An additional 18% of the variation in an F1 team performance is explained by the variation of the RB after the DR has been considered.

Those indicate that the additional contribution of the DR in the model, once the RP effect is included, is relatively low and vice versa. Hence, the RP of a team with a low RB will not be dramatically changed due to its drivers' abilities (a phenomenon that is reasonable and frequently observed in F1).

4.3 Multivariable regression residual analysis

The residuals derive from the multivariable regression model and allow for identifying which teams have been more efficient during the studied period. The residuals per season plots for each F1 team are presented in **Figures 6a-j** and descriptive statistics are documented in **Table 5**. Our analysis suggests that the teams that thrived during the studied period (namely, Ferrari, Red Bull and Mercedes) were also efficient (since their average residuals are positive), performing better than the average F1 team would, given the same budget and drivers. This is an important finding proving that their dominant periods should not be attributed solely to their high budgets and the fact that they hired capable drivers. More generally, the assessment proves that it takes more than a high budget to be successful in Formula 1. The aforementioned teams have won 17/20 championships between 2000 and 2019 and are grouped among the most efficient ones. On the contrary, teams that had relatively high budgets and good drivers but did not succeed as much are considered inefficient (e.g., McLaren, Williams).

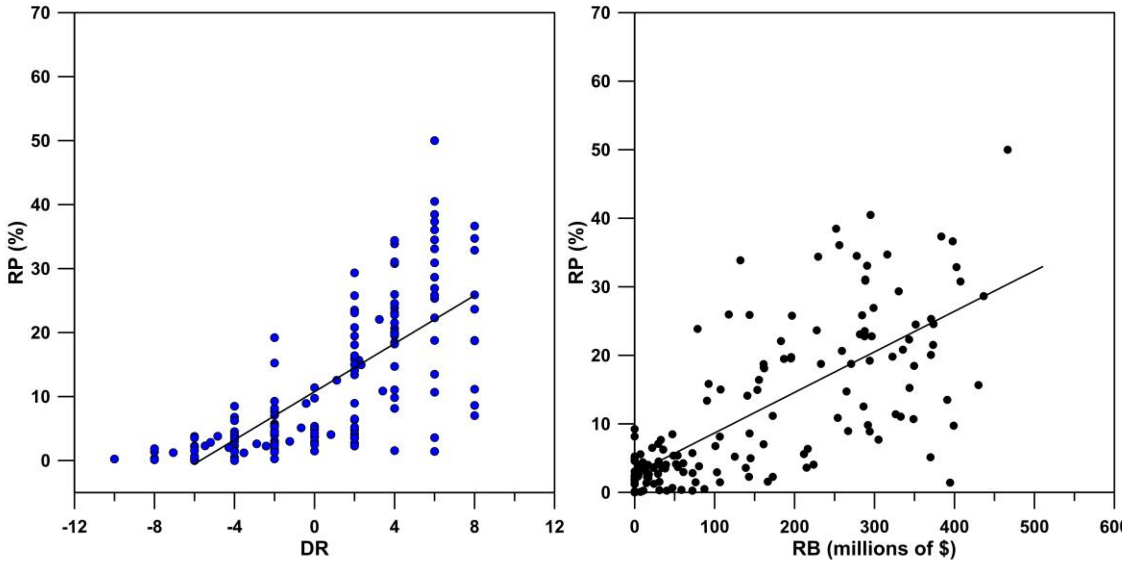


Figure 4. Correlation of relative performance-RP with drivers' effect-DR (left) and relative performance-RP with relative budget-RB (right) using the multivariable regression model.

