Organizational exploration, exploitation, and performance differential: A simulation model of Formula 1 competition 1970-2013

George Papachristos
TU Eindhoven
School of Innovation Sciences
5600 MB Eindhoven
The Netherlands
g.papachristos@tue.nl

Fernando F. Suarez
Northeastern University
D'Amore McKim School of Business
360 Hungtinton Avenue, 471 Dodge Hall
Boston, MA 02115
fsuarez@northeastern.edu

Abstract

Technological innovation can disrupt the competitive landscape of an industry and the performance differential of incumbents and their challengers. The challenge for both is to adapt to their changing competitive conditions and environmental dynamics. Adaptation necessitates timely responses, rapid and flexible product innovation, and ambidexterity i.e. managing over time the tension between exploitation for short term gains and exploration for long term improvement in performance. This paper develops a model of innovation and competition in Formula 1 racing where technology development, new team entry, organizational and supplier changes, and annual regulation changes place a premium on ambidexterity as a dynamic capability for firm adaptation. Simulation results show how firm level and environmental changes such as organizational changes and resource acquisition, influence team capability development and erosion and can alter the intra industry performance differential in favour of incumbents or their challengers.

1 Introduction

Innovations are crucial to organizations, they change the performance differential in an industry and can transform competitive landscapes (Abernathy and Clark, 1985; Anderson and Tushman, 1990; Tushman and Anderson, 1986). The literature discusses the threat of innovations to incumbents (Anderson and Tushman, 1990; Henderson and Clark, 1990), and why challengers have often an advantage (Christensen et al., 2018; Christensen and Rosenbloom, 1995). Nevertheless, competitive threats do not always bring about incumbent decline as suggested in the literature (Tripsas and Gavetti, 2000; Tushman and Anderson, 1986; Utterback, 1994).

Incumbents may adapt and survive because an innovation typically affects the performance of a few key technology components or provides a new alternative, but it rarely renders obsolete the entire range of complementary technologies associated with it (Pavitt, 1998; Tripsas, 1997). Thus, incumbent firms fail rarely due to lack of technological knowledge, or inability to master a technology, but because they fail to adapt and match their organizational control and coordination systems to emergent technological opportunities (Christensen, 1997; Christensen and Rosenbloom, 1995; Pavitt, 1998; Rosenbloom and Christensen, 1994).

Research interest on organizational adaptation and change has grown after March's (1991) seminal paper on exploration and exploitation. The question is why and how some firms manage to adapt and survive in the face of change and others cannot. Successful incumbents or new entrants, manage the coordination of their capabilities and resources as they switch their focus between adaptation to the present and the future (Eisenhardt and Martin, 2000; Teece et al., 1997). Switch early and you might lose out to competition you currently face, switch late and you might lose out to prospective competition.

The ability to change continuously and adapt is a critical factor for firm success (Brown and Eisenhardt, 1997). This capability manifests often in sequential product innovation and development (Brown and Eisenhardt, 1997; Burgelman, 1991; Helfat and Raubitschek, 2000), where product development must refocus and rebalance the available technical skills and resources within the current managerial system of the organization (Hobday et al., 2005; Iansiti and Clark, 1994). A firm's new product development capability (Danneels, 2008; Verona, 1999), is commonly considered as one of the most important dynamic capabilities for reconfiguring a firm's resource base (Schilke, 2014).

The focus on product development is justified because of the primacy of firm level factors over industry factors in generating intra-industry performance differential (Coen and Maritan, 2010; Cool and Schendel, 1988; Rumelt, 1991; Walker et al., 2002). Nevertheless, the dynamics of industry level factors are also important for organizational performance and responses to emergent competitive innovation threats (Posen and Levinthal, 2012). Organizational core capabilities may become rigidities (Leonard-Barton, 1992) when the underlying business environment changes. Persist with the same logic, and core rigidities lead to the competence trap (Levinthal and March, 1993), and change the pecking order in the industry.

The response and adaptation to environmental changes requires exploration, the level of technology related innovation that an organization undertakes beyond its current knowledge base (Benner and Tushman, 2003; Marino et al., 2015; O'Reilly and Tushman, 2008). Maintaining the appropriate level of balance between exploration and exploitation over time is a challenge. Exploration and exploitation can be seen as mutually exclusive ala (March, 1991), where long periods of exploitation are punctuated by short bursts of exploration, but can also be seen as two orthogonal activities pursued in tandem in ambidextrous organizations (Chen and Katila, 2008; Gupta et al., 2006). In either case, this balancing act is particularly difficult under limited resources in a dynamic context (Bourgeois and Eisenhardt, 1988; Davis et al., 2009; Jansen et al., 2006), and requires an understanding of environmental changes (McCarthy et al., 2010).

To address the balance of exploration and exploitation over time at the firm level and their interaction with environmental dynamics the paper investigates Formula 1 competition (F1) from 1970 to 2013. F1 is chosen because it is a dynamic environment with frequent technical, organizational and regulation changes of varying magnitude that constitute a unique case of capability development and erosion, industrial and technological evolution. F1 exhibits a regular annual product development pattern similar to other industries e.g. fashion or software (Brown and Eisenhardt, 1997; McCormack et al., 2012). Competitive advantage in F1 depends on team ability to exploit - introduce incremental updates to their car during a season - and explore - redesign a significant percentage of the car of up to 40% (F1i.com, 2020a) from season to season to stay ahead of their competitors.

Very few F1 teams have won races and championships, and the competitive balance of incumbents to new entrants seems to historically favour the former. This persistent pattern of intra-industry performance differential is also observed in industries such as software, ICT, entertainment and fashion where firms engage in a series of interconnected product development projects (Cool and Schendel, 1988; Rumelt, 1991; Wiggins and Ruefli, 2002). The question, then, is how the pattern of exploration and exploitation operates to maintain the status quo in F1, how can late entrants rise to front runner ranks, and what can be done to maintain a “level playing field”. These are questions that FIA, the current F1 governing body, grapples with.

The paper develops an evolutionary simulation model of the 18 teams that won at least one race during 1970–2013, based on available F1 team performance data (see F1 online sources), and discussions with F1 team engineers. The model is used to investigate the dynamics of F1 team resource allocation to product development capability for exploration and exploitation under regulation changes i.e. reproduce the historical pattern of incumbent success and explore patterns of new entrant rise and incumbent adaptation or demise. A generic version of the model is developed to explore further the effect of organizational disruption to firm adaptation and ways to make new entrants succeed against incumbents.

The model integrates dynamic resource allocation decision making process to sequential product development and launch (Brown and Eisenhardt, 1997; Coen and Maritan, 2010; Fu et al., 2021; Helfat and Raubitschek, 2000; Kitaguchi and Uchihira, 2022; Noda and Bower, 1996). In this respect, the model has five differences to prior relevant work (Coen and Maritan, 2010; Denrell, 2004; Knott, 2003; Rahmandad, 2011; Zott, 2003) as it considers: (i) multiple firm competition, (ii) intergenerational product development, (iii) endogenous regulation changes and resource allocation flows, (iv) continuous innovation in dynamic competition, and (v) real case data.

The rest of the paper is structured as follows. Section two presents relevant theoretical background. Section three discusses the method and the research setting. Section four develops a simulation model of F1 competition. Section five presents simulation results and insights. Section six concludes the paper.

2 Organizational Adaptation

The adaptation and survival of organizations in the face of environmental change is a fundamental question with which scholars have engaged in diverse disciplines. Research on organizational adaptation and change has grown substantially after March’s (1991) seminal paper on exploration and exploitation. Central to the adaptation process is the ability to exploit current assets and positions in a profitable way and to simultaneously explore new technologies and markets; to configure and reconfigure organizational resources to capture existing as well as new opportunities (Helfat et al., 2007; Helfat and Raubitschek, 2000; March, 1991; Teece, 2009, 2007). Exploitation involves efforts to improve efficiency, productivity, control, certainty, and variance reduction. Exploration involves efforts to initiate search, discovery, innovation and embrace variation.

This ability is also referred to as ambidexterity (Tushman and O’Reilly, 1997, 1996). Ambidexterity encompasses both exploitation and exploration and it is the locus of the fundamental tension between the short-term and long-term adaptation of organizations (March, 1991). Research associates the combination of exploration and exploitation with longer survival (Cottrell and Nault, 2004), better financial performance (Markides and Geroski, 2004), and improved learning and innovation (Adler et al., 1999; Katila and Ahuja, 2002; Rothaermel and Deeds, 2004).

The management of exploration and exploitation trade-offs over time is challenging and is most often tilted toward exploitation where short term returns arising from customer demand and profits form a positive feedback loop that produces path dependence (Benner and Tushman, 2003; Gupta et al., 2006; Henderson and Clark, 1990; Levinthal and March, 1993). This positive loop left unchecked will lead established firms to specialize in exploitation, increase their efficiency and productivity, and eventually become dominant in the short term, but will plant the seeds of their obsolescence and failure in the long-term (O’Reilly and Tushman, 2008). In contrast, long-term returns arising from exploration are more uncertain, more distant in time, and may even threat existing organizational units. The relative dominance of the exploitation over the exploration loop renders organizations vulnerable to technological and market changes (Siggelkow, 2001).

There is an ongoing discussion on how to pursue exploration and exploitation sequentially over alternating periods (Brown and Eisenhardt, 1997; Ebben and Johnson, 2005; Gibson and Birkinshaw, 2004; Nickerson and Zenger, 2002; Siggelkow and Levinthal, 2003), or simultaneously (Adler et al., 1999; Knott, 2003; Markides and Charitou, 2004; O'Reilly and Tushman, 2008; Tushman and O'Reilly, 1996). To this, we turn next.

2.1 Sequential Ambidexterity

Many studies on organizational adaptation propose that firms can readily change their structure in response to changes in environmental conditions (Boumgarden et al., 2012; Kauppila, 2010; Lovas and Ghoshal, 2000; Rosenbloom, 2000; Tripsas, 1997). For example, small electronics firms adapt to changes in technology and products through rhythmic switching between periods of exploitation and exploration (Brown and Eisenhardt, 1997). Firms like Ford and Hewlett-Packard switch between exploration and exploitation to keep in sync with changes in their business environments (Boumgarden et al., 2012; Nickerson and Zenger, 2002). Lovas and Ghoshal (2000) describe the Danish hearing aid firm Oticon and its evolution over a century and show how firm strategy and structure evolved. Firms like General Electric and DuPont evolved to adapt to market conditions over time by changing their structure (Chandler, 1977).

The temporal sequencing of exploration and exploitation may be feasible in many circumstances, but it is predicated on the assumption that markets and technologies change at a rate that permits firms to pursue sequential ambidexterity. The alternative proposition is that given the complexity and rate of change that organizations face and the lead time for new products and services, organizational ambidexterity may require that exploitation and exploration be pursued simultaneously, with separate subunits, business models, and distinct incentives, competences and alignments for each one (O'Reilly and Tushman, 2013; Tushman and O'Reilly, 1997).

2.2 Structural Ambidexterity

The alternative to sequential ambidexterity is structural ambidexterity where the exploration units are buffered from the exploitation units in loosely coupled organizations (Burgelman, 1991; Leonard-Barton, 1995; Levinthal, 1997). The rationale for this is that process management tends to drive out experimentation, so it must be prevented from permeating exploratory units and processes (Benner and Tushman, 2003; O'Reilly and Tushman, 2008). These buffered units are held together by a common strategic intent, the overarching vision of senior managers that legitimates the need for exploration and exploitation, a shared set of values, and targeted structural linking mechanisms and incentives to leverage shared assets (Burgers et al., 2009; Burton and O'Reilly, 2021; Jansen et al., 2009; Lubatkin et al., 2006; Martin and Eisenhardt, 2010; O'Reilly et al., 2009; O'Reilly and Tushman, 2011, 2004).

Studies on structural ambidexterity suggest that it is associated with firm performance and explore the determinants of ambidexterity itself (Burgers et al., 2009; Katila and Ahuja, 2002; Lubatkin et al., 2006). However, research also raises the counterpoint that organizational attempts to pursue simultaneously exploration and exploitation strategies result in average outcomes (Ebben and Johnson, 2005; Ghemawat and Costa, 1993). It is suggested that it may be more efficient for companies to pursue a single strategy until they fail, rather than attempt to adapt over long periods (Anand and Singh, 1997; Knott and Posen, 2005). These suggestions are not easily reconciled with the imperative of senior managers to ensure their firms are profitable in the short-term and are able to adapt to changes and remain successful in the long-term.

