Power Laws and Path Dependence in Formula One

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ABSTRACT

Evidence of a Power law points to the existence of a complex system – a system that exhibits feedback loops, hierarchical organization and some degree of spontaneous order. Traditional models are ineffective in analyzing how and why these systems operate. The distribution of success in Formula One matches that of a Power law but the question remains how and why? The key factors for success in Formula One appear to be financial and human resources. Through the use of an Agent Based Model (ABM) this paper explores the likelihood that Path Dependence and Increasing Returns to Scale are responsible for the presence of a Power law in Formula One.

Table of Content

Background

Formula One (F1) is the oldest global motorsport category that is supervised by the International Automobile Federation (or FIA). Since the modern era began in 1950, 893 Grand Prix have been held[1]. Table 1 provides a summary of the outcome of those races. The key message is that reaching the pinnacle of F1 is difficult with only 22% of teams having recorded a win and 16% recording more than one victory. Additionally, while 137 teams have competed only ten remain today.

Table 1: Historical Summary of Formula One (source Wikipedia)

Races Held	Teams that have competed	Teams that have won at least one race	Teams that have won > 1 race	Teams that have recorded a Pole	Teams that have recorded a fastest laps
893	137	31	23	34	38

F1 is clearly about performance – and in particular relative performance with recording race wins the ultimate aim. Other measures of performance include; pole positions – a measure of outright speed, fastest laps – balancing the need for outright speed with the need to finish a race and podiums – a measure of consistent in performance.

Since its inception F1 has transformed from a medium for auto manufactures to showcase their wearies into an entertainment and luxury brand business, with (Jenkins, 2010) suggesting more specially that F1 is a technology based entertainment product, producing an engineering product (the car) with the purpose generating money via selling a marketing service (sponsorship). F1 is now the third largest annual sporting event in the world in terms of revenue and the most watched annual sporting event in the world[2] making it particular attractive to sponsors.

Table 2 Revenue Generation By Sporting Championships (source: Cabral, Forthcoming)

Global Sporting Event	2006/07 Seasons
National Football League (NFL)	£3.2bn
Major League Baseball (MLB)	£2.5bn
F1's global revenues	£1.9bn
The Premier League	£1.4bn

[1] Update until the 2015 Bahrain Grand Prix. Data source: Wikipedia

[2] The Olympics and the World Cup have larger audiences but are not held annually

The £1.9bn billion revenue generated by F1 in 2006/07 comprised of central revenues - from broadcasting, race sponsorship and corporate hospitality, team revenues - including sponsorship and contributions from their commercial partners and owners, and circuit revenues - from ticketing and certain sponsorships.

Empirical Findings

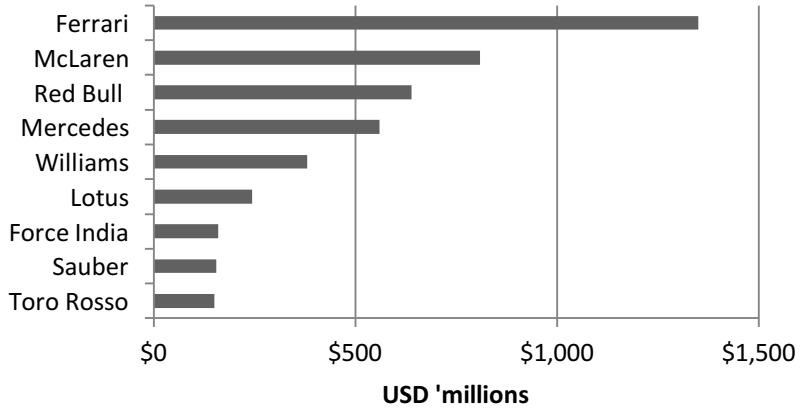
To further highlight the difficuly of becoming and remaining competitive in F1, Table 3 shows the top 10 teams in terms of wins and whether they are still racing. Supporting the theory that it is difficult to maintain performance is the fact that five of the top ten teams of all time are no longer racing. It should also be noted that the two most successful teams in the last 5 years - Red Bull and Mercedes have won 25% of the races they have entered. In terms of the last three seasons those two teams have won 43 of a possible 58 races (75%) and won ever race between them in 2014 as teams struggled with the introduction of new engine regulations.

Table 3 The Top Ten Formula One Teams in Terms of Wins 1950 - May 2015 (source Wikipedia)

Constructor	Status	Races	Wins	Winning %
Ferrari	Active	893	222	25%
McLaren	Active	764	182	24%
Williams	Active	619	114	18%
Lotus (1958–1994)	Not-Active	493	79	16%
Red Bull	Active	187	50	27%
Renault	Not-Active	303	35	12%
Brabham	Not-Active	402	35	9%
Mercedes	Active	111	31	28%
Benetton	Not-Active	260	27	10%
Tyrrell	Not-Active	433	23	5%

Ferrari is clearly the dominant team over the history of F1 - having won 16 constructor and 15 driver championships and achieving a winning percentage equivalent to the recent upstarts (Red-Bull and Mercedes). Its achievements on the track have translated into a brand worth $1.35 billion (see Figure 1). Forbes lists Ferrari as one of the 50 most valuable sports teams in the world; of the 50 only two (McLaren being the other) are involved in any form of motorsport.