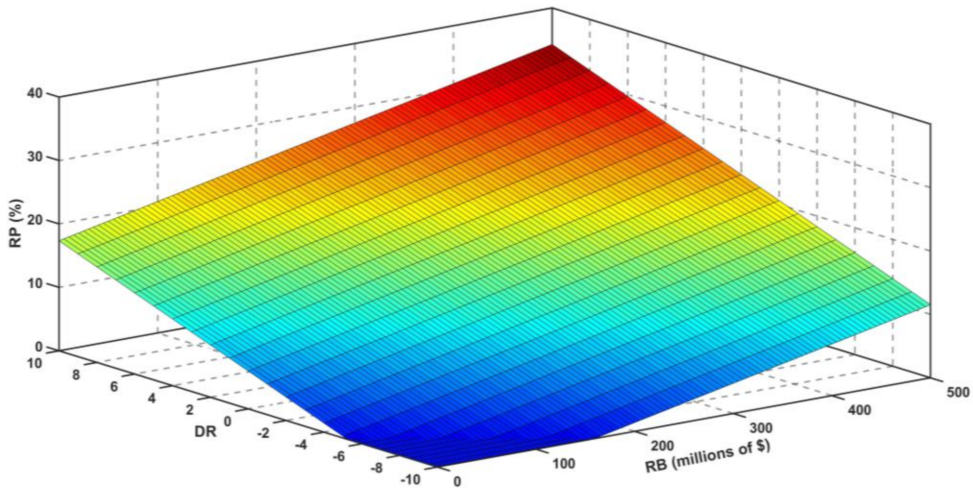
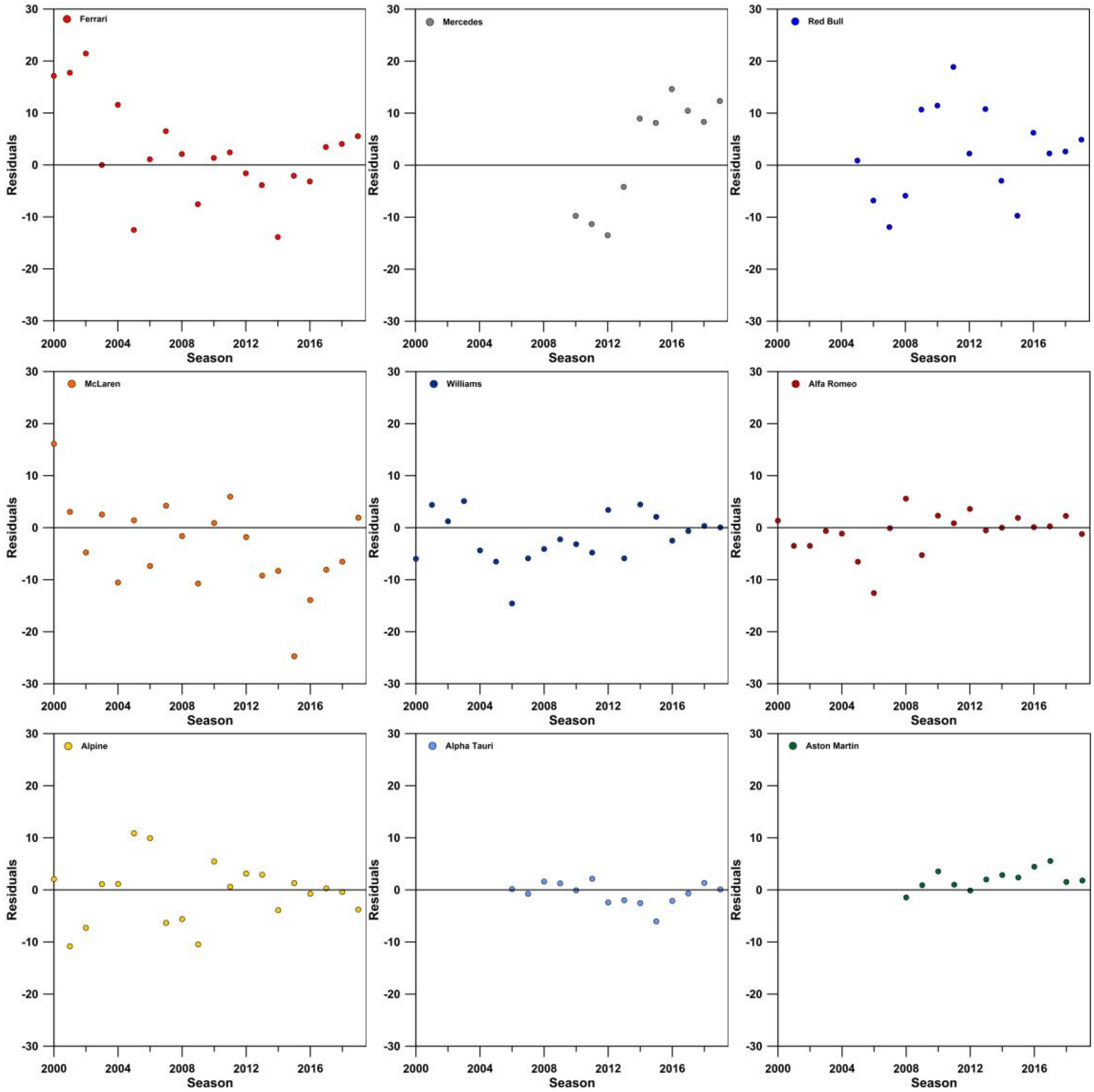


Figure 5. A 3D surface plot of the multiple regression model between the independent variables (relative budget-RB and drivers' effect-DR) and the predicted relative performance (RP).