2.3 Contextual Ambidexterity

Contextual ambidexterity is put forward in the literature as a third approach to balance exploration and exploitation in an organizational context that supports individual employees in their decision on the best way to divide their time between the two (Gibson and Birkinshaw, 2004; Rogan and Mors, 2014). Contextual ambidexterity differs in three ways from sequential and structural ambidexterity (O'Reilly and Tushman, 2013).

First, the emphasis is on individuals rather than units for exploration and exploitation. Second, ambidexterity is achieved when individuals agree that their unit is aligned and adaptable. Third, the organizational systems and processes that enable individual adjustment promote stretch, discipline and trust, but they are not fully specified. A striking example of contextual ambidexterity is in the operation of the Toyota Production System (Adler et al., 1999). In this system, workers engage in exploitation when they perform routine tasks like automobile assembly, while they also engage in exploration when they change their jobs to learn more about how the production system is put together.

Contextual ambidexterity may be conducive to alleviating the exploration/exploitation tension under a given technological regime, but disruptive or discontinuous changes in technologies and markets for which new skill sets for employees would be necessary may warrant a different organization response altogether. Such large-scale, far-reaching acquisition of new skill sets requires the approval and investment of senior management. For example, the decision of print newspapers to compete in the digital space required significant restructuring and the reallocation of resources by senior managers as well as the endorsement of the new technology or business model (Gilbert, 2005; O'Reilly and Tushman, 2004).

Each of the three modes of ambidexterity are proposed as a coping mechanism for the tension between exploitation and exploration, and the evidence suggests that all three are potentially viable. In-depth studies often illustrate how firms may use combinations of these to balance exploitation and exploration over time (Raisch, 2008). Organizations typically face a variety of competitive markets and these will vary in the rates of exploration and exploitation required (Chen and Katila, 2008; Rosenkopf and Nerkar, 2001). The different modes of ambidexterity may be more or less useful across different markets with different pace of change (O'Reilly and Tushman, 2013). For example, a simultaneous approach may be more appropriate in dynamic markets where conditions are changing, while in more stable environments firms may be able to afford a sequential approach. Contextual ambidexterity within a business unit may promote the local innovation and change needed to continually adapt to small changes in the environment (Adler et al., 1999; Benner and Tushman, 2003).

2.4 Ambidexterity as a Dynamic Capability

Dynamic capabilities underly the ambidexterity of a firm, and its ability to compete simultaneously in mature and emerging markets (O'Reilly and Tushman, 2013, 2008). The key factors necessary to succeed at exploitation require a short-term perspective, efficiency, discipline, incremental improvement, and continuous innovation. The key factors necessary to succeed at exploration require a long-term perspective, more autonomy, flexibility and risk taking and less formal systems and control. Ambidexterity requires senior leaders to configure and manage completely different and incohesive organizational alignments (O'Reilly and Tushman, 2008; Tushman and O'Reilly, 1997). To be effective, ambidextrous senior teams must develop processes for the establishment of new, forward-looking cognitive models for exploration units, and allow backward-looking experiential learning to rapidly accumulate from exploitation units (Gavetti and Levinthal, 2000; Louis and Sutton, 1991).

In this sense, dynamic capabilities include specific activities such as new product development, alliances, joint ventures, cross line of business innovation, and other more general actions that foster coordination and organizational learning (Gulati, 1998; Gulati and Gargiulo, 1999; Powell, 1990; Uzzi, 1997). New product development is particularly relevant to organizational adaptation because the series of product development projects that organizations engage in, is associated with changes in products/services that are eventually mirrored in changes of organizational structure (Clark, 1985; Colfer and Baldwin, 2016; Leo, 2020; McCormack et al., 2012), and the development and renewal of organizational capabilities (Helfat and Peteraf, 2003; Helfat and Raubitschek, 2000). This mirroring of product architecture in organizational configuration is possible in industries characterized by a dominant design, because the resultant stability in architectural knowledge facilitates the latter's embeddedness in the practices and procedures of the organization (Henderson and Clark, 1990). Nevertheless, new product development is not always equivalent to ambidexterity (Ebben and Johnson, 2005; O'Reilly and Tushman, 2008).

2.5 Ambidexterity and Environmental Dynamics

The nature and challenge of organizational ambidexterity is likely to vary with the pace of environmental change that may warrant continuous or discontinuous organizational change (Jansen et al., 2006; Lee et al., 2003; Raisch et al., 2009; Siggelkow and Levinthal, 2003; Siggelkow and Rivkin, 2005). Managers must continually readjust their strategies and realign their organizations in line with the underlying dynamics of technological change in their markets (Christensen et al., 1998; Suarez and Utterback, 1995; Utterback and Suárez, 1993).

The dilemma of managers and organizations is clear: in the short run they must constantly increase the alignment of strategy, structure, and culture. But for sustained success in the long-run, managers may be required to destroy the organizational alignment that is at the root of short-term success. These contrasting managerial demands require that managers periodically destroy what has been created in order to reconstruct a new organization better suited for the next wave of competition or technology (Tushman and O'Reilly, 1996).

However, it is not matter of either-or but of degree i.e. how much an organization is geared towards sequential or structural ambidexterity contingent on the pace of environmental change. Firms might occupy an intermediate point and do a bit of both because sequential might be difficult to sustain due to environmental pace, and organizational structure will likely need adjustment in the long term. As the pace and magnitude of environmental change will likely vary, the effect of ambidexterity on organizational performance will likely vary as well and will require ongoing re-adjustment of organizational structure for exploration and exploitation.

The view adopted in this paper is of ambidexterity as a dynamic capability for adaptation to a dynamic environment (O'Reilly and Tushman, 2013, 2008). Ambidexterity is not an issue of a static configuration of organizational structure for exploration and exploitation (Gupta et al., 2006; O'Reilly and Tushman, 2004). Ambidexterity as a dynamic capability is also not equivalent to ad hoc problem solving in which a business may ''solve'' a problem on a one time basis by setting up a successful exploratory venture (Eisenhardt and Martin, 2000; Winter, 2000).

3 Method and Research Context

The study of F1 competition and adaptation uses a longitudinal research design as there is a wealth of reliable data available on team performance such as lap times and race results (Gino and Pisano, 2011), with which to construct longitudinal time series of microstate adaptation events (Lewin and Volberda, 1999). Data on F1 teams have been collected from online data sources, news sites, and dedicated sites (see online sources at the end). The literature on the subject has also been consulted and complemented with two, hour long discussions with active F1 engineers[1].

A longitudinal research design with modelling and simulation is used for the study of organizational performance and success in a competitive environment because the balance between exploitation and exploration requires an understanding of environmental changes as well (Davis et al., 2007; Harrison et al., 2007; McCarthy et al., 2010). The need to establish an endogenous link between firm level and environmental dynamics leads to the choice of system dynamics (Papachristos, 2012; Richardson, 2011; Sterman, 2000). Moreover, some factors that drive organizational change and survival are essentially stock variables while others can be characterized as flows (Levinthal, 1992). System dynamics is used for this reason as it offers an appropriate language to operationalize theoretical concepts as stocks and flows (Sterman, 2000).

3.1 Research Setting

F1 is considered as the top motorsport category with an annual worth of $6 billion (Sylt and Reid, 2011). Technology development in F1 is intense and the team with the most capable combination of car, drivers, development resources and team management wins the championship in a racing season (Brawn and Parr, 2016). Teams fund car R&D primarily through sponsors that are attracted to F1 due to its worldwide audience and marketing potential (ESPN, 2013; Jenkins et al., 2009). Spectators are drawn to F1 due to its high level of competition, risk, speed, and technological development.

The study of F1 begins with the emergence of a dominant design in an industry which marks an inflexion point in technology and market evolution (Christensen et al., 1998; Klepper, 2002, 1996). The dominant car design involves the engine and gearbox behind the driver seat, and wings for downforce drawing on a lot of technology from aerospace industry (F1i.com, 2019a; Jenkins and Floyd, 2001). These key architectural design components became integral parts of the dominant design in the early 70s and have defined it ever since (Christensen et al., 1998; Henderson and Clark, 1990). The study of F1 ends in 2013 because it marks the end of conventional internal combustion engines in F1 and the introduction of hybrid engines in 2014 for the first time in F1

---

[1] Williams F1 engineer

history. Moreover, a structural change in competition has become evident as major automotive manufacturers that develop their own engines, begun supplying engines to smaller teams too. The latter are not direct competitors to top teams, they function rather as junior teams that provide drivers with a chance to mature in F1.

3.2 Coevolution of F1 Regulation and Car Design Based Competition

The dominant design of F1 cars is a tightly integrated system of components that evolves constantly towards more speed, efficiency, safety, reliability, and less weight, through innovation sequences punctuated by regulation changes. The integration of chassis and engine is fundamental and is accommodated through co-specialized investments (Teece, 1986). Any change in car design, its weight distribution, the engine, and the gearbox requires concomitant changes in other car components to offset performance trade-offs or utilise the car design potential for further performance improvements (BBC, 2019a; Castellucci and Podolny, 2017; F1i.com, 2019b).

After the emergence of the dominant F1 design architecture, subsequent design evolution involved increasingly peripheral components e.g., the number or geometry of cylinders in the internal combustion engine (Murmann and Frenken, 2006). The evolution of F1 car design followed a hierarchy of design logic (Clark, 1985), in which prior design choices constrained the paths that further technological evolution can follow and limit subsequent design changes (Sahal, 1985). This evolutionary process is driven by the core performance selection attributes for F1 car development that have remained the same: high levels of grip, low drag, reliability and driveability.

This implies that the main architecture of the dominant design is consolidated, but car components and their structure changes. Prior design choices and regulation changes lock engineers into a design hierarchy that allows subsequent design evolution to develop only within the trajectory defined by earlier ones. From 1970 to 2013, F1 has moved from unrestricted, exploratory technology development, evidenced in the variability of early car designs, to a tightly regulated, evolutionary design competition (F1i.com, 2016a).

F1 is governed by Federation Internationale de l’Automobile (FIA). Regulation changes apply across all teams and constrain the available engineering options for car development, disrupt team development strategies, erode their capabilities, and can potentially change F1 competitive dynamics. Driver safety has always been a major cause for regulation change particularly in the 70s and 80s due to fatal accidents (Jenkins, 2010). In the 1990s ICT technologies improved car performance and helped some teams dominate F1. This was perceived as a threat to the popularity of the sport because it reduced F1 appeal to spectators, and regulations were introduced to control this (Jenkins, 2010). Recent regulations focus on high costs that threaten F1 team viability (BBC, 2017; Judde et al., 2013).

For example, Toyota entered F1 in 2002 and withdrew in 2009 along with Honda, BMW and Jaguar-Ford for financial reasons (Aversa et al., 2015; BBC, 2009, 2008). Cost cutting regulations such as the reduction in testing time and the use of standardized components have shrunk the potential advantage that teams can achieve through car development around a single innovation (F1i.com, 2022a). A more nuanced, cumulative effect of regulation introduction is that the engineering design space of car design evolves to become more multidimensional but also more restrictive (Figure 1). This is simply because there are more regulations about what is and what is not allowed in the design of cars.

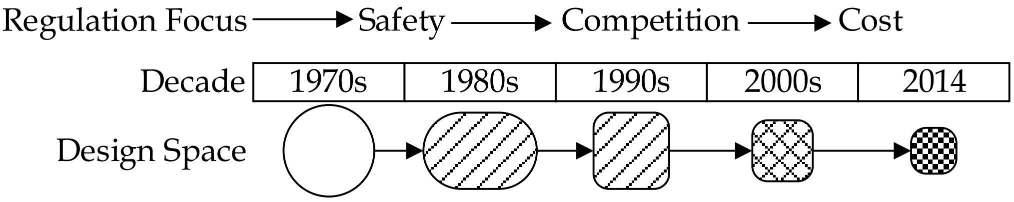

Figure 1. Evolution of Formula 1 car engineering design space with regulations

Another effect of increased regulation is the standardization of technologies in use, which increased the reliability of cars (see Figure 2). At the same time, F1 team size increased significantly, so organizational management factors became more important for team competition and success. Theory suggests that a source of failure for firms is their inability to match their organizational control and coordination systems to emergent technological opportunities (Christensen, 1997; Christensen and Rosenbloom, 1995; Pavitt, 1998; Rosenbloom and Christensen, 1994), or their inability to change their organization structure, redirect practices and reallocate resources in synch with the evolution of technology and market preferences in the industry (Iansiti and Clark, 1994; Noda and Bower, 1996; Utterback and Suárez, 1993). Thus, it is plausible to assume that organizational aspects take precedence in explaining performance differentials and why only some F1 teams succeed. This is the focus of the model developed in section 5.