Figure 1 The Value of F1 Teams (Source Smith 2014)



Given the lopsided distribution of success in F1 the existence of a Power law was tested for. Table 4 summarizes the statistics for the data set (all races from 1950 as per Wikipedia) while Figures A1 through A8 below show the cumulative distributions for podiums, pole positions, race wins and fastest laps. Results indicate that a Power Law is present in F1 and were present in the four categories utilized to judge competitiveness. The remainder of the paper explores the rationale for how path dependence and increasing returns (Arthur, 1994) could be responsible for the creation of the Power law distribution in F1.

Table 4 Power Law Distributions in F1

	Wins	Podiums	Pole Positions	Fastest Laps
Xmin (automatic)	8	58	9	14
Alpha	1.78	2.14	1.74	1.94
log-likelihood	-81.9	-69.5	-71.8	-66.1
Kolmogorov-Smirnov (KS) stat	.131	.132	.20	.131
KS Probability	.919	.985	.579	.969
Xmin (manual)	6	12	7	8
Alpha	2	1.667	2	1.675
log-likelihood	-88.1	-133.6	-78.52	-78.26
Kolmogorov-Smirnov (KS) stat	.311	.142	.326	.202
KS Probability	.061	.69	.066	.531

Figure A1 – Cumulative Distribution Podiums

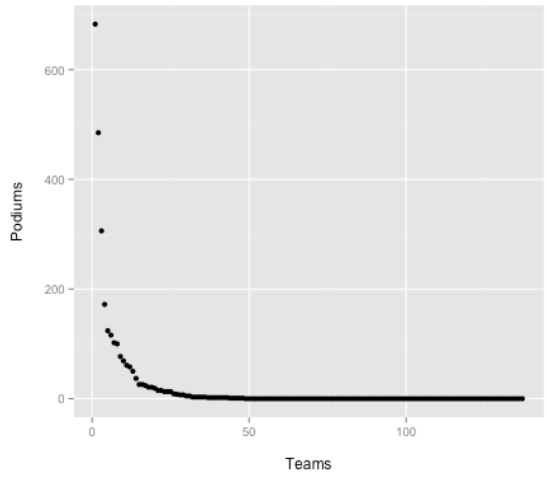


Figure A2 – Log Log Plot for Podiums

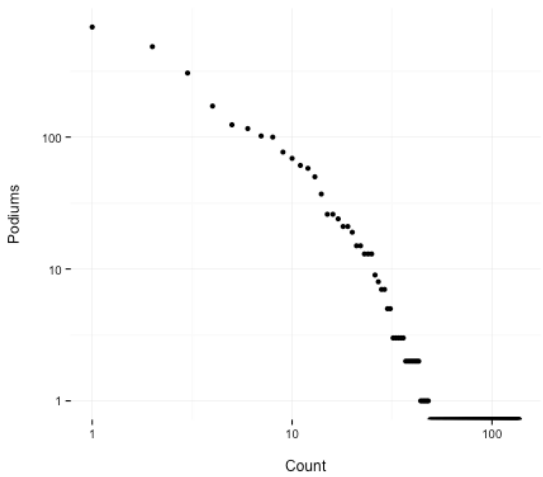


Figure A3– Cumulative Distribution Wins

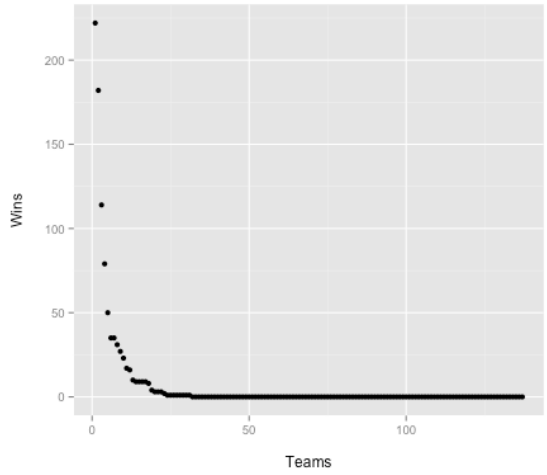


Figure A4 – Log Log Plot for Wins

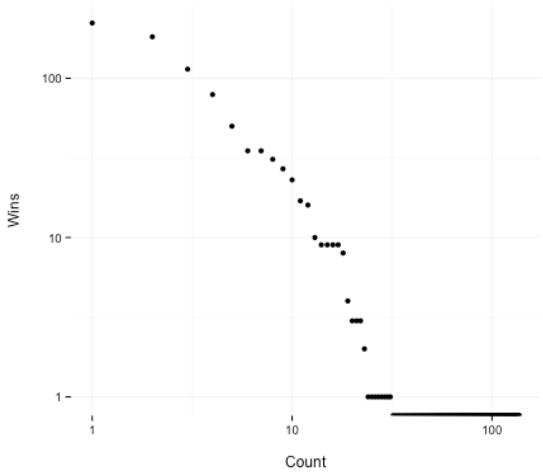


Figure A5 – Cumulative Distribution Poles

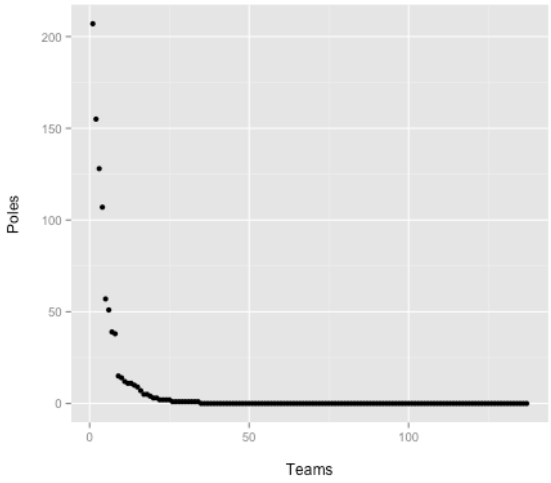


Figure A6 – Log Log Plot for Poles

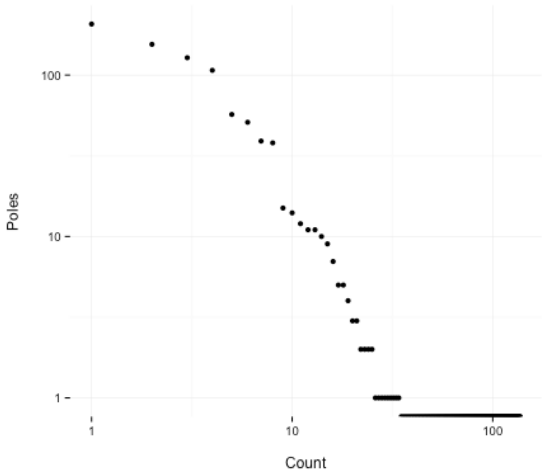


Figure A7 – Cumulative Distribution Fastest Laps

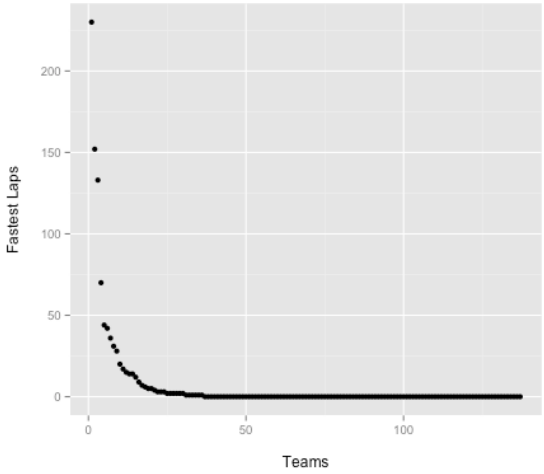
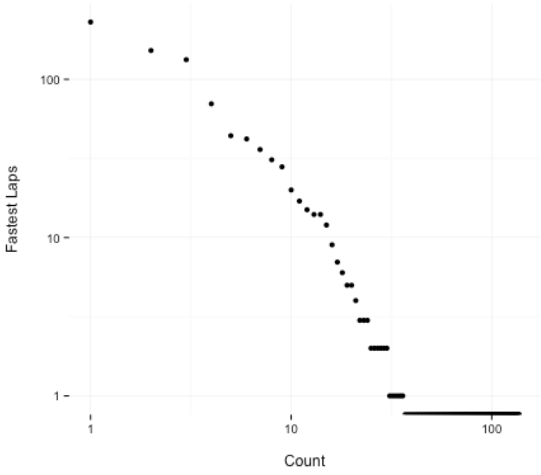


Figure A8– Log Log Plot for Fastest Laps



Success in F1

"The difference between the top teams is so small – detail, really – and focus and determination and winning mentality" Martin Brundle (Jenkins, Pasternak, & West, 2005)