Statistics	Ferrari	Mercedes	Red Bull	McLaren	Williams	Alfa-Romeo	Alpine	Alpha Tauri	Aston Martin	Haas
Mean	**2.48**	**2.41**	**2.24**	**-3.58**	**-1.99**	**-0.84**	**-0.53**	**-0.72**	**2.04**	**-1.04**
Standard Error	2.0	3.4	2.2	2.0	1.1	0.9	1.3	0.6	0.6	0.6
Standard Deviation	9.2	10.8	8.6	8.7	4.8	4.0	5.8	2.2	1.9	1.2
Range	35.3	28.1	30.8	40.8	19.7	18.2	21.7	8.2	7.0	2.7
Minimum	-13.9	-13.5	-11.9	-24.7	-14.6	-12.6	-10.8	-6.0	-1.4	-2.4
Maximum	21.4	14.6	18.9	16.1	5.1	5.6	10.9	2.1	5.5	0.3
Seasons	20	10	15	20	20	20	20	14	12	4

Table 5. Descriptive statistics of the relative performance residuals for each F1 team (multivariable regression model).



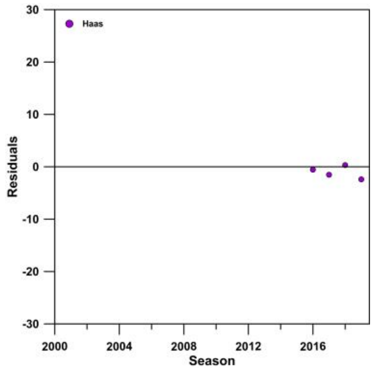


Figure 6. Residuals of relative performance (RP) per season (2000-2019) for a) Ferrari, b) Mercedes, c) Red Bull, d) McLaren, e) Williams, f) Alfa Romeo, g) Alpine, h) Alpha Tauri, i) Aston Martin and j) Haas.

Nonetheless, before further assessing the efficiency of each F1 team, a certain adjustment should be introduced. The aforementioned findings include all the data collected for F1 teams in the studied period. However, there are two types of teams involved in the F1 championship; those that existed before 2000 and those that formed after 2000 (Red Bull, Alpha Tauri, Aston Martin, Haas, Mercedes). The latter experience a competitive disadvantage in their initial seasons as they have to adjust to the sport. To remedy this, the data will be re-evaluated by excluding the first 3 seasons for the teams that entered the championship after 2000. This will allow the new teams to have a transition period to adjust to the sport. To be fair, this adjustment should also apply to newly formed teams in the early 2000s. The only team that was formed at that time is Alpine (as Renault) which bought the team of Benetton in 2000, hence it can be considered as a new team for 2000-2002 (3 seasons). This adjustment could not be applied to Haas since the team formed in 2016, therefore three out of four seasons would have to be excluded from the analyses. The mean residual RPs per team after these adjustments were implemented are documented in **Table 6**. Observe that the performance of Mercedes significantly increases to a residual of 8.37% while Red Bull's efficiency almost doubles. The efficiency of Alpine is also reversed presenting a positive mean residual. The only team that is negatively affected is Alpha Tauri which performed better in its initial seasons.

4.4 The efficiency ratio

To further understand the efficiency of the F1 teams, a relative measure should be employed. This measure must account for the differences in the expected relative performance of each team. The relative efficiency of each F1 team will be taken into consideration by introducing the efficiency ratio:

$$EF = \frac{ARP_j}{ARP_{e,j}} \tag{10}$$

$$ARP_{e,j} = ARP_j - Mean\ Residual\ RP_j \tag{11}$$

Where ARP_j is the average relative performance of team j (**Table 6**) and $ARP_{e,j}$ is the expected average relative performance of team j given the multivariable regression model (Equation 8).