In summary, F1 car development is driven by regulation changes that shape the design space of technological opportunities (Levinthal and March, 1981), and the pace and cumulativeness of F1 team R&D (Brawn and Parr, 2016).

3.3 F1 Team Competition

Teams develop a single car design and compete, thus the core competence in F1 is product development and the mechanism associated with it is iterated resource allocation over time, a common theme across industries (Iansiti and Clark, 1994; Noda and Bower, 1996). New F1 cars are introduced at the start of a racing season and receive car component updates throughout the season. The timing of resource allocation shift from current car development to future racing seasons is a core strategic decision (Brawn and Parr, 2016; Eisenhardt, 1989; Judge and Miller, 1991; Noda and Bower, 1996). The timing may vary due to a team's close involvement in a championship battle, and/or the intention to pre-empt future regulation changes and competitors (Chen and Katila, 2008; F1i.com, 2017a).

Novel engineering solutions can confer a competitive advantage in car development and may arise from superior access to, and integration of specialized knowledge (Grant, 1996a, 1996b). Three knowledge integration characteristics are critical to create and sustain competitive advantage in F1 (Brawn and Parr, 2016): (i) how efficiently teams access, integrate and utilize the specialized knowledge that their individual members have, (ii) the scope of the integrated knowledge teams draw upon, and (iii) team flexibility to integrate and reconfigure the current and newly acquired knowledge in F1 car development.

F1 teams try to acquire and develop new technologies and resources to expand their engineering design space options, and integrate novel and current knowledge into superior car designs, faster than their competitors, just as in other industries (Brown and Eisenhardt, 1995; Eisenhardt and Martin, 2000; Helfat et al., 2007; Schilke, 2014). The core performance attributes for F1 car development have remained the same: high levels of grip, low drag, reliability and driveability. In this respect, there is little room for competence destroying innovations. F1 team organizational strategic choices are limited so R&D solutions and capability improvements often build on current solutions (Barnett and Hansen, 1996; Brawn and Parr, 2016).

The pace of technology development is reflected in the average speed of pole position qualification (Figure 2, left panel) and race reliability (Figure 2, right panel). For example, changes in track layout were made in Imola in 1995, to reduce car speed after the 1994 fatal accidents of Senna and Ratzenberger. Nevertheless, the average qualifying speed rose by 2004 back to 1994 levels despite the reduction in engine size from 3.5 to 3 litres in 1995 and an incremental 35% car weight increase from 515 kg to 695 kg in 2004. These changes were compensated by a 36% increase in engine rpm from 14300 in 1994 to 19500 in 2006, which increased horsepower by approximately 11% (F1technical.net, 2014). The average reliability and standard deviation of all 18 teams is calculated based on historical data excluding race accidents.

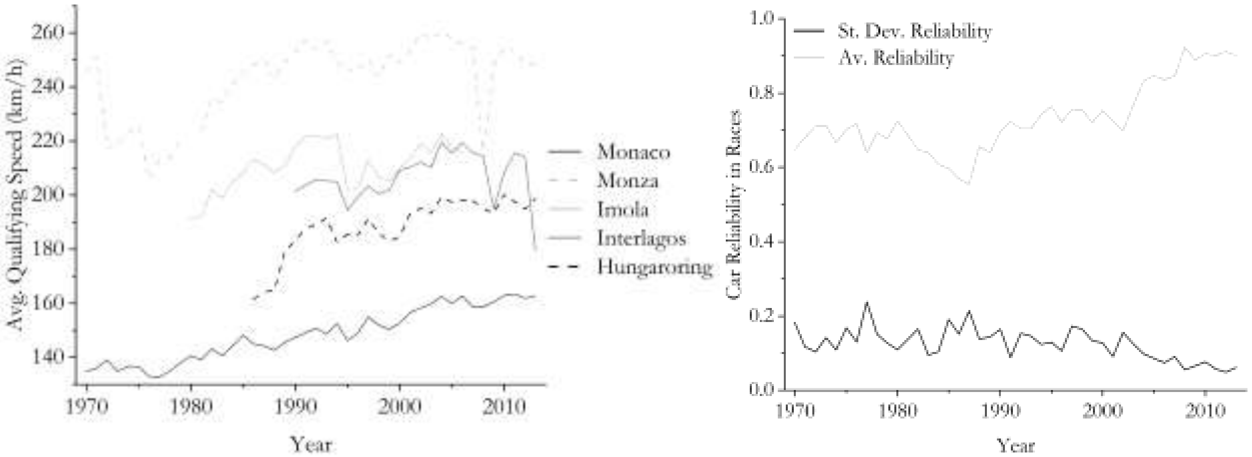

Figure 2. Left panel: average pole position qualifying speed (km/hr) in 5 classic racetracks, Right panel: average F1 team reliability and standard deviation per season (1970- 2015) for the 18 F1 teams that have won a race excluding non-mechanical failures (data compiled from statsf1.com)

The discussion on regulation and team competition reveals a fundamental two-level tension: F1 teams try to develop their cars and dominate their opponents, while at the macro-level FIA regulation aims to level the competitive field and raise audience interest, and modulate the trajectory of F1 technology for safety, audience interest, and competition cost/viability. Successful teams become better competitors through repetitive rounds of adaptation that raise the F1 entry barriers while at the same time competitive advantage becomes ever more transient due to regulation changes that alter the design space (Brawn and Parr, 2016).

This two-level tension has produced a particular distribution of team wins and poles during 1970–2013 (Figure 3, left panel). From 1970 to 2013, 71 unique teams have competed in F1 (Appendix B), 18 have scored at least a win, and nine have won a constructor’s championship (Appendix C) once team acquisitions and name changes are accounted for. The top 6 teams have won more than 75% of wins and pole positions, once team acquisitions and name changes are accounted for. Figure 3 (right panel) shows the sum of wins and pole positions as a percentage of races per season for the most successful teams overall currently competing in F1[2].

---

[2] Accounting for team acquisitions these are: Ferrari, Williams, Mclaren, Benetton (continuing as Renault, Lotus F1 team, and then Renault again in 2016) and Red Bull.

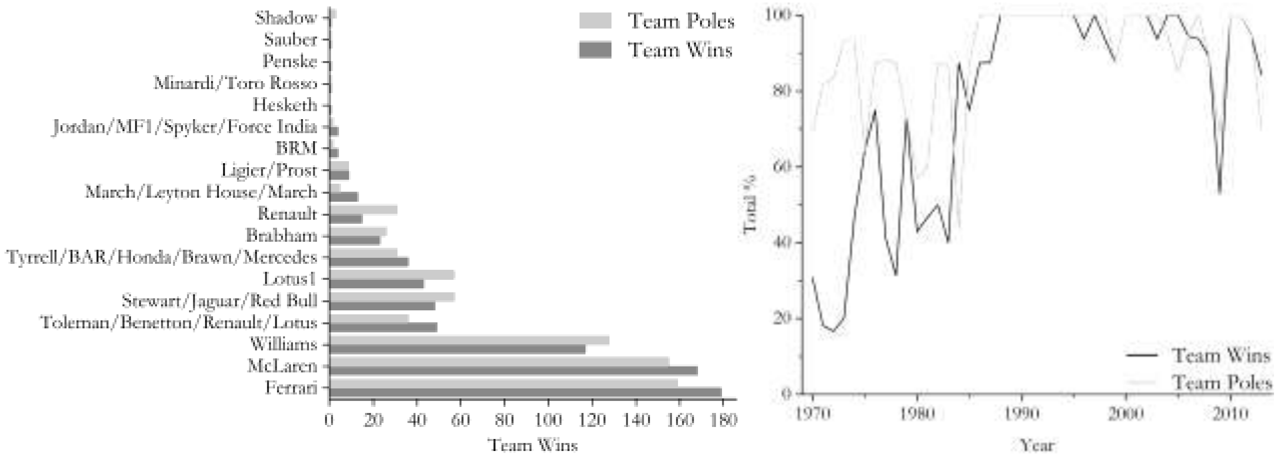

Figure 3. Wins and pole positions of F1 teams 1970–2013 (left), percentage of wins and pole positions for the 6 most successful teams as listed on the left. (data compiled from statsf1.com)

3.4 Assessing explanatory avenues for F1 competition

This section provides an overview of characteristics that are specific to F1 innovation and competition and are pertinent to framing it in theoretical terms. The period from 1970 to 2013 is not a period of stability with no new entrants. The absence of successful new entrants could signify a period of stability where industry incumbents retain and strengthen their competitive positions. However, new car and engine manufacturers enter every year in F1[3] some of which become eventually successful (Figure 4). In addition, annual regulation changes and tyre supplier changes tend to change the engineering design space available to teams (Figure 1). Consequently, no era in F1 can be used as a template for stability. One would expect a greater number of successful teams given the pace of technology development, the massive technology and regulation changes in F1 (Jenkins et al., 2009; Jenkins and Floyd, 2001), the competition intensity (Brawn and Parr, 2016; D'Aveni et al., 2010), and the team and engine supplier turnover. Nevertheless, F1 incumbent team success persists and points to the fact that F1 success is a long-term endeavour that requires considerable innovation resources and support infrastructure[4].

---

[3] F1 team entry and consolidation, leads the demand for engine supply.

[4] The apparent rapid success of Red Bull and Mercedes is an outcome of their entry through acquisition of teams that competed for decades in F1 (see Appendix D Timeline).

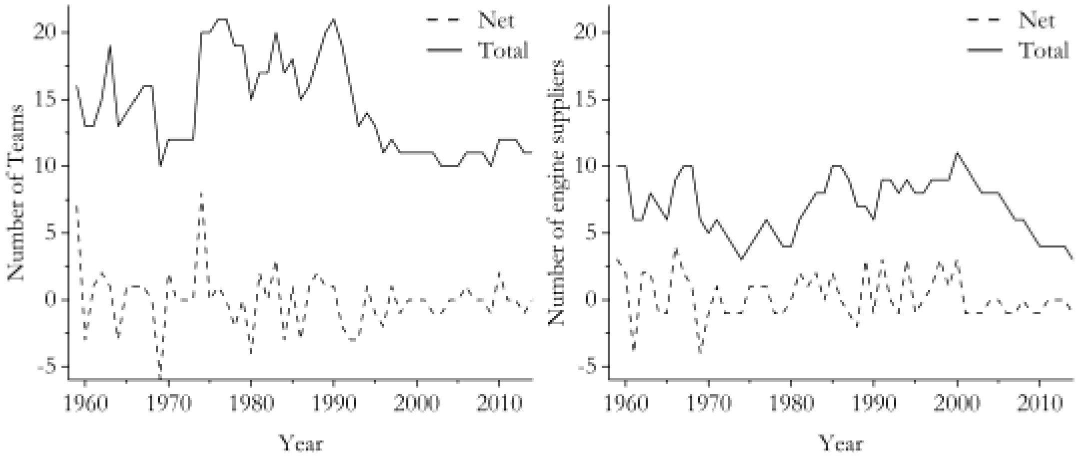

Figure 4 Total number and turnover from 1959 to 2014 for F1 teams (let panel), engine manufacturers (right panel).

Explanations based on competence destruction through innovation are not applicable in F1 where technology is highly regulated and develops continuously from race to race as fast as team budgets allow. F1 innovations such as the semi-automatic gearbox, and carbon chassis where not competence destroying (Tushman and Anderson, 1986) but did require the development of complementary competences on the part of F1 teams[5]. Similarly, the adoption of ICT in every aspect of F1 competition during the 1990s did not replace the knowledge and competences related to car design and testing but it was a complementary innovation that generated significant improvements on many aspects of F1 competition.

Furthermore, the core technical requirements for a winning car have remained the same: high cornering and straight-line speed and high levels of grip, reliability and driveability. Successful car designs may become obsolete due to regulation changes, but the core knowledge and competences accumulated during car development do not become obsolete. Moreover, competition rules are agreed upon by all teams, so core rigidities (Leonard-Barton, 1992) do not constitute a weakness for any F1 team. The implication is that competence based explanations where industry incumbents are laden with core rigidities and the legacy of old technology (Tushman and Anderson, 1986; Utterback and Suárez, 1993), do not hold in the F1 context.