While the difference in the top teams may be very small, to win in F1 requires cash and key personal (not just a driver) – i.e. it requires an unique combination of financial resources and human capital (Jenkins et al., 2005). This is because F1 is a people based industry that relies on cash to fund R&D and HR resources to undertake the technological development. The findings of (Essays, n.d.) are consistent with this argument, adding that a successful team requires a combination of physical and financial resources, and intellectual capital. The need to attract and retain HR talent and sponsors will form the basis of an Agent Based Model (ABM) designed to simulate the distribution of success in F1.

Success in F1 is a two-stage process where the teams must firstly become successful and secondly remain competitive. To achieve this (Jenkins et al., 2005) identifies three vital steps;

- Building a competitive team;
- Adapting to new conditions; and
- Continuing to innovate.

Building a Competitive F1 Team

From its humble origins, where amateur mechanics could design and enter a car into a Grand Prix, F1 has developed into a highly specialized and competitive sport. As Table 1 highlighted gaining success in F1 is a difficult if not impossible task. This competitive environment sees the average life of F1 team being half that of a public UK company – 6 years (Jenkins, 2010). In addition to the aforementioned steps that are required to become and remain competitive, (Jenkins et al., 2005) propose that there are a further three key requirements for simply creating a competitive team - not necessarily a winning team. These requirements and their components are;

- The creation of a competitive F1 car;
    - Possessing the skills and budget to design and engineer a fast and reliable car;
    - The team must have the capability to manufacture the car and its various parts; plus
    - Have R&D facilities to continue development (Essays, n.d.).
- Deliver consistent race winning performance;

- With a consistently changing environment a F1 team must be able to solve problems quickly and innovate during the course of the season.