F1 team	Mean RP_{adj}
Ferrari	2.48
Mercedes	8.37
Red Bull	4.29
McLaren	-3.58
Williams	-1.99
Alfa Romeo	-0.84
Alpine	0.33
Alpha Tauri	-1.00
Aston Martin	2.38
Haas	-

Table 6. Average relative performance (RP) residuals adjusted for newly formed teams (multivariable regression model)

Following this rationale, the efficiency ratios for all teams are calculated and documented in **Table 7**. The efficiency ratio can be interpreted as follows: For every 1% of the RP points that the average F1 team with a specific budget and drivers would acquire, the studied team would convert it into its efficiency ratio (i.e., Ferrari would convert it into 1.11%, Mercedes into 1.35%, Red Bull into 1.26%, etc.). Observe that, in relative terms, Aston Martin is even more efficient than Mercedes (1.66%).

Conclusively, based on our analyses in the studied period, the teams can be classified in terms of relative efficiency among the following groups:

- Efficient teams: Ferrari, Mercedes, Red Bull, Aston Martin (EF>1.00)
- Quasi-balanced teams: Alpine (EF≃1.00)
- Inefficient teams: McLaren, Williams, Alfa Romeo, Alpha Tauri, Haas. (EF<1.00)

F1 team	Efficiency ratios
Ferrari	1.11
Mercedes	1.35
Red Bull	1.26
McLaren	0.82
Williams	0.80
Alfa Romeo	0.84
Alpine	1.03
Alpha Tauri	0.68
Aston Martin	1.66
Haas	0.69

Table 7. Efficiency ratios for each F1 team. Data from the three initial seasons for newly formed teams are excluded (except for Haas)

4.5 Establishment of a prediction model

Herein the efficiency ratios derived in the previous section will be incorporated into the multivariable regression model to establish a prediction model. Based on the efficiency ratios (**Table 7**) and the results from the multivariable regression model (Equation 8), the following prediction model is established:

$$RP_j = \left(5.981 + 0.0338 * RB_j + 1.136 * DR_j\right) * EF_j \qquad (12)$$

Where EF_j is the efficiency ratio of each F1.

The new model has a higher adjusted coefficient of determination compared to the previous one, namely 70%. Therefore, 70% of the variation in RP can be explained by the variability of the RB, DR and EF. The relationship between the predicted versus the real RP of all the accumulated data is illustrated in **Figure 7**. The efficiency ratios regard the *average* relative efficiency of each F1 team and cannot account for the performance of each team on a seasonal basis. For example, observe the variability in the performance of each F1 team (**Table 3**). This cannot be predicted using a single coefficient but it is associated with more complex issues such as the initial conditions of each season, errors or success in the design of the car made in that season, the synergy of the staff, or even the instance of good or bad luck during races. It should not be neglected that F1 is fundamentally a sport and thus, unpredictable factors (e.g., fortune) play an important role in the overall performance of the contestants.

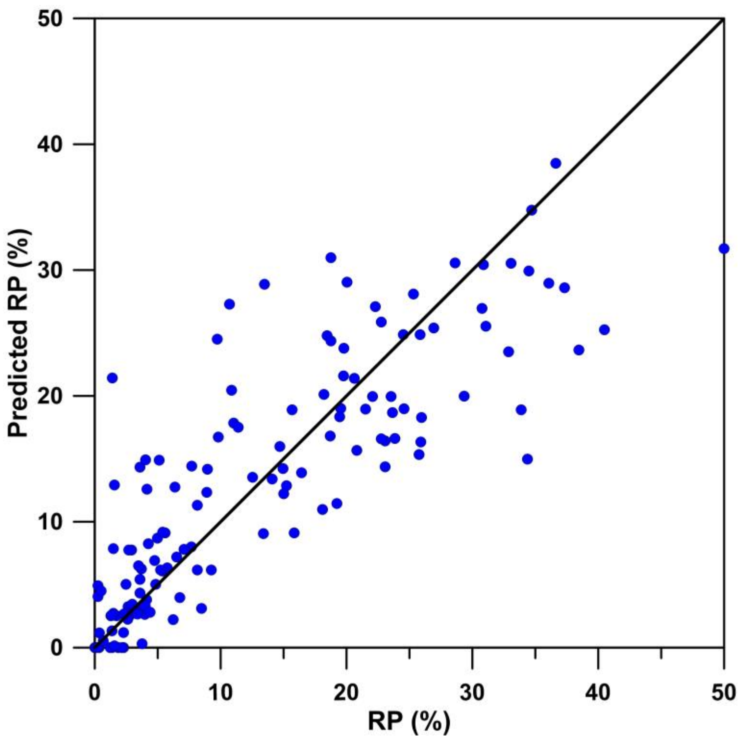


Figure 7. Predicted versus observed relative performance (RP) of all F1 teams given the established prediction model.