Explanations based on competence enhancing discontinuities do not fit F1 context either, as teams are able to rapidly innovate and even outcompete the originators of innovations. For example, Lotus dominated the 1978 season with its revolutionary ground effect car. It provided a step increase in performance, and it originated in an incumbent firm (Lotus entered F1 in 1959). However, this advantage did not last, as all teams adopted the ground effect principle in their own car designs

---

[5] The initial problems in the development of the semi-automatic gearbox were overcome with the help of team sponsor Magnetti Marelli.

(Jenkins, 2014, 2010). Ferrari and Williams adapted the ground effect principle to design a better car and won the championships in the following seasons (1979-1983) with the same Ford engines that Lotus used (Jenkins, 2014).

Explanations based on disruptive innovation (Christensen, 1997) cannot be directly applied to F1. Each racetrack can be seen as a "market" with a particular preference mix for car performance attributes: some racetracks require more top speed, others more downforce in the car setup, while all of them require high reliability[6]. However, track layout changes are rare and small, and changes in the F1 race calendar are very few each year, so F1 "market" characteristics remain the same or change very slowly and allow the best overall performing cars to succeed. Moreover, teams that compete for a championship aim to perform well in all racetracks. This is not congruent with the core idea in disruptive innovation that incumbents neglect a market segment because they perceive it unattractive for investment and this gives the opportunity to new entrants to gain a foothold in the market (Christensen, 1997).

In conclusion competence-based or market-based explanations may not be suitable for F1. These observations inform the use of ambidexterity as the basis to frame F1 competition. All teams face essentially the same challenge as they alter strategically the balance of exploration and exploitation over time, they integrate and reconfigure their resources and competences, to generate competitive advantage, win races and appropriate the benefits (Brawn and Parr, 2016). Technological diversity is minimum in F1 teams, as in other high-tech industries (Pavitt, 1998). So, it is plausible to assume that organizational aspects take precedence in explaining performance differentials and why only some F1 teams succeed. When teams lose their position, it is not because their competences are destroyed, new performance attributes replace current ones, or the "market" changes, but because other competitors raise their innovation pace, follow a better rhythm of resource allocation and utilisation, and adapt promptly to regulation changes which alter the optimum configuration of car, engine and tyres.

For example, teams on four occasions won four or more consecutive championships: McLaren, Ferrari, Red Bull and Mercedes. Their dominance was eventually disrupted through competition in the case of McLaren in 1992, or massive regulation changes in the case of Ferrari in 2005, Red Bull in 2014, and Mercedes in 2022. This rare, prolonged performance dominance is a combination of car design adaptation to regulations, engine performance which dedicated suppliers provide, and driver ability to develop the car and win races, tightly integrated in a team (Brawn and Parr, 2016). Other

---

[6] An expression often used in F1 race commentary is: "to finish first, first you have to finish".

teams simply make the best of the circumstances to outcompete them. The next section develops a model to formalize these dynamics.

4 A Model of F1 Competition

Firm level competences encompass employee knowledge and skills, technical systems, managerial systems, and values and norms (Leonard-Barton, 1992). The model developed in the paper accounts for these and incorporates six important factors for F1 competition at the firm and environment level to reflect the complexity of competitive dynamics between incumbents and challengers (Brawn and Parr, 2016): (i) significant organizational and supplier changes, (ii) the time span each team competes, (iii) the rules for iterated resource allocation (Noda and Bower, 1996), (iv) sponsorship that each team secures based on performance, (v) the team learning pace, and (vi) regulation changes.

Technological diversity is minimum in F1 teams, as in other high-tech industries (Pavitt, 1998). So, it is plausible to assume that organizational aspects take precedence in explaining performance differentials and why only some F1 teams succeed. Factors i and ii impact team capability development and performance, competition, and adaptation. If capability development is disrupted temporarily due to organizational changes that necessitate team response and adaptation, then the capability base of the organization will suffer and consequently its performance. These factors are introduced as time series data in the model. Significant organizational changes of team ownership, management or chief designer changes in each team are compiled from online data. Executive leadership is the primary agent capable to manage the exploration-exploitation tension (O'Reilly and Tushman, 2008; Tushman and O'Reilly, 1997).

F1 teams take a system focused approach on the impact of novel technical concepts (Brawn and Parr, 2016; Iansiti, 1995; Iansiti and Clark, 1994). Senior managers have system level knowledge of the organization and chief designers, or engine suppliers have system level knowledge of the technologies deployed in races. They serve as integrators and drivers of the evolution of the firm's capability base (BBC, 2019b; Brawn and Parr, 2016; Iansiti and Clark, 1994). If senior managers or engineers leave, then system level knowledge is lost (Iansiti, 1995; Kogut and Zander, 1992), and firm capabilities are temporarily eroded (Teece, 2007).

New F1 team principals or chief engineers that come onboard aim to improve team and car performance respectively, through organizational changes in team structure, operations and product development. These take up to a year to be implemented and become effective because they influence organisational team coherence and alignment dynamics (Brawn and Parr, 2016; Formula1.com, 2015, 2014; Helfat and Raubitschek, 2000). It is assumed that one year is required to restore team coherence after a change in team principal or chief designer (Brawn and Parr, 2016; Formula1.com, 2019). A time series of 59 organizational changes during 1970–2013 has been constructed through online historical data (Appendix E).

The second time series indicates engine supplier changes (Appendix F). Such changes affect some core firm competences (Leonard-Barton, 1992), employee knowledge and skills and team technical systems. They are a major technical-organizational development as F1 teams build close, long-term partnerships with their engine suppliers where technical knowledge is embedded (F1i.com, 2017b, 2017c; Kogut and Zander, 1992). It is assumed that a year is required to align operations between the team and the supplier. 86 engine changes during 1970–2013 have been identified through online historical data.

The third time series indicates the years each of the 18 teams compete and accounts for team acquisitions, ownership and name changes (Appendix D). Team entry and exit is not endogenous in the model as it involves financial, political and management considerations for each team, and it is also subject to FIA approval (Brawn and Parr, 2016; F1i.com, 2017d).

4.1 Team competition dynamics

The model integrates F1 team competition and resource allocation dynamics at the firm level, and regulation dynamics at the system level. F1 teams develop their *Car_Design* and compete for *Race_Wins* (Figure 5). Their success creates a virtuous circle as they acquire more *Sponsor_Funding* to develop their *Car_Design* at a faster pace than their competitors and achieve more wins. *Car_Design* and the development pace of car component upgrades during the racing season is critical to keep up with competition and can reach one upgrade per day on average (BBC, 2014). Car development and upgrades require *Sponsor_Funding* to develop and sustain the necessary level of *Team_Resources*, *Team_R&D*, and *Product_Development_Capability* (*PDC*) to develop improve *Car_Design*, and enable flexibility in *Race_Strategy*. Past success, *Sponsor_Funding*, *PDC* and regulations constrain the search directions for *Car_Performance* improvements (Nelson and Winter, 1982; Patel and Pavitt, 1997).

Each time *Organizational_Changes* in human resources or engine suppliers take place, team resources and *PDC* erode and teams loose competitive momentum to an extent. This is because close collaboration is necessary between engine supplier and the F1 team to integrate car and engine design and adjust it to driver style. This takes considerable time even with experienced engine manufacturers like Honda and Ferrari that have “works engine” deals (ESPN, 2014; F1i.com, 2017b, 2017e).

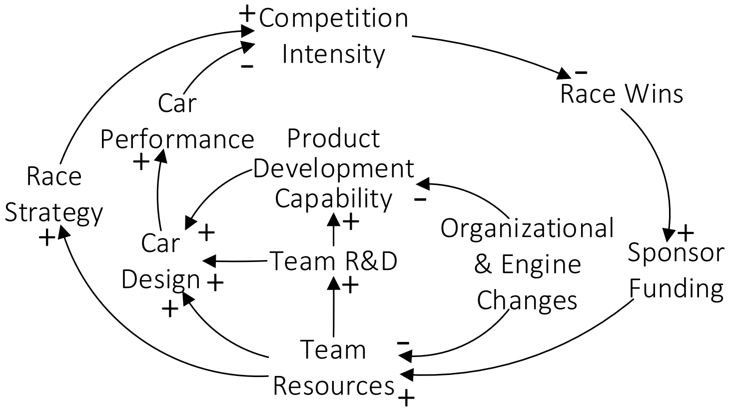

Figure 5. Self-reinforcing competition dynamics at the F1 team level

A crucial decision rule for car development concerns the timing of *Team_Resources* allocation between *Present_Car_Performance* development and *Future_Car_Development* in anticipation of regulation changes that take place annually (Figure 6). F1 teams engage in strategic competition, where management uses its capabilities to sense opportunities to gain competitive advantage (Teece, 2009), and allocate resources to their current car design development if they anticipate they can improve their *Championship_Position,* defend it from their opponents or win the championship. If they do not, or if they can maintain their *Championship_Position* until the end of the season, then they focus on long term development anticipating future regulation changes (Brawn and Parr, 2016; F1i.com, 2020b, 2019c, 2017a; TheRace.com, 2020). It is also possible that a team will prefer to switch to future car development primarily because of inherent limitations in its current car design that limits chances for race wins (F1i.com, 2023a).

Crucially, if radical *FIA_Regulation_Changes* are planned for next season then teams that focus on *Present_Car_Performance* to win the championship may face a development and resource allocation dilemma (TheRace.com, 2020). They can exploit their current design to secure wins and the championship at the risk of falling behind in their car development for the forthcoming season, or explore more the opportunities and limitations that future regulations hold. Taking a long term, multi season perspective on resource allocation to car development and performance is important for success (F1i.com, 2020a, 2020b, 2019c, 2017f).

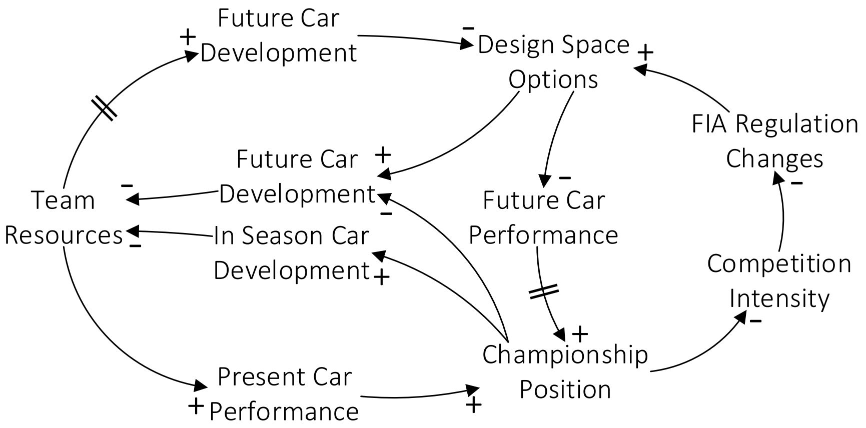

Figure 6. Resource allocation between present and future car performance development

4.2 Regulation Dynamics

Early changes in FIA regulations in the 60s and 70s were the result of fatal accidents as car safety lagged behind car performance. Regulation changes in mid 1990s aimed to prevent ICT technologies from supplanting the driver role and thus undermining interest of the spectators. Very often, sweeping regulations and car redesign succeed in levelling temporarily the performance differential among teams and they raise audience interest. More recent regulations try to control the spiralling cost of F1 innovation.

Regulations introduce new technical opportunities but generate diminishing marginal returns to team R&D as they increase car design complexity. It has become so large that performance improvements are extremely small, even within error measurement margins[7] (F1i.com, 2017e, 2016b). Cost has also increased with an estimated 4 milliseconds of lap time gained for every million dollars spent on engine development, and 20 milliseconds for every million dollars spent on optimizing car aerodynamics (Trabesinger, 2007). Regulations to reduce off season car testing have shrunk further the advantage that top teams can develop despite the increase in their size and budget. It follows that smaller advantage should lead to smaller average differences in race performance. The effect of design space and regulation evolution on relative performance is evident in the downward trend of average race finish difference and standard deviation of the top 6 finishing cars (Figure 7).

---

[7] Personal communication with Williams F1 engineer.