- Generate consistent revenue streams for the following reasons;
  - The need for revenue is evident in Figure 2. This index captures the proportion of points gained over the proportion of the total F1 budget. If the team has an index value greater than one they are outperforming because they are capturing a greater proportion of the points than their budget would suggest is warranted.
  - There are high start-up and continued running costs associated with F1.

The costs associated with running a team and how teams generate revenue is discussed below.

Figure 2. Do budgets explain performance? (Jenkins et al., 2005)

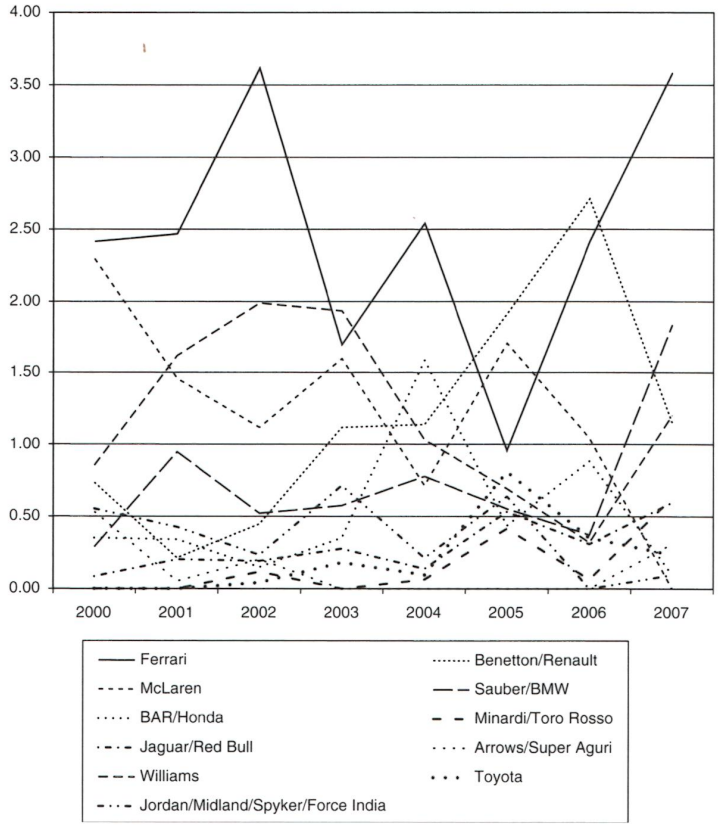


Figure 24 Value for money in Formula 1: share of points v. share of budget, 2000–07

Revenue, Budgets and Costs

The transformation of F1 into a global sporting phenomenon had a significant impact on the costs associated with running a team. In the period from 1980 to 1987 the budgets of leading teams quadrupled and all but destroyed the dreams of many in pit lane (Cabral, Forthcoming). The major

consequence of the increased cost was the number of teams competing. In 1960 21 teams competed while only ten are competing in the 2015 Championship (with Manor Marussia F1 Team struggling to qualify). Since the Global Financial Crisis (GFC) team budgets have reduced materially (Cabral, Forthcoming) due to the economy and cost cutting measure by the regulator.

Success in F1 requires long-term R&D investments, which is affordable only through attracting sufficient sponsorship and the right people to generate a return on that investment. The typical costs for a F1 team are shown on Figure 3 with most of the money spent on technology - a requirement for ensuring the team remains competitive.

Figure 3. Typical Costs for a Formula One Team (source http://wtf1.co.uk/f1-team-budgets-infographic/)