4.6 Future predictions

The future predictions presented herein are based on the two (2) following assumptions:

1. The budget cap will not be manipulated and will serve its purpose so that the teams' expenditures will be more balanced.
2. The F1 teams will maintain their historical efficiency as this was quantified through the efficiency ratios.

The fundamental difference between the studied period (2000-2019) and the future is that the effect of the budgets on performance will be mitigated. Still, some differences in the budgets are expected since not all teams will presumably reach the budget cap in the following years. According to G. Steiner, team principal of Haas, the differences will be reduced to "$10-20 million" [Mitchell, 2022]. Therefore, it would be reasonable to deduce that the relative budget of an F1 team will not be greater than $40 million from now on (2 times the amount that G. Steiner suggested).

Furthermore, the drivers' effect will be incorporated but the current form of the drivers participating in the 2022 championship cannot be derived from **Table 4**. That database includes the drivers' ranking up to 2019 and fits the studied period. However, young drivers who were considered rookies at that time have evolved and are currently performing very well, thus, the results based on that date would be unrealistic. According to their recent performance, the 2022 drivers' rankings are presented in **Table 8**. In addition, since the future drivers' lineups are unknown, it is essential to observe how the efficiency will affect the predicted RP if drivers with the same capabilities are assumed for all the teams. **Figures 8a** and **8b** illustrate the expected RP and RB correlation for all teams given the current drivers' ranking and assuming all the drivers are alike, respectively. In **Figure 8a**, the team with the highest expected performance is Mercedes since it has both a high driver's ranking (6) and an efficiency ratio (1.35). Red Bull and Ferrari follow in the 2nd and 3rd place. The efficiency of Aston Martin is not so evident since it currently features a driver's lineup with a moderate rating (-2). It may seem that the balance has not changed but the field is, in fact, much closer. The highest RPs predicted are less than 20% when the corresponding values during 2000-2019 reached up to 50% (Ferrari, 2002) with an average value of 32%. This indicates that the championship will be more competitive. Moreover, the data plot proves that the differences in the budgets will not make a significant variance and, thus, winning will be a matter of efficiency and drivers' skills. The predicted performance of the teams is much closer when all drivers are considered equivalent (**Figure 8b**). In that case, the championship is expected to be very unpredictable and only the details will be making the difference.

Finally, the historical RP of F1 teams from 2000 to 2019 and the predicted RP (with and without the drivers' effect) are illustrated in **Figure 9**. Observe that the advantage of the Ferrari, Mercedes and Red Bull is mitigated in the predicted RP model with the DR incorporated and it is almost eliminated once the DR is assumed to be equal for every team. This extreme case will entirely balance the field since all teams will have the same funds (more or less) to design and develop their car and the skills of their drivers will be equal. Therefore, the efficiency of each team will play the most important role.