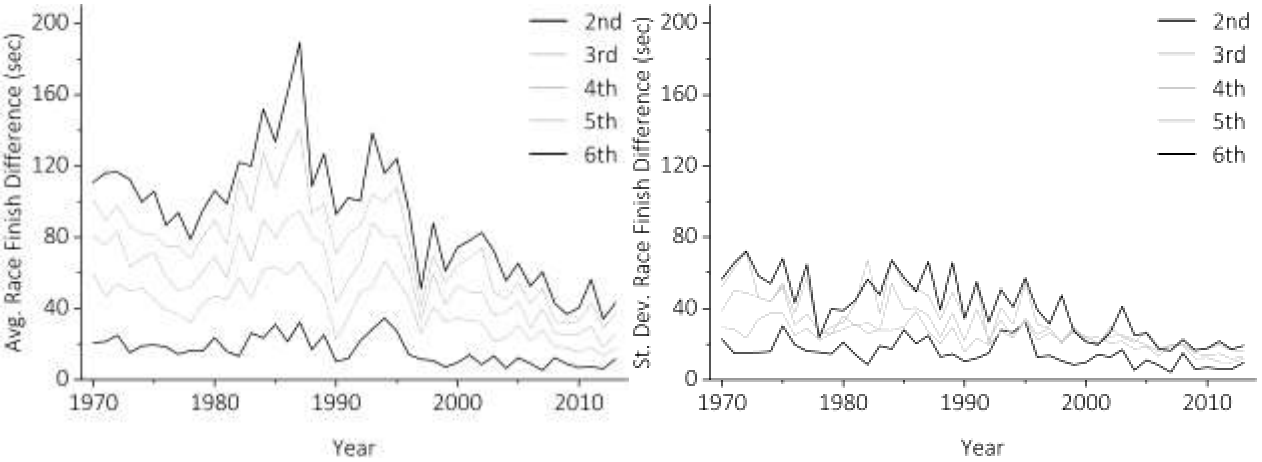

Figure 7. Average annual difference between the top 6 race finishing positions per season (left), annual standard deviation per position (right) (data compiled from: statsf1.com, chicanef1.com)

The feedback relations identified in previous sections provide an empirically and theoretically grounded picture of F1 competition dynamics. Next, a system dynamics model is developed to explore whether the causal logic detailed in previous sections is a valid explanation for F1 and if it can generate the distribution of wins that each team has actually achieved in F1 during 1970-2013. The first step towards the simulation model is to integrate Figures 5 and 6 in Figure 8.

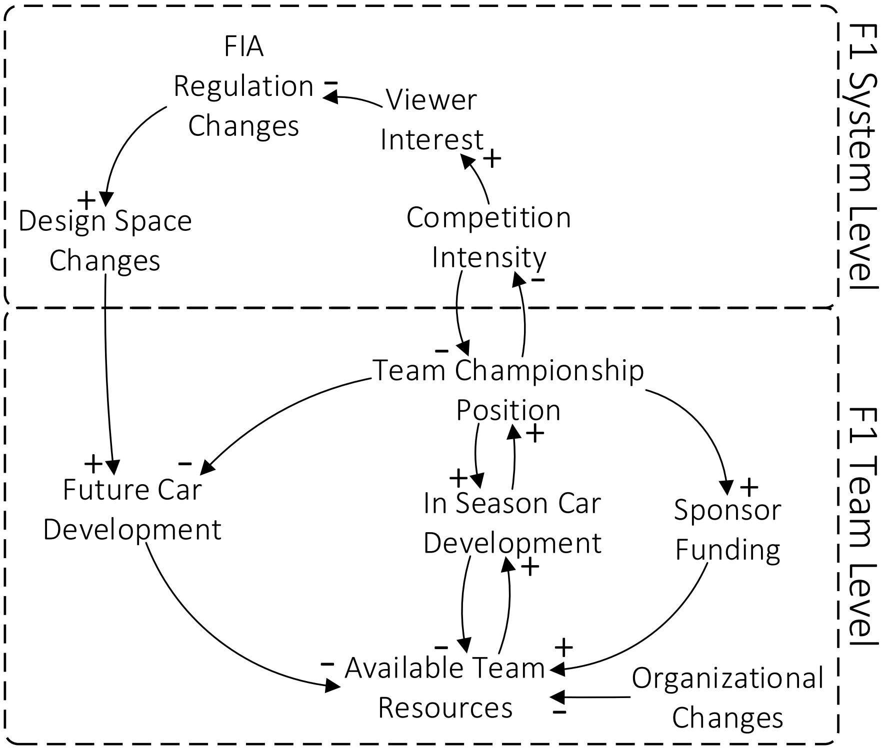

Figure 8. Two level dynamics of F1 competition dynamics

4.3 Car development dynamics

F1 teams in the model compete for the actual number of races per season, and races are assumed to take place every two weeks as this is the case in reality with most F1 races. The number of wins and points each team scores from 1970 to 2013 is recorded annually. In line with actual practice, all teams receive a share of the profits from tv commercial rights in proportion to the points scored

(Solitander and Solitander, 2010). F1 teams use sponsor funding to build their resources and develop their car for the present or future season. It is assumed that sponsor funding is proportional to the points a team scores in the previous season.

Car development is a continuous process subject to resource availability, so resources are allocated to future car development only if the team cannot lose or gain a position in the current championship standings based on the maximum remaining points in the season (BBC, 2013; Brawn and Parr, 2016; F1i.com, 2016c, 2016d). It is assumed that each team cannot anticipate the resource allocations decisions of its rivals, so this decision is made independently. F1 teams produce only one product, and this simplifies their model representation with the same array structure for *PDC* and dynamic resource allocation. Since the design architecture of the cars is the same by regulation, its related development tasks are assumed to be reflected in the underlying organizational structure based on the mirroring hypothesis (Baldwin and Clark, 2000; Colfer and Baldwin, 2016; Henderson and Clark, 1990; Leo, 2020; McCormack et al., 2012; Sanchez, 1995; Sanchez and Mahoney, 1996). The level of mirroring between product and organization increases with the organization's architectural knowledge, cumulative experience with the product architecture, and stability of the dominant product architecture in the industry (Leo, 2020).

It is assumed that teams pursue the development of their own design and innovation capability (Jenkins, 2014). Organizational capabilities and resources are "stocks" that change only through accumulation and depletion flows (DeCarolis and Deeds, 1999; Dierickx and Cool, 1989; Karadag and Poppo, 2023; Rahmandad and Repenning, 2016). *PDC* is a capability, so it is modelled as a stock that changes through accumulation and erosion processes. In the F1 context *PDC* of team *i* improves knowledge about the car and its performance $K_{i,t}$. Problem solving leads to more knowledge generation that leads to better performance in the race track (Eisenhardt and Martin, 2000; Zahra et al., 2006; Zollo and Winter, 2002). $K_{i,t}$ is given by:

$$K_{i,t} = \int_0^t C_{i,t} dc \qquad (1)$$

The improvement rate $C_{i,t}$ of car performance for team *i* is given by:

$$C_{i,t} = R_{i,t}/D_{i,t} \qquad (2)$$

The amount of resources $R_{i,t}$ for team *i*, depends on FIA prize money and sponsors in direct proportion to season performance[8]. Resource availability depends on how well teams leverage their competitive performance to secure sponsorship funding (Appendix G). This is a highly political and vital process to team competition and depends on F1 team status and individual manager skills (F1i.com, 2019a).

---

[8] Ferrari being the oldest manufacturer in F1, receives $68m from FIA in recognition of the brand value for F1 (Guardian, 2017).

A time series was constructed to account for this based on available online historical information and race season reports (see F1 online sources)[9].

F1 teams spend their budget as fast as possible to develop their car development capabilities (Brawn and Parr, 2016). Performance gains from car development become more difficult when regulations remain relatively stable (F1i.com, 2016a). This is in line with the general observation in the literature, and evidence (Figure 7) that R&D is subject to diminishing returns. As firms explore more of the engineering opportunities allowed by regulations, they may stand to benefit less from the value and novelty of what they discover (Klevorick et al., 1995; Marino et al., 2015). $D_{i,t}$ is the difficulty to further improve car performance:

$$D_{i,t} = (K_{i,t}/k)^{\gamma_t} \tag{3}$$

The k parameter is calibrated based on the product of car reliability, standard deviation of reliability, and qualifying speed improvement. This product is used as an index for total car performance with 1970 as the reference year. The improvement in qualifying speed is calculated for the Monaco race as it is the only track with races throughout this period, and with no significant track changes that could distort qualifying speed results. The k value is set so that performance improvement from 1970 to 2013 matches the percentage improvement in average qualifying speed for Monaco. Exponent γ_t is proportional to the standard deviation $\sigma(P_{i,t})$ of points P for team i in season t, and the increase in regulation changes g per unit point increase in $\sigma(P_{i,t})$ (Mastromarco and Runkel, 2009). The actual F1 point system for each season is used for this and γ_t is given by:

$$\gamma_t = g \cdot \sigma(P_{i,t}) \tag{4}$$

FIA regulation changes influence team performance, they reduce the advantage of winning teams, and increase competition intensity. It is assumed that *PDC* for each team erodes in proportion to its magnitude and the magnitude of regulation changes. It is assumed that regulation changes are implemented and have an effect when the racing season ends and F1 teams lose an amount Δ_i of their product development capability:

$$\Delta_{i,t} = \gamma_t \cdot K_{i,t} \tag{5}$$

The race performance of each team i is assumed to follow a normal distribution with average car performance $K_{i,t,}$ and deviation values derived from the normalised the average rankings of both team drivers for the whole season. The model does not include weather or race accidents and only one car competes for each team. This assumption does not alter race dynamics as there can be only one winner at each race. Drivers and their characteristics are not explicitly modelled as total car

---

[9] Data prior to 2008 are difficult to obtain (https://www.spotrac.com/formula1/)

performance and reliability is significantly more important than race skill in terms of race results and modelling drivers explicitly would complicate considerably the model and data.

4.4 Model Validation

The model was tested through standard system dynamics tests for dimensional consistency, extreme conditions where high or low values were assigned to input parameters, and numerical sensitivity to simulation time step (Sterman, 2000). This was set to 1/8 month as races in the model take place biweekly. Model tests confirmed that the sum of team wins per season equals the number of races in the season, the removal of a team for a racing year or completely, always increases wins for the remaining teams. If all 18 teams compete with identical initial resources, capabilities, and exogenous time series, they all achieve an average of 39.6 wins and a standard deviation of 1.16 wins. If only one single team is allowed to develop its car and compete, then it achieves the vast majority of wins. This makes sense as other teams still have the operational capability to compete in races but lack the resources to improve their car following regulation changes.

5 Simulation Results

The model was set to run from 1970 to 2013 and was tested with the following exogenous time series setup: 1. engine supplier and organizational changes, 2. engine supplier changes, 3. organizational changes, and 4. no engine or organizational changes. Each set up was simulated 200 times. Table 1 shows simulation results, and error metrics for cumulative team wins in 2013 (for detailed results see Appendix A Table 1). Overall, the difference in error between setup 1, 2, 3 and 4 indicates that organizational changes and engine supplier changes have an effect on differential competitive performance. Deviation in teams with few wins was expected as they participated in few races and some achieved wins due to the Ford DFV engine availability (Jenkins, 2010), others due to fortuitous race circumstances that the model does not account for[10]. For example, Penske team had 1 win in 4 racing seasons.

Table 1 Statistical error metrics of simulation results for cumulative team wins results.

Setup	Time Series	Mean Square Error	Mean Absolute Error	Root MSE
1	Organizational changes & engine supplier changes	18.0553	2.9983	4.2492
2	Organizational changes	24.3548	3.6750	4.9351
3	Engine supplier changes	74.1933	5.3683	8.6136
4	None	79.6260	5.4850	8.9233

---

[10] Ligier's last win in 1996 in Monaco was an eventful, attrition race where only 3 out of 22 cars finished.

Further model tests concern longitudinal results of team wins versus the corresponding historical time series data (Homer, 2019). Metrics for these tests are based on data for Ferrari, McLaren and Williams that participated continuously from 1970 to 2013. Table 2 shows the average of the error metrics for the three teams (see analytical results in Appendix Table 2). Setup 1 performs better than the rest in alignment with Table 1. Tables 1 and 2 indicate that the best performing setup is 1 and it is used to explore further the dynamics of F1 competition.

Table 2 Statistical error metrics of simulation results for longitudinal team wins results

Setup	Mean Square Error	Mean Absolute Error
1	45.5945	4.9436
2	62.4206	5.6690
3	152.6881	8.5939
4	161.5175	8.6596

The timing of resource allocation between in season competition – exploitation, and future car development – exploration is important. Teams that secure a good championship position early in a season can switch resources earlier to future car development to get a head start (F1i.com, 2020b, 2017e, 2017a). Model output indicates that the number of early switches to future car development correlates with wins achieved by each team with Pearson correlation 0.9915. This is in agreement with literature that suggests that the ability of firms to invest timely in new technologies over the long term is critical for performance, and dynamic capabilities flow from more than just learning and technological accumulation (Chandler, 1990; Ferrier et al., 1999; Lazonick and Prencipe, 2005; Teece, 2009; Zott, 2003).