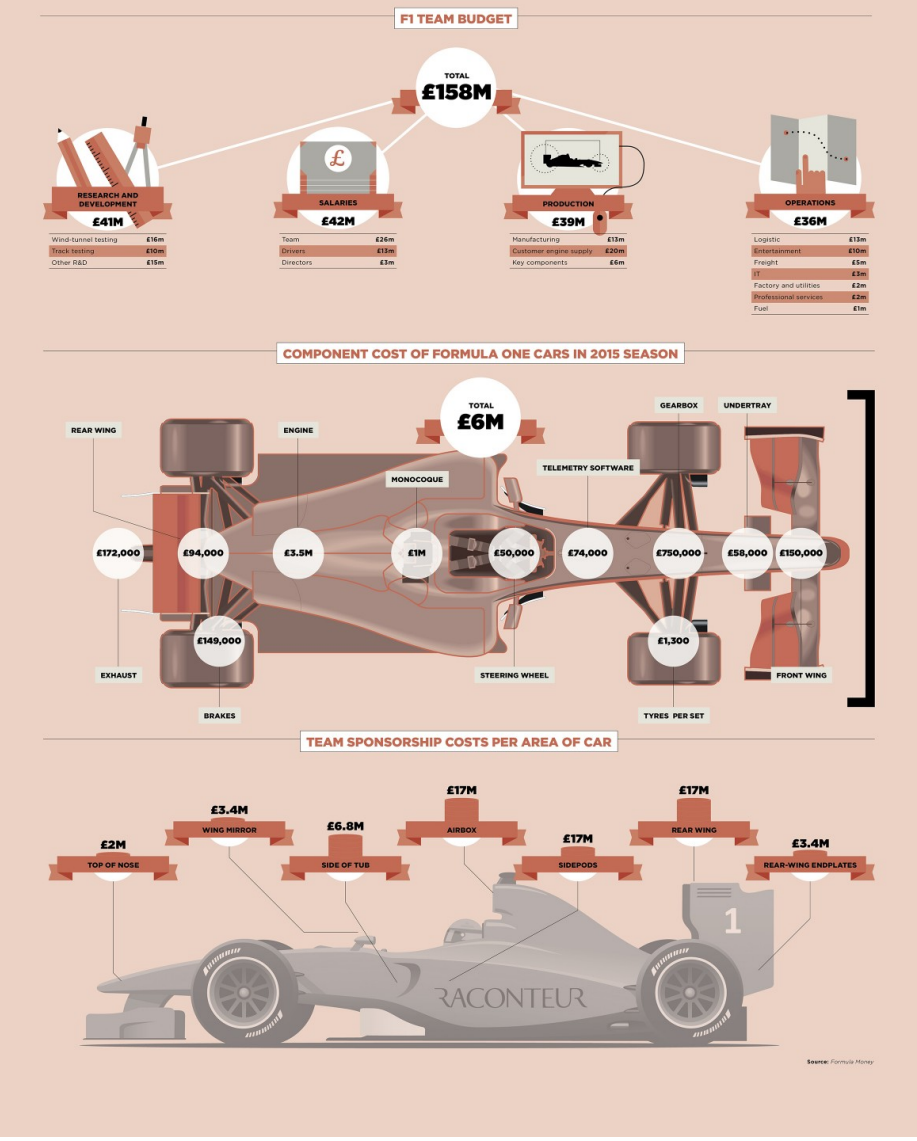
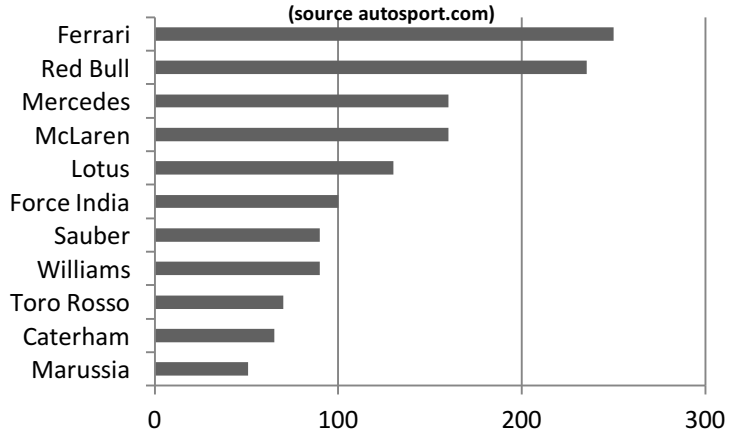


Figure 4. 2013 Formula 1 Budgets (£ million)



"F1 a celebration of unfairness; if you win you get more money, you get more TV" Tony Purnell CEO Ford Performance Division (Jenkins et al., 2005, pg 198).

Financial resources are vital because a successful team needs the latest and best technologies that money can buy. Teams rely of funding from the sport, manufacturers and a range of sponsors to meet their budget requirements. One source of the revenue is prize money but as the quote from Tony Purnell indicates this revenue is very much path dependent. The teams shared just over 60% of F1 profit, which was worth about $800 million in 2013 (Smith, 2014). This situation arouse because F1 the man behind F1 -Bernie Ecclestone, built a system that favored the larger more successful teams. Interestingly, this approach is being tested at present, as the current F1 season is not only the most lopsided in years but also the smallest grid following the bankruptcy of two teams in 2014.

In 2007 there were 310 sponsors associated with F1, of those 97 companies paid total of $834 to get their name onto a car (Jenkins et al., 2005). Figure 3 illustrates the dollars required to gain exposure on a F1 car. Apart from raising sponsorship dollars F1 teams also benefit from signing technical and/or corporate partners. A technical partner assist in carrying R&D while a corporate partner provides in kind products. Examples of these are Shell who helps Ferrari with oils, fuels and lubricants and MAN trucks that provide the Williams team with transport equipment.

Human Resources:

Due to the highly competitive environment intangible skills and knowledge are vital to success in F1. A successful team needs a minimum level of experience and knowledge, which will either be developed over time, or recruited from elsewhere. To acquire this knowledge and expertise is very expensive and requires investment in staff, as well as technologies – underling the need for financial resources. The HR requirement has also expanded in step with the growth of F1 with the size of the

Williams team growing 190 in 1992 to 500 in 2008 (Jenkins et al., 2005).

It is important to not only achieve a critical team size but also recruit the rights skills. Teams managed by individuals who know the sport inside and out, win twice as many races as their general manager counterparts (Goodall & Pogrebna, 2014). Examining all F1 races from 1950-2011, the study revealed that former drivers and mechanics are significantly more successful than those with degrees in engineering or who were managers by trade.