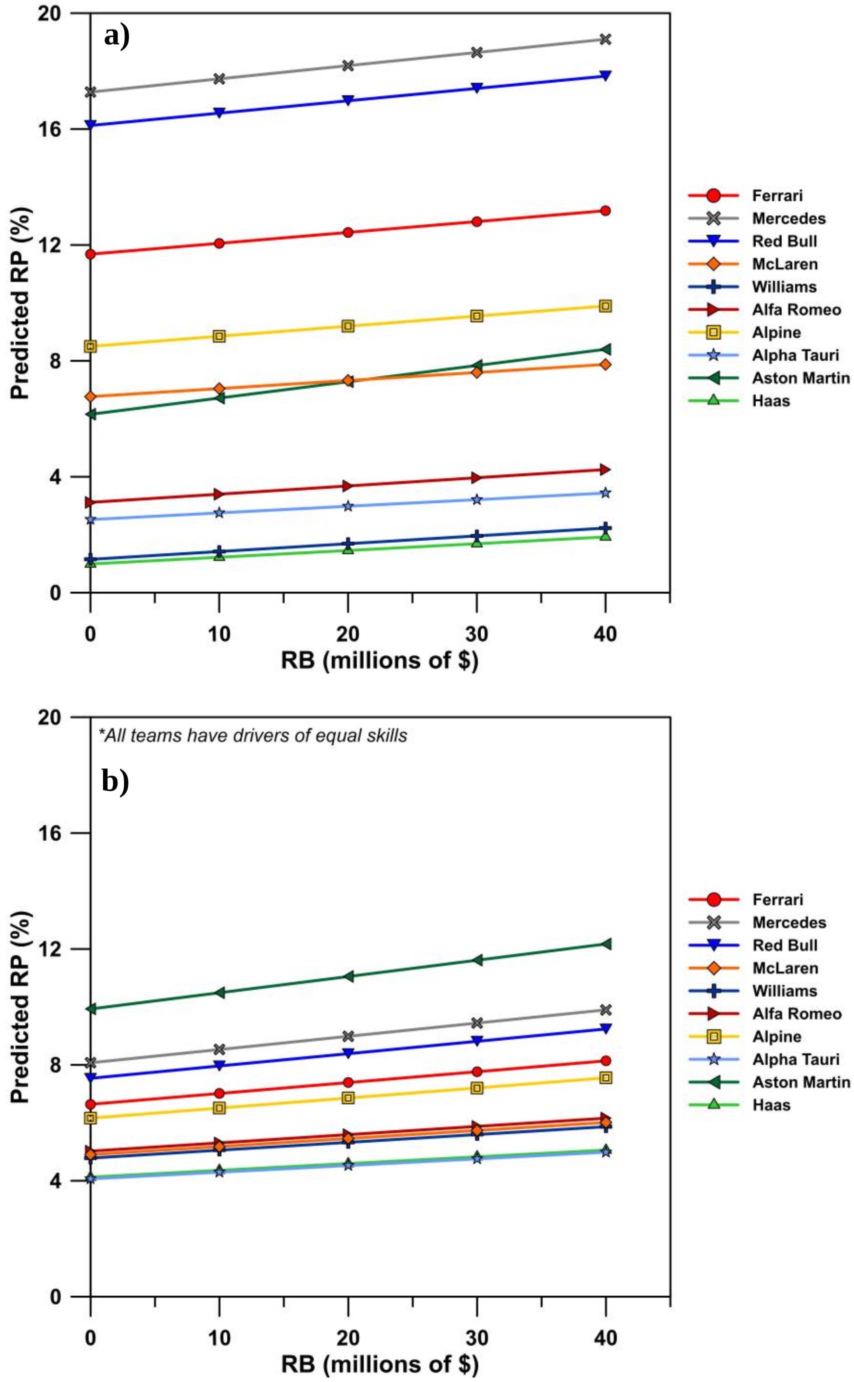


Figure 8. Predicted relative performance (RP) versus relative budget (RB) for all F1 teams given their historical efficiency and a) current drivers' lineup and b) assuming drivers of equal skills for all F1 teams.

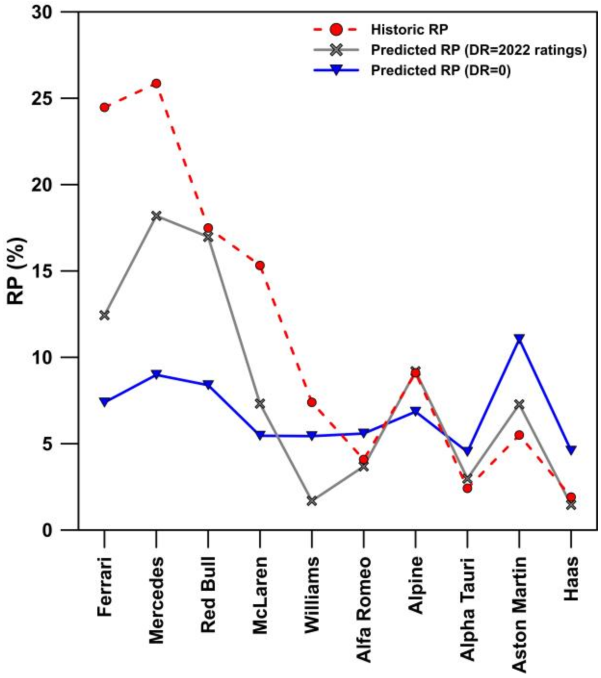


Figure 9. *Average historical and predicted relative performance (RP) (with and without the drivers' effect) for all F1 teams participating in the 2022 championship*.