When all teams switch to future car development at the same time annually, results are significantly less accurate to setup 1, with MSE equal to 221.9. So, the switch decision from exploration to exploitation matters a lot for model accuracy. Thus, sustaining competitive advantage in F1 involves achieving a series of temporary advantages that bridge present and future car development through rhythmic, time paced transitions processes between seasons (Brown and Eisenhardt, 1997; D'Aveni et al., 2010). The duration of team presence in F1 is also important. Pearson correlation of team wins with years in F1 is 0.7378 and it improves to 0.8061 if the teams that entered later than 1980 are removed.

The effect of regulation change magnitude was tested with setup 1 and varying g between 0% and 18% in equation 4. Results confirm that the minimum MSE occurs at 3% as suggested by Mastromarco and Runkel (2009). High g values represent a more dynamic environment where regulation changes have a greater effect on car development, reduce performance differences between F1 teams, and erode team competitive advantage. This result supports the idea that new product development capability is most valuable in moderately dynamic environments because firms can utilise their current experience to innovate and introduce products in a relatively frequent fashion (Eisenhardt and Martin, 2000; Schilke, 2014).

5.1 Can late entrants succeed?

Setup 1 generates results where some incumbent teams have a persistent advantage, sometimes even when aided by FIA (F1i.com, 2017g). The question is how new entrants like Torro Rosso (TR) and Force India (FI) can utilise exploration and exploitation patterns to succeed against incumbents Ferrari, McLaren, Williams. These new entrants were chosen because they entered after early entrants Ferrari, Williams and McLaren, but before the late dominance of Mercedes and Red Bull after 2010[11].

FIA has to regulate a situation where the early entry advantage, experience and vast resources of incumbents like Ferrari, McLaren, Red Bull and Mercedes have to be controlled to maintain healthy levels of competition intensity and the long-term viability of the sport. A way FIA tries to moderate the competitive advantage of big teams and maintain interest in the sport is through annual regulation changes to the specifications of the car design and engine. These changes tend to reset the development direction of car design to a certain extend and force all teams to explore technical opportunities from scratch again.

However, this alleviates only temporarily the predicament of midfield teams. Big teams that secure a good championship position early in a season can switch earlier their greater resources to future car development to get a head start. FIA discussions to set a maximum annual budget to reduce the early entry and resource advantage of big incumbents that are supported by automotive manufacturers seems to be in the right direction (F1i.com, 2019d, 2017h). In 2021, FIA implemented an incremental budget reduction and cap that will reach $135m from 2023 onwards (F1i.com, 2020c). Moreover, the timing of resource allocation switch between in season and future car development is important. A potential FIA intervention is to limit the development time of teams for the car they race and for future season car development. FIA has moved in this direction as well, limiting pre-season and aerodynamic tunnel testing, and banning in season testing (F1i.com, 2020d, 2019e). This creates a competitive context where teams have to switch and choose between exploration and exploitation.

---

[11] Strictly speaking Red Bull and Mercedes are not new entrants. Red Bull traces its origins back to the Stewart Grand Prix that that made its debut in 1997. Mercedes can trace its origins back to Tyrrell in 1970 through a series of team ownership changes. Torro Rosso traces back its origins to the entry of Minardi in 1985. Force India can trace its origins back to Jordan team entry in 1991. So, the latter two can be considered as late comers.

The model is used to explore the ideas of limited budget and resource allocation timing. Results in Figure 9 show the reference results, scenario 2 where budget cap is set equal for all teams, scenario 3 where all teams shift simultaneously their resource allocation to next year, and start future car development simultaneously, and scenario 4 as a combination of 2 and 3. Scenario results show that the advantage of early entrant teams is significantly reduced, and a more level competitive field is generated. The variance of team wins with setup 1 is 4446.266353, with scenario 2 is 1420.68, with scenario 3 is 2346.85, and with scenario 4 is 1071.55.

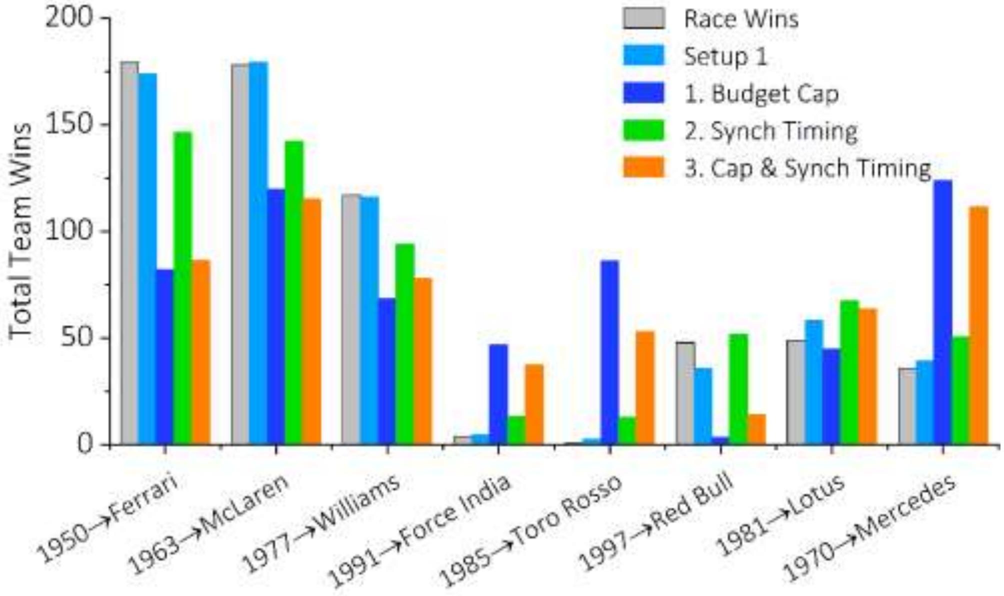

Figure 9 The effect of resource acquisition and synchronised timing of resource allocation

5.2 Further results with a generic model

Taking stock of the results and insights drawn from the calibrated model, the effect of organizational disruption on competitive performance is explored further. A more compact version of the model is created with 6 identical teams that compete for 40 years and their standard deviation for race performance is set to the average of the empirical data (0.38). The case for exploring a generic version of the model rests on the evidence in many industries in support of the mirroring hypothesis (Colfer and Baldwin, 2016). It is reasonable to assume that the degree of product modularity is mirrored albeit never completely, in the organizational structures prevalent in those industries (Colfer and Baldwin, 2016; Henderson and Clark, 1990; Leo, 2020; McCormack et al., 2012).

This generic model version allows us to test alternative rules that team managers might follow to balance exploration and exploitation i.e. decisions on resource allocation for product development between seasons. In the face of complexity and uncertainty, managers adopt rules of thumb and heuristics that are intended to be consistent with their mental models of the business environment (Cyert and March, 1963; Levitt and March, 1988; March and Simon, 1958; Nelson and

Winter, 1982; Simon, 1991). These heuristics that managers employ modulate the organizational responses to competition and changes in their environment.

Research shows how the capability trap arises from two organizational responses to competitive performance gaps (Repenning and Sterman, 2002; Sterman, 2015; Sterman et al., 1997). The first response is to close immediately the performance gap through cost cuts in maintenance and operations, more resources, and more intense work. This response generates consistently immediate improvement results. The second potential response has a longer lead time because it requires resource re-allocation from value generation processes to process improvement activities that temporarily reduces organizational performance. This generates worse before better behaviour in the short term and an organization has to persist until performance improves when it tries to escape the capability trap.

Research on capability trap shows how self-reinforcing dynamics arise from short-run pressure for output that lead to long work hours and corner-cutting in maintenance, training, and investment in process improvement and capability development that is required for long-run success (Perlow et al., 2002; Rahmandad, 2011; Repenning and Sterman, 2002, 2001). Such "worse-before-better" dynamics lead to learning traps, where managers learn to focus on short-term capabilities at the expense of valuable long-term capabilities. In the strategic management literature, the capability trap is known as the competency trap (Pennings and Harianto, 1992). This arises when firms prioritize repeatedly the exploitation of innovation mechanisms in which they have some competencies, over the exploration of alternative innovation mechanisms.

The generic model is used to investigate whether an early switch strategy generates favourable results for the teams that employ them. Teams are set to switch their resources for car development in an adaptive manner subject to their in-season performance ranking. This heuristic involves a trade-off between exploitation, the maximum team effort in each season to achieve the highest possible ranking and secure sponsorships, and exploration, a switch to next season when nearby competitors cannot overcome them.

To explore this, three scenarios are tested. First, all the teams balance exploration and exploitation and switch early on month 6, halfway through the racing season. Second, five teams switch on month 6 and one switches adaptively based on in season performance. Third, three teams switch early and three switch adaptively. Simulation results show that an early switch strategy works better in the long term than the adaptive strategy (Figure 10, left panel). This holds irrespective of the number of teams that follow each rule. The results make sense as future car development is assumed to be just as effective with in season car development[12]. The reason why switching early performs better is because the effect of regulation change is assumed to influence current car design and performance rather than future performance. Thus, investment in future car development does not incur the penalty of regulation change. Removal of regulation effect augments the advantage of the early switching strategy (Figure 10, right panel).

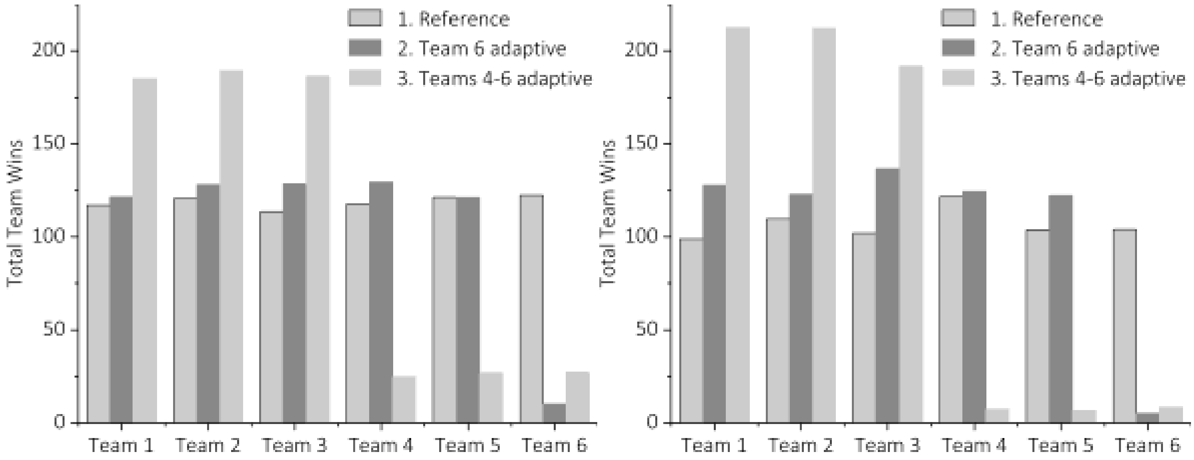

Figure 10 Simulation results where: 1. all teams switch early, 2. Five teams switch early and one team switches adaptively, 3. three teams switch early and three switch adaptively with regulation changes (left), without regulation changes (right)

Results in Figure 10 corroborate the notion that predictable time intervals and rhythms of transition perform best in fast changing environments (Brown and Eisenhardt, 1997). This raises the question of intermediate strategies for ambidexterity. Current practice in F1 is that learning and car design development in a season is consolidated and up to 60% is carried over to the next one (F1i.com, 2022b, 2020a). The percentage carried over leaves some room for competing in season with an adaptive strategy, but also there is a substantial scope for exploration each year which points to the benefits of a switch early strategy.

The model is used to test the idea of exploration-exploitation overlap in product development sequences (Brown and Eisenhardt, 1997), and thus of resource allocation between current car design and future season. The underlying rationale is that F1 teams are ambidextrous at their core (Chen and Katila, 2008; O'Reilly and Tushman, 2013, 2008; Tushman and O'Reilly, 1996) i.e. they develop new car designs for future seasons and optimize the one they compete with. They might alternate between the two to a certain extent (Birkinshaw et al., 2016), because their strategic

---

[12] This assumption is less valid currently with limited testing allowed for cost reasons. Teams, enabled by ICT, treat each race as a car test.

intent might alternate between competing and winning in a season or having more long-term objectives of development in hopes of breakthrough (Andriopoulos and Lewis, 2009).