The need to adapt and improvement

If producing a competitive car was not difficult enough F1 is consistently changing due to;

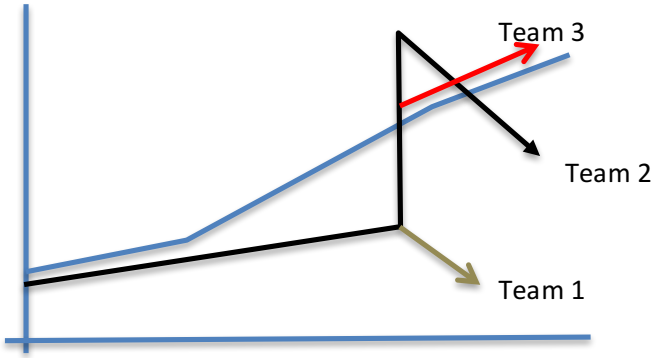
- One team gaining a competitive advantage through innovation – such as Mercedes since 2014; or
- New regulation being introduced by the governing body. Regulatory changes are akin to a shock to the system and have proved to be very disruptive in the past.

F1 teams use a combination of developing their own innovations and imitating those of their competitors to remain competitive. The need to innovate and improve in F1 car is evidenced when you compare the Monaco GP 1950 Pole Time of 1 minute 50 seconds to the time recorded in 2004 of approximately 1 minute 14 seconds (1.13.96) – a 33% improvement.

Given the above and the requirement to adapt to be successful, (Jenkins et al., 2005) put forward three explanations that explains the lifecycle of a team:

- A team fails to adapt to change – Team 1 Figure 5;
- Over-anticipate and can not get the full benefits of their efforts as they lacked resources to fully exploit or maintain their advantage– Team 2 Figure 5; or
- Undertake sufficient change to maintain success - Team 3 Figure 5.

Figure 5. Possible Paths of a Formula One Team (adapted from Jenkins et al., 2005)



In attempting to understand the impact of regulatory changes on the competitiveness of teams (Jenkins, 2010) identified five key regime changes that teams have had to endure in the modern F1 era. Since that study a sixth has come into effect with the introduction of hybrid turbo engines in 2014. The changes relating to the six regimes along with the dominant teams of each regime is found in Table 5. In summary those six regimes are;

1. Engine capacity reduced and weight limits introduced;
2. Engine capacity increased;
3. Ground skirts banned;
4. Turbo engines banned;
5. Car width reduced along with the introduction of grooved tyres; and
6. Kinetic energy recover (KERS) and 1.6 turbo engines introduced.

To highlight the disruptive nature of the changes the study identified 27 teams who had recorded a win but of these more than ½ (15) only did so during one of the regimes. In addition, only four of the 27 teams were able to win in more than three periods.

The disruptive nature of changes was also uneven:

"*The impact of these regulatory discontinuities on the competitive population was more significant in some cases than others. In 1966 – 1980 there were a total of 12 new Grand Prix winners compared to the previous period; whereas in 1989 – 1993 there were none. Ten of the 18 Grand Prix winners in 1966 to 1980 failed to continue their success into the following period; whereas all of the five teams winning in 1989 – 1993 did so. It can therefore be discerned that the identified discontinuities had differing effects on the competitive population at different points in time. In particular the regulatory changes made in 1961, 1966, 1981 and 1998 appeared to have the most significant impact on competitive dynamics and the performance of individual firms.*" (Jenkins, 2010)

Success in F1 is no easy task yet the rewards are large if it can be achieved. Ferrari is the team that has managed to win, adapt and endure better than any. However, despite their overall success Ferrari has had periods of un-competitiveness but due to its ability to attract vital resource given its history and prestige, they have always recovered and returned to being competitive if not the dominant team. A theory as to how and why they have managed to achieve this is laid out below.

Table 3 Regime Change in Formula One

Decade	1950's	1960's	1970's	1980's	1990's	2000's	2010's
Top 3 Teams	Alfa Lago-Talbot Ferrari	Cooper Lotus Ferrari	Lotus Ferrari March	Williams Ligier Brabham	McLaren Ferrari Benetton	Ferrari McLaren Benetton	Red-Bull Mercedes Ferrari
Regime[3]		**1 2**		**3**	**4**	**5**	**6**
Engines	Front mounted 4.5l Normally aspirated (NA)	Rear mounted 2.5l -> 1.5l->2.5l NA	Rear mounted 3.0l NA or 1.5l Turbo	Rear Mounted 1.5l Turbo	Rear mounted 3.5l V8 , V10 and V12	Rear mounted 3.0l -> 2.4l V8	Rear mounted 3.0l V8 replaced by 1.6l V6 Turbo
Key Technological changes		Maximum engine size reduced from 2.5 to 1.5 litres. Supercharging now banned. Weight limit of 450kg introduced. Maximum engine size increased from 1.5 to 2.5 litres	Slick tyres introduced Ground-effect cars appear Renault introduce the 1.5L Turbo Engine	Use of Ground Effect 'skirts' banned. (safety) Use of Turbo-chargers banned. All engines required to be normally aspirated. (cost reduction)	Removal of automated driver aids. Car maximum width reduced and use grooved tyres introduced.	Engines have to have 10 cylinders, with a maximum of five valves per cylinder. Traction and Launch Control re-introduced. Engine size reduced to 2.4L; 8 Cylinders only.	Slick tyres re-introduced Move to 1.6l V6 Turbo with Kinetic Engine Recovery and Hybrid power

[3] Regime 1 -5 from (Jenkins, 2010)

An Explanation – Path Dependence and Increasing Returns

Any feasible explanation of the looped sided success in F1 needs to consider how past success leads to future success through the ability of a success team to attract and retain sponsorship dollars and human resources. The rationale for including sponsorship and human resources is clear when you consider Ferrari - the most successful team, has the largest budget and the franchise is the most valuable in F1. The theory of Path Dependence and Increasing Returns (IRS) as pioneered by (Arthur, 1994) is one theory capable of explaining this relationship. To support this argument IRS is seen to reign in knowledge-based industries (Arthur, 1996), which is consistent with the environment that F1 operates in.