5. Discussion

The present study showed that the budgets and performances are interconnected in F1. However, additional parameters are incorporated when it comes to the total output of an F1 team. Those were grouped into the team effects (efficiency) and drivers' effect (driver rating). Our prediction model indicates that the budget cap will eventually reduce the gap between top teams and the midfield. The fact that the top-3 teams (i.e., Ferrari, Mercedes and Red Bull) have also proved to be efficient (besides having higher budgets) and currently occupy the best drivers in F1 will certainly make the attempts of the subsequent teams more difficult but, not unachievable. Also, note that the aforementioned findings concern the long-term performance of the F1 teams. F1 is a motorsport that relies on past development and experience. Evidently, the top teams will still have an advantage in the early years of the budget cap enforcement due to past R&D, knowledge and experience.

Regarding the limitations of the present study, it should be noted that the performance assessment is a highly complex procedure that cannot be exactly predicted (as in all sports). Herein, its variability was explained adequately up to 70%, with the use of the three (3) main independent variables (budgets, drivers' effect and team efficiency) which are used to assess the historical performance of F1 teams. The subsequent 30% is due to numerous factors that cannot be readily quantified. An accident, a defective component, a bad strategic decision during a race, or a human error are all examples of incidents that will affect the performance of an F1 team but cannot be accounted for.

In addition, we evaluated the teams' performance over the past 2 decades, drew conclusions on their current form and, based on these results, we established predictions for the future. The assumption made here is that the teams will continue to perform as they did during the studied period. It is unknown whether each team's efficiency will improve or deteriorate in the future.

Finally, it is also noted that the budgets for each season were derived from journal papers, reliable sources available online, or hard copies of F1 magazines. This was necessary since the F1 teams do not publish their financial statements and therefore, no financial information could be obtained from official sources.

References

Autosport. Team budgets and employees in 2010. 2010. URL https://www.autosport.com/

BB. US media firm Liberty Media to buy Formula 1. 2016 URL https://www.bbc.com/news/business-37303230

Bell A., Smith J., Sabel C.E. and Jones K. Formula for success: Multilevel modelling of Formula One Driver and Constructor performance, 1950–2014., Journal of Quantitative Analysis in Sports, vol. 12, no. 2, 2016, pp. 99-112., 2016. https://doi.org/10.1515/jqas-2015-0050

Berenson M.L., Levine D.M., Szabat K.A. and Stephan, D. Basic Business Statistics: Concepts and Applications. 14th edition. Global Edition.ISBN-10:1-292-26503-5, 2020.

Boxall-Legge J. The last budget Formula 1 car. 2019. URL https://www.autosport.com/general/news/the-last-budget-formula-1-car-5111750/5111750/

Business F1. Credit Suisse Formula 1 Office, March and April issues, 2003.

Collantine K. $4,378,133–the price of a point in 2008. 2008. URL https://www.racefans.net/2008/11/09/4378133-the-price-of-a-point-in-2008/

Duggal R.N. Impact of Budget, Drivers and Team Personnel on Team Performance: Evidence from Formula 1 Motorsport Industry. Bachelor Thesis (IBEB). University of Rotterdam. 2020.

F1 Racing. F1 Racing Magazine, March issue. 2003a

F1 Racing. F1 Racing Magazine, September issue. 2003b

F1 Racing. F1 Racing Magazine, April issue. 2004

F1 Racing. F1 Racing Magazine, February issue. 2005

F1 Racing. F1 Racing Magazine, September issue. 2006

F1skill. F1 skill rating, Rating Indices. 2022. URL https://f1skill.com/

Fédération Internationale de l'Automobile. 2021 Formula 1 Financial Regulations. 2021. URL https://www.fia.com/sites/default/files/2021_formula_ 1_financial_regulations-52020-04-30.pdf

Forbes. Most Valuable Formula 1 Racing Teams. 2010. URL https://www.forbes.com/2010/06/24/formula-one-valuations-business-sportsmoney-formula-one_slide.html?sh=76e33a4f53b6