Scenario 1 in Figure 11 shows the total team wins with a fixed fraction for resource allocation to exploration i.e. future car development, for each team that varies from 10% to 100% for teams 1-6. Extreme exploration pays off in the long term even under budget cap conditions, although the latter are certainly conducive to the aims of the FIA. Scenario 2 shows results sequential ambidexterity where all teams switch instantly from exploitation to exploration at month 6 with a fixed percentage of 10-100% for teams 1-6. The next two scenarios reflect the fact that when teams switch to future car development they still try to incrementally optimise the cars they race with (F1i.com, 2023b, 2023c, 2023a). Scenario 3 relaxes the instant switch assumption and shows results where teams switch at month 6 with a slope that is varied uniformly between 0.4-4.4 for teams 1-6 which end up switching 18%-90% by end of the season. Finally, scenario 4 shows results where teams 1-6 switch from month 11 to 6 with goal seeking behaviour so that by month 12 all teams reach 100%.

A key insight is that performance is close in all scenarios and scenarios 2-4 perform better in intermediate values of switch behaviour and exploration than scenario 1 of structural ambidexterity. The result can be interpreted as indicating that an intermediate position on ambidexterity between pure sequential and structural ambidexterity performs better in the long term. This intermediate area of managing for ambidexterity is the area enclosed between scenarios 2-4 for team 3 and 5. One could argue that teams would want to plan for stable operations across seasons, but actually this is not optimally competitive. So, most teams operate in the area somewhere between the solid black line and the grey lines. They don't switch instantly all their resources away from in season development, but they tend to switch around month 6-7, even when they are in competition for the championship.

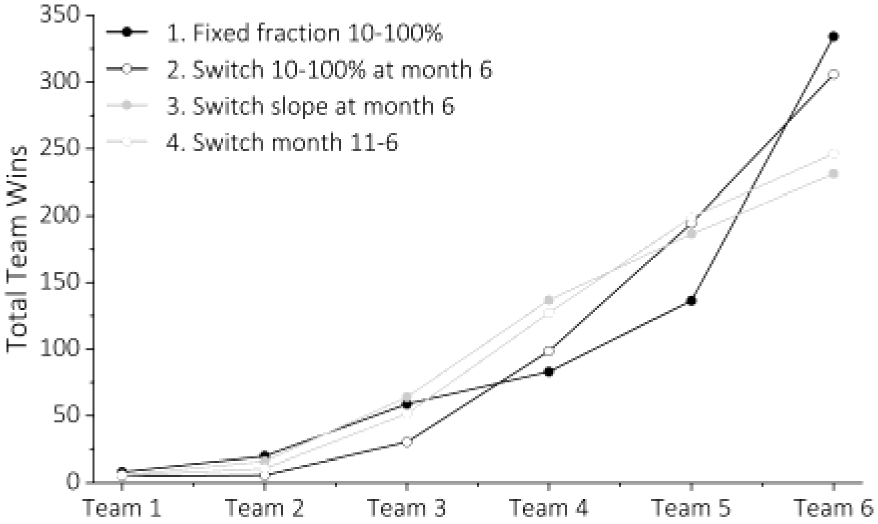

Figure 11 Total team wins of teams with fixed allocation fraction vs fixed switch time 11-6 month for team 1-6.

Even though large investments in long-term capabilities may promise high downstream rewards, a team may not be able to sustain the required investments in the face of an eroding performance (Rahmandad, 2011). Figure 12 tests the idea that a new entrant in an industry may have to forego short term competition and success to succeed in the long-term. In F1 terms, this implies that the new entrant team will compete but switch car development early each year for a number of consecutive seasons to catch up with incumbents in performance. This will hurt its short-term performance but will enhance its competitiveness in the long-term.

Figure 12 shows that the later a team enters, the greater the window of opportunity necessary to reach competitive performance levels and win vis a vis industry incumbents. It seems that 5 to 15 years are necessary to get to front runners with a possibility of winning (F1i.com, 2022c). Entering 4 years late requires 15 to 20 years of switching early, a substantial amount of time in which the entrant needs to continue to attract sponsorship funding. Any sponsor is unlikely to be that persistent. An alternative for entry is the acquisition of an existing team so that budget is not spent on developing infrastructure, or the implementation of a budget cap for incumbents that is waived for entrants for a time window. Figure 12 (right panel) shows that the time window necessary is shorter. The difference to Figure 12 (left panel) is that the team does not need to switch early in any season and forego competitive performance. This is a more attractive proposition for new entrants and sponsors. In reality in F1 other options in addition to a budget cap are explored in F1 on a case by case basis such as the transfer of intellectual property (F1i.com, 2020b). These results are actually corroborated by the trajectory of some teams. Stewart F1 team entered in 1997 and competed up until 1999, winning once. Then, it was acquired by Ford and continued racing as Jaguar which was later acquired by Red Bull that scored its first win in 2009 and won the championship in 2010, a total of 14 seasons after the initial team entry.

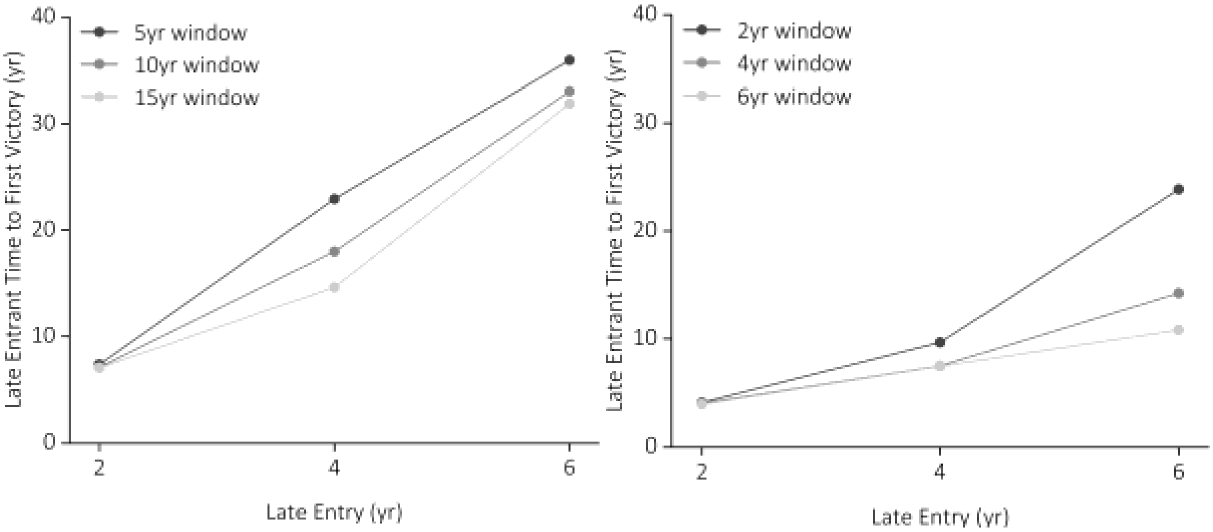

Figure 12 Average time of late entrant to first victory under early switch strategy for window of time with budget cap (left panel), late entrant average time to first win under budget cap regulation for incumbents and double budget for new entrants over a window of time (right panel)

5.3 Discussion

The two models and the results in previous sections make three contributions. First, they provide a two-level explanation on the persistence of incumbents in the face of competition from new entrants, and regulation changes that influence F1. The latter is endogenous in the model and depends on annual team performance. The results indicate the disruptive effect that organizational changes may have and in turn their impact on competitive outcomes.

Second, the results highlight a distinctive element of motorsport, its annual punctuation cycle that can be applied by analogy to other similar sectors where performance depends on the ability to introduce innovative products within a short time span (e.g. software, ICT, entertainment and fashion). It provides a case on intra-industry competition dynamics and introduces capability erosion to produce a more complete theory of differential performance rooted in creative accumulation dynamics. The model generates results where such dynamics can favour incumbents or new entrants.

Third, this study highlights the importance of temporal consistency in exploration and exploitation and the role of innovation experience and organizational aging in shaping temporal consistency (Turner et al., 2012). The F1 case and model results shows that competitive success comes from strategy, a continuous pattern of decisions and actions (Mintzberg and Waters, 1985) to manage valuable organizational assets, and guide product development capability over time

(Brawn and Parr, 2016). Team managers adjust or renew firm resources when time, competition and regulation change and erode their value. For many organizations, temporal consistency is a goal for the innovation process (Gersick, 1994; Nelson and Winter, 1982).

This idea is supported by research on time pacing, which argues that development and introduction of innovations at regular time intervals helps organizations attain efficiencies in coordination and resource allocation (Brown and Eisenhardt, 1997; Turner et al., 2012). Successful managers move from one project to the next balancing exploration and exploitation instead of leaving shifts to chance or rigidly avoid shifts altogether. The role of senior managers and their mental models is important for resource allocation in a timely manner and orchestration of team activities. These practices form a core capability to create recurrent and relentless change that is associated with firm success in high-velocity, competitive settings (Brown and Eisenhardt, 1997).

Future work may fruitfully examine under what conditions and in what ways firms benefit from different aspects of strategic momentum, including acceleration, deceleration, and temporal consistency. Moreover, the generic model structure could be modified and applied to other team sports where incumbents persist, as in the Spanish Primera Division, or they don’t, as in the English Premier League, America’s Cup or NBA. The F1 industry is unique in its extensive use of scientific research and highly regulated and tightly timed product development cycle. Despite these unique characteristics, the study could be generalizable to other industries, or could be used by analogy as argued in the introduction, as basic science, interfirm cooperation become increasingly important in a diverse set of industries.

6 Conclusions

This paper explores F1 competition during 1970–2013 and team performance under continuous regulation changes and industry turnover. It provides an understanding of how exploration and exploitation generates persistent intra-industry performance differential, an important topic in strategic management (Barney, 1986; March, 1991; O’Reilly and Tushman, 2013, 2008; Peteraf, 1993; Rumelt et al., 1994). The paper unbundles the sources of firm performance differences and traces them to: (i) the time span each team competes, (ii) the timing of resource allocation, (iii) the funding each team secures, (iv) the learning pace, (v) significant organizational changes, and (vi) regulation changes.

All teams develop similar capabilities, which in a turbulent environment would suggest that new teams may have the opportunity to unseat incumbents. However, the eighteen F1 teams that have won races from 1970 to 2013, show a persistent performance differential pattern. If dynamic capabilities do not confer a sustainable competitive advantage, then where does the potential for long-term competitive advantage lie? A simulation model in this paper is used to explore this.

The core dynamic is that F1 teams compete and develop their cars continuously. Sponsorship funding, proportional to their season results, allows them to compete, improve their facilities, resources, and cars at a pace that exceeds that of their closest rivals. This virtuous circle is disrupted by organizational, engine supply and annual regulation changes that aim to increase safety, competition intensity and control F1 costs. This logic was tested in the simulation model. The results show that organizational, regulatory, resource and capability development factors must be considered in order to develop a comprehensive explanation.

The key message of this research for management practice is that competitive advantage can be achieved, but sustainable competitive advantage is difficult to achieve through ambidexterity under capability and resource accumulation and erosion. The findings of the case contribute to ongoing strategy research on the determinants of competitive advantage, especially with respect to R&D-intensive industries where superior performance rests on consistent innovation. The F1 case shows that competitive success comes from a continuous stream of decisions for managing the organization’s most valued assets and developing its capabilities over time.

Formula 1 Online Data Sources

http://www.statsf1.com/en/saisons.aspx
http://www.chicanef1.com/allconsts.pl
http://en.wikipedia.org/wiki/2013_Formula_One_season

References

Abernathy, W.J., Clark, K.B., 1985. Innovation: Mapping the winds of creative destruction. Res Policy 14, 3–22.

Adler, P.S., Goldoftas, B., Levine, D.I., 1999. Flexibility versus efficiency? A case study of model changeovers in the Toyota Production System. Organization Science 10, 43–68.

Anand, J., Singh, H., 1997. Asset redeployment, acquisitions and corporate strategy in declining industries. Strategic Management Journal 18, 99–118.

Anderson, P., Tushman, M.L., 1990. Technological discontinuities and dominant designs: a cyclical model of technological change. Adm Sci Q 35, 604–633.