IRS occurs if output increases by more than the proportional change in an input. The relevance to F1 is that if a team gets ahead by chance or strategy, increasing returns will magnify their advantage and the team has a greater probability of attracting the right people and sponsorship required to fund R&D and hire staff. This will see the team lock into a period of success. However, while a lock in may be present in the short term, IRS generates not equilibrium conditions but instability (Arthur, 1989) and the system is open to a disruption. The preceding scenarios has been evident in F1 since 1950 – i.e. one team becomes dominant for a period only for the domination to be distributed by a new innovation from an existing team or a regulator change.

Figure 6 Path Dependence and Increasing Returns to Scale (adapted from Arthur, 1994)

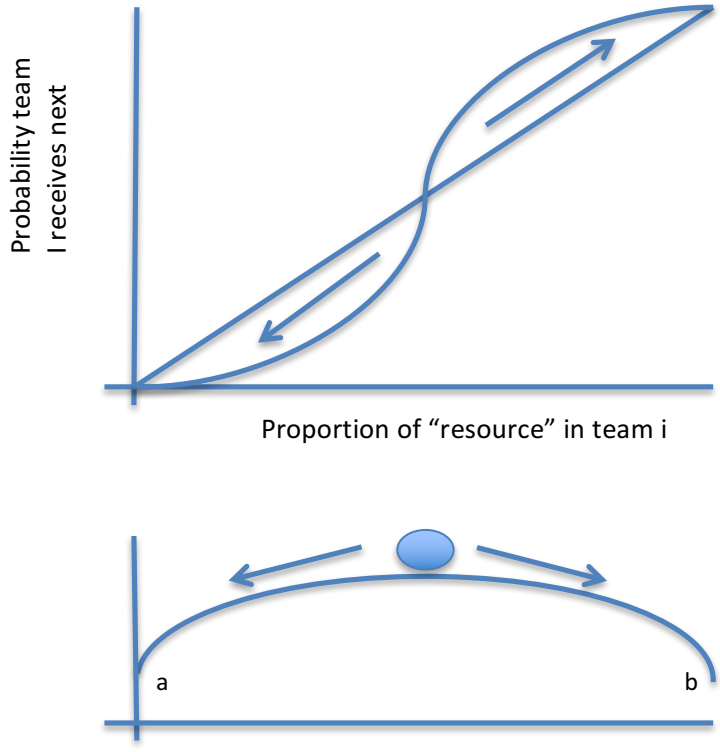


Figure 6 demonstrates how IRS and Path Dependence impact the probability of a team gaining a competition advantage. The bottom chart is a stylized representation of the environment that a F1 team operates with the "shape" being non-connex due to the presence of IRS. The key consequence is that the path the team takes is unclear as there are two possible outcomes (a and b). In addition, the initial position of the F1 team at the summit of the non-connex curve is unstable and whether it is by design or by luck, the team will move either to the left or the right from the summit. Once this move is made the team will continue down one path until it reaches a stable equilibrium of either dominance or disgrace.

The rationale for IRS in F1 is that as if a team moves to the right the probability of them receiving increased resources is greater than the portion of resources they currently have – as seen in the top chart of Figure 6. As they gain more resources the team will continue to improve their competitiveness. As (Arthur, 1994) states "resources" are attracted to existing and growing agglomerations. This theoretical framework is evidenced in Figure 2, which shows how the most successful teams have a higher proportion of resources. On the other hand if a team starts to move left, they miss out on the initial resources required to remain competitive and will continue in a death spiral. However, disruptions to the system or securing a valuable resource by luck are two possibilities that are capable of changing the direction.

In terms of removing any luck (Arthur, 1996) suggests that the rewards will go to the "players who are first to make sense of the new games looming out of the technological fog, to see their shape, to cognize them". Within F1, the regulator has provided at least 6 regime change opportunities for teams to emerge from that fog. While some new winners have emerged it is Ferrari who has done so consistently.

If IRS were not present the environment would be convex, meaning that there is an unique equilibrium and historical chance can not influence the outcome (Arthur, 1989). Under this scenario the competitiveness of a team would be stable through time. The evidence from F1 suggests this is not the case. To test this a model as specified in the following section was developed to simulate the importance of IRS and Path Dependence in F1.

Model Design

Given the characteristics of a complex system more traditional analytical approaches are rendered ineffective. Computer simulation is required to understand the dynamics of complex system and in particular agent based models (ABM's). ABM's allow for the interaction between individual agents (sponsors, teams and staff in this instance), who act and undertake actions based on the context of their environment and basic rules. Important considerations of these models are that agents' behavior is not fixed and evolves in response to the behavior of others.

A further benefit of using an ABM is the discovery and explanation of emergent behavior. Emergent behaviors or characteristics of complex systems are patterns generated by the interactions of the components of a system. ABM provides a toolkit for both discovering emergent behavior and understanding it in terms of interactions of components.