Forbes. Formula One's Most Valuable Teams. 2012. URL https://www.forbes.com/pictures/emdm45kllj/formula-ones-most-valuable-teams/?sh=4291d6f12acc

Forbes. Formula One's Most Valuable Teams 2014. 2014. URL https://www.forbes.com/pictures/emdm45ekedf/2-mclaren-3/?sh=46233aef638d

Forbes. Formula One's Most Valuable Teams 2015. 2015. URL https://www.forbes.com/pictures/emdm45emfmk/9-sauber/?sh=5583707f74c7

Heathfield D.F. Production Functions. In: Heathfield, D.F. (eds) Topics in Applied Macroeconomics. Palgrave, London. 1976. https://doi.org/10.1007/978-1-349-86197-2_2

Henderson J.C., Foo K., Lim H., and Yip S. Sports events and tourism: The Singapore formula one grand prix. International Journal of Event and Festival Management, 1, 60–73. 2010. http://dx.doi.org/10.1108/17852951011029306

Herbrich R., Minka T. and Graepel T. TrueSkill: A Bayesian Skill Rating System, Advances in Neural Information Processing Systems 19, MIT Press, pp. 569–576. 2007.

Judde C., Booth R. and Brooks R. Second Place Is First of the Losers: An Analysis of Competitive Balance in Formula One. Journal of Sports Economics, 14(4), 411–439. 2013 https://doi.org/10.1177%2F1527002513496009

Marquardt D.W. Generalized Inverses, Ridge Regression, Biased Linear Estimation, and Nonlinear Estimation. Technometrics, 12, 591–612. 1970.

Mitchell, S. Budget Differences between F1 teams down to 10-20M. 2022. URL https://the-race.com/formula-1/budget-differences-between-f1-teams-down-to-10-20m/

Mourão P. The economics of motorsports: the case of Formula One. ISBN: 978-1-137-60249-7. 2017. https://doi.org/10.1057/978-1-137-60249-7

Phillips A.J. Uncovering Formula One driver performances from 1950 to 2013 by adjusting for team and competition effects. Journal of Quantitative Analysis in Sports 10(2): 261-278. 2014. https://doi.org/10.1515/jqas-2013-0031

Rencken D. How much did Formula 1 teams spend in 2016? 2016. URL https://www.autosport.com/f1/news/how-much-did-formula-1-teams-spend-in-2016 5109312/5109312/

Rencken D. Revealed: What F1 teams really spent in 2017. 2017. URL https://www.autosport.com/f1/news/revealed-what-f1-teams-really-spent-in-2017 5110279/5110279/

Rencken D. The cost of F1 revealed: How much teams spent in 2018 – part one. 2018a. URL https://www.racefans.net/2018/12/19/how-much-f1-teams-spent-race-2018-part-one/

Rencken D. The cost of F1 revealed: How much teams spent in 2018 – part two. 2018b. URL https://www.racefans.net/2018/12/26/the-cost-of-f1-revealed-how-much-teams-spent-in-2018-part-two/

Rencken D. The cost of F1 2019: Team budgets analysed–part one. 2019. URL https://www.racefans.net/2019/12/27/the-cost-of-f1-2019-team-budgets-analysed-part-one/

Rencken D. The cost of F1 2019 part two: What the top teams spent. 2020. URL https://www.racefans.net/2020/01/02/the-cost-of-f1-2019-part-two-what-the-top-teams-spent/

Rottenberg S. The baseball players' labor market. The Journal of Political Economy, 64, 242–258. 1956.

Straw E. F1 must act on existential threat of its first cost cap impasse. 2022. URL https://the-race.com/formula-1/f1-must-act-on-existential-threat-of-its-first-cost-cap-impasse/

Sylt C. Red Bull Reveals How Much It Really Costs To Run An F1 Team. 2020. URL https://www.forbes.com/sites/csylt/2020/01/14/red-bull-reveals-how-much-it-really-costs-to-run-an-f1-team/?sh=5023cf2477c1

U.S. Bureau of Labor Statistics. Employment situation summary. 2022. URL https://www.bls.gov/cpi/tables/

Wood R. F1 Info Guide (Pt. 1): Money, Money, Money—The Fuel of Formula On. 2008. URL https://bleacherreport.com/articles/40593-f1-info-guide-pt-1-money-money-money-the-fuel-of-formula-one