Borrowing from the Urban Suite – Path Dependence NetLogo model (Rand & Wilensky, 2007) which explores the concept of path dependence as explained by (Arthur, 1994), a model was developed that performed the following;

- Teams (as represented by patches) are initiated with a random level of competitiveness between 0 and 1;
- Sponsors are initiated and randomly assigned a value between 0 and 1 (using a normal distribution). This reflects the uneven nature of sponsorship dollars;
- Personnel agents are initiated with a skill level between 0 and 1 (using a normal distribution) reflecting different levels of skills within the population. These agents set a salary demand that is equal to their skill level;
- Sponsors (money) and human resources (personnel) search the landscape looking for the best place to allocate their resources. For sponsors the determining factor is whether a team's competitiveness is greater than the amount of money they are prepared to sponsor the team with– as defined by each sponsos' *dollar* variable. This simulates the fact that all sponsors are not the same size. Competitiveness is determined as a function of the team's;

    - *budget* - the sum of the dollars of the sponsors that are sponsoring the team;
    - *skill level* - the sum of the skills of the personnel that have joined the team;
    - the number of *staff* at the team; and

- the level of *increasing returns* for the system which is set exogenously. The increasing returns parameter influences the significance of the current state of the team versus its initial state. If the parameter is set to 1.0 then the only thing that determines whether or not an agent settles in the current location is the number of resources there at the time the agent inspects the team. If it is set to 0.0 then the only thing that determines whether or not a sponsor and therefore the staff settles there is the initial quality of the location.

- The determining variable for the personnel agents is whether the team has a sufficient budget to meet their salary requirements with the team's budget being a function of the sponsor's they attract.
- Once an agent settles they continue to check whether their team meets their requirements and will relocate if it does not;
- If an agent happens to be in the most competitive team their skill level increases by a factor of ^.9 and to reflect this their salary demand is also increased;
- Based on the disruption variable, the system will be shocked after a certain number of ticks. The disruption re-distributes the base level of competitiveness of the team. The implications of this shock and whether agents relocates is discussed below;

Model Results

The summary findings of the model are contained in Table 4[4].

		Increasing Returns	
		Low	High
Disruption Frequency	Low	Competitiveness evenly spread and no lock in winner	After an extended period of time a lock in is achieved despite disruptions. A Power law like distribution of competitiveness is seen on the way to the lock-in
	High	Similar to the above but greater volatility with regards the most competitive team	Same as the above but it takes less time to find the lock-in position

[4] Assume no entry of new sponsors and five attempts per step

Consistent with the original model, the higher the level of IRS the more likely one patch will collect all the resources. It is very hard for a team with a small budget to attract staff, which in term harms their potential to attract future sponsors. However, given that all sponsors do not have the same dollars behind them there is the possibility that a team with low competitiveness attracts a large sponsor. This is something that has been seen in F1 with new teams attracting sponsors on the hope of success – for example British American Racing, or a paid driver bring dollars with them.

The key take away from the model is that if increasing returns are high one team will dominate and disruptions have little impact. Lower levels of IRS see the resource redistribute after a shock. Given the success of Ferrari and the presence of Power laws the former finding of the model is therefore an accurate reflection of reality.

The results of the model provide policy insights into how to make F1 more competitive. To make F1 more competitive the governing body needs to reduce effect of increasing returns. This could be achieved by either increasing the frequency of major rule changes so team is able to "dominate" a technology or through making by key component generic across the class. Generic parts would also diminish the importance of specialty skills within teams which in terms will lower the capacity of skilled team members to demand pay rises.

Another policy would be to increase the resources available to the teams. While this version of the model did not explicitly test this, the greater availability of resources/sponsors will allow teams to retain their staff as they become more competitive.

Bibliography

Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal*, 116–131.

Arthur, W. B. (1994). *Increasing returns and path dependence in the economy*. University of Michigan Press.

Arthur, W. B. (1996). Increasing Returns and the Two Worlds of Business. *Harvard Business Review*, *74*(4), 100–109.

Cabral, L. (Forthcoming). The Economics of Entertainment: Concepts and Cases.

Essays, U. (n.d.). What Is Needed To Succeed In Formula One Management Essay. Retrieved April 24, 2015,

Goodall, A. H., & Pogrebna, G. (2014). Expert leaders in a fast-moving environment. *The Leadership Quarterly*.

Jenkins, M. (2010). Technological discontinuities and competitive advantage: a historical perspective on Formula 1 motor racing 1950–2006. *Journal of Management Studies*, *47*(5), 884–910.

Jenkins, M., Pasternak, K., & West, R. (2005). *Performance at the limit: business lessons from Formula 1 motor racing*. Cambridge University Press.

Rand, W., & Wilensky, U. (2007). *Urban Suite - Path Dependence* [NetLogo]. NetLogo Model Library.

Smith, C. (2014). Formula One's Most Valuable Teams: Red Bull, Mercedes On The Rise. Retrieved from http://www.forbes.com/sites/chrissmith/2014/11/12/formula-ones-most-valuable-teams-red-bull-mercedes-on-the-rise/

Wikipedia - http://en.wikipedia.org/wiki/List_of_Formula_One_constructors