Andriopoulos, C., Lewis, M.W., 2009. Exploitation-exploration tensions and organizational ambidexterity: Managing paradoxes of innovation. Organization Science 20, 696–717.

Aversa, P., Furnari, S., Haefliger, S., 2015. Business model configurations and performance: A qualitative comparative analysis in Formula One racing, 2005–2013. Industrial and Corporate Change 24, 655–676.

Baldwin, C.Y., Clark, K.B., 2000. Design Rules: The Power of Modularity.

Barnett, W.P., Hansen, M.T., 1996. The red queen in organizational evolution. Strategic Management Journal 17, 139–157.

Barney, J.B., 1986. Strategic factor markets: Expectations, luck and business strategy. Manage Sci 32, 1231–1241.

BBC, 2019a. Azerbaijan Grand Prix: The secret aerodynamicist on design icon Adrian Newey [WWW Document]. https://www.bbc.com/sport/formula1/47838557.

BBC, 2019b. Formula 1: How Toto Wolff made Mercedes one of sport's greatest teams [WWW Document]. https://www.bbc.com/sport/formula1/48911849.

BBC, 2017. Formula One teams' costs rocket after rules changes [WWW Document]. http://www.bbc.co.uk/news/business-41610963.

BBC, 2014. Lotus F1 Team hopes technology will give it the edge [WWW Document]. http://www.bbc.com/news/business-26358575.

BBC, 2013. McLaren "probably" diverted fewer resources to 2014 than planned [WWW Document]. http://www.bbc.com/sport/0/formula1/22606809.

BBC, 2009. Toyota withdraws from Formula 1 [WWW Document]. http://news.bbc.co.uk/sport2/hi/motorsport/formula_one/8341602.stm.

BBC, 2008. Global crisis ends Honda F1 era [WWW Document]. http://news.bbc.co.uk/sport2/hi/motorsport/formula_one/7766092.stm.

Benner, M.J., Tushman, M.L., 2003. Exploitation, exploration, and process management: The productivity dilemma revisited. Academy of Management Review 28, 238–256.

Birkinshaw, J., Zimmermann, A., Raisch, S., 2016. How do firms adapt to discontinuous change? Bridging the dynamic capabilities and ambidexterity perspectives. Calif Manage Rev 58, 36–58.

Boumgarden, P., Nickerson, J., Zenger, T.R., 2012. Sailing into the wind: Exploring the relationships among ambidexterity, vacillation, and organizational performance. Strategic Management Journal 33, 587–610.

Bourgeois, L.J., Eisenhardt, K.M., 1988. Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. Manage Sci 34, 816–835.

Brawn, R., Parr, A., 2016. Total Competition: Lessons in Strategy from Formula One. Simon & Schuster, London, UK.

Brown, S.L., Eisenhardt, K.M., 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. Adm Sci Q 42, 1–34.

Brown, S.L., Eisenhardt, K.M., 1995. Product development: Past research, present findings and future directions. Academy of Management Review 20, 343–378.

Burgelman, R.A., 1991. Intraorganizational ecology of strategy making and organizational adaptation: Theory and field research. Organization Science 2, 239–262.

Burgers, J.H., Jansen, J.J.P., Van den Bosch, F.A.J., Volberda, H.W., 2009. Structural differentiation and corporate venturing: The moderating role of formal and informal integration mechanisms. J Bus Ventur 24, 206–220.

Burton, M.D., O'Reilly, C.A., 2021. Management systems for exploration and exploitation, in: Beckman, C.M. (Ed.), Carnegie Goes to California: Advancing and Celebrating the Work of James G. March. pp. 53–77.

Castellucci, F., Podolny, J.M., 2017. The dynamics of position, capability, and market competition. Industrial and Corporate Change 26, 21–39.

Chandler, A.D., 1990. The enduring logic of industrial success. Harv Bus Rev 68, 130–140.

Chandler, A.D., 1977. The Visible Hand. Harvard University Press.

Chen, E.L., Katila, R., 2008. Rival interpretations of balancing exploration and exploitation: Simultaneous or sequential?, in: Scott, S. (Ed.), Handbook of Technology and Innovation Management. Wiley, New York, pp. 197–214.

Christensen, C.M., 1997. The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business School Press, Boston.

Christensen, C.M., McDonald, R., Altman, E.J., Palmer, J.E., 2018. Disruptive innovation: An intellectual history and directions for future research. Journal of Management Studies 55, 1043–1078.

Christensen, C.M., Rosenbloom, R.S., 1995. Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value network. Res Policy 24, 233–257.

Christensen, C.M., Suarez, F.F., Utterback, J.M., 1998. Strategies for survival in fast-changing industries. Manage Sci 44, S207–S220.

Clark, K.B., 1985. The interaction of design hierarchies and market concepts in technological evolution. Res Policy 14, 235–251.

Coen, C.A., Maritan, C.A., 2010. Investing in capabilities: The dynamics of resource allocation. Organization Science 22, 99–117.

Colfer, L.J., Baldwin, C.Y., 2016. The mirroring hypothesis: theory, evidence, and exceptions. Industrial and Corporate Change 25, 709–738.

Cool, K., Schendel, D., 1988. Performance differences among strategic group members. Strategic Management Journal 9, 207–223.

Cottrell, T., Nault, B.R., 2004. Product variety and firm survival in the microcomputer software industry. Strategic Management Journal 25, 1005–1025.

Cyert, R., March, J.G., 1963. A Behavioral Theory of the Firm. Prentice Hall, NJ, US.

Danneels, E., 2008. Organizational antecedents of second-order competences. Strategic Management Journal 29, 519–543.

D’Aveni, R.A., Dagnino, G.B., Smith, K.G., 2010. The age of temporary advantage. Strategic Management Journal 31, 1371–1385.

Davis, J.P., Eisenhardt, K.M., Bingham, C.B., 2009. Optimal structure, market dynamism, and the strategy of simple rules. Adm Sci Q 54, 413–452.

Davis, J.P., Eisenhardt, K.M., Bingham, C.B., 2007. Developing theory through simulation methods. Academy of Management Review 32, 480–499.

DeCarolis, D.M., Deeds, D.L., 1999. The impact of stocks and flows of organizational knowledge on firm performance: an empirical investigation of the biotechnology industry. Strategic Management Journal 20, 953–968.

Denrell, J., 2004. Random walks and sustained competitive advantage. Manage Sci 50, 922–934.

Dierickx, I., Cool, K., 1989. Asset stock accumulation and sustainability of competitive advantage. Manage Sci 35, 1504–1511.

Ebben, J.J., Johnson, A.C., 2005. Efficiency, flexibility, or both? Evidence linking strategy to performance in small firms. Strategic Management Journal 26, 1249–1259.

Eisenhardt, K.M., 1989. Making fast strategic decisions in high-velocity environments. Academy of Management Journal 32, 543–576.

Eisenhardt, K.M., Martin, J.A., 2000. Dynamic capabilities: what are they? Strategic Management Journal 21, 1105–1121.

ESPN, 2014. Red Bull struggle shows importance of works engine deal [WWW Document]. http://en.espnf1.com/mclaren/motorsport/story/164351.html#XHse3YYweIYL3F4P.99.

ESPN, 2013. F1 TV audiences fall in 2012 [WWW Document]. http://en.espnf1.com/f1/motorsport/story/100893.html (access 4/1/2014).

F1i.com, 2023a. Mercedes to quit “diva 2.0” and focus development on 2024 car [WWW Document]. https://f1i.com/news/480678-mercedes-to-quit-diva-2-0-and-focus-development-on-2024-car.html.

F1i.com, 2023b. Tech take: A rundown of the teams’ updates for Spa [WWW Document]. https://f1i.com/news/482446-tech-take-a-rundown-of-the-teams-updates-for-spa.html. URL (accessed 7.29.23).

F1i.com, 2023c. Wolff says Mercedes “sails now set for 2024” [WWW Document]. https://f1i.com/news/483701-wolff-says-mercedes-sails-now-set-for-2024.html.

F1i.com, 2022a. Mercedes challenged by limited wind tunnel time [WWW Document]. https://f1i.com/news/431249-mercedes-challenged-by-limited-wind-tunnel-time-elliott.html.

F1i.com, 2022b. Mercedes: Final W13 upgrade in Austin also about learning for 2023 [WWW Document]. https://f1i.com/news/457077-mercedes-final-w13-upgrade-in-austin-also-about-learning-for-2023.html.

F1i.com, 2022c. VW CEO: Board has voted in favor of Audi/Porsche F1 entries! [WWW Document]. https://f1i.com/news/439896-vw-ceo-board-has-voted-in-favor-of-audi-porsche-f1-entries.html.

F1i.com, 2020a. Red Bull labels 2020 Mercedes “most complete and rounded car” yet [WWW Document]. https://f1i.com/news/385923-red-bull-labels-2020-mercedes-most-complete-and-rounded-car-yet.

F1i.com, 2020b. Mercedes admits development of W11 halted “a long time ago” [WWW Document]. https://f1i.com/news/387218-mercedes-admits-development-of-w11-halted-a-long-time-ago.html.

F1i.com, 2020c. FIA formally approves F1 cost-saving and rule changes [WWW Document]. https://f1i.com/news/373870-fia-formally-approves-f1-cost-saving-and-rule-changes.html.

F1i.com, 2020d. How F1’s aerodynamic testing reduction rule will work [WWW Document]. https://f1i.com/news/373900-how-f1s-aerodynamic-testing-reduction-rule-will-work.html.

F1i.com, 2019a. Brown “comfortable” with McLaren’s 2019 commercial outlook [WWW Document]. https://f1i.com/news/326947-brown-comfortable-with-mclarens-2019-commercial-outlook.html.

F1i.com, 2019b. Wolff: Mercedes success rooted in optimal “merging” of engine and chassis [WWW Document]. https://f1i.com/news/343229-wolff-mercedes-success-rooted-in-merging-of-engine-and-chassis.html.

F1i.com, 2019c. McLaren will fight for P4, but won’t “compromise” 2020 car [WWW Document]. https://f1i.com/news/354445-mclaren-will-fight-for-p4-but-wont-compromise-2020-car-seidl.html.

F1i.com, 2019d. Formula 1 to impose $175m cost cap on teams in 2021 [WWW Document]. https://f1i.com/news/343609-formula-1-to-impose-175m-cost-cap-on-teams-in-2021.html.

F1i.com, 2019e. Teams “agree to reduction in testing” in 2020 [WWW Document]. https://f1i.com/news/352074-teams-agree-to-reduction-in-testing-in-2020.html.

F1i.com, 2017a. RB14 design brought forward to avoid slow 2018 start [WWW Document]. http://en.f1i.com/news/282837-red-bull-racing-2018-design-got-early-start-ricciardo.html.

F1i.com, 2017b. Honda corporate culture inadequate for F1 [WWW Document]. http://en.f1i.com/news/262665-honda-corporate-culture-inadequate-f1-boullier.html.

F1i.com, 2017c. McLaren-Renault relationship will take time to build [WWW Document]. http://en.f1i.com/news/282535-mclaren-renault-relationship-will-take-time-build-boullier.html.

F1i.com, 2017d. Marko: Change the engine rules or Red Bull will quit! [WWW Document]. http://en.f1i.com/news/268540-marko-change-engine-rules-red-bull-will-quit.html.

F1i.com, 2017e. Early start on 2017 car was huge benefit for Ferrari - Wolff [WWW Document]. http://en.f1i.com/news/269732-early-start-2017-car-huge-benefit-ferrari-wolff.html.

F1i.com, 2017f. Ferrari spent “100s of millions” to play catch up, says former engineer [WWW Document]. http://en.f1i.com/news/262470-ferrari-spent-100s-millions-play-catch-says-former-engineer.html.

F1i.com, 2017g. Ecclestone: “F1 and the FIA often helped Ferrari win!” [WWW Document]. http://en.f1i.com/news/284049-ecclestone-f1-fia-often-helped-ferrari-win.html.

F1i.com, 2017h. McLaren’s Brown: “F1 budget cap inevitable” [WWW Document]. http://en.f1i.com/news/280734-mclarens-brown-f1-budget-cap-inevitable.html.

F1i.com, 2016a. Paddy Lowe, the pioneer [WWW Document]. http://en.f1i.com/magazine/50159-paddy-lowe-the-pioneer.html.

F1i.com, 2016b. How Eric Boullier is keeping McLaren on its toes. http://en.f1i.com/magazine/67917-eric-boullier-keeping-mclaren-toes.html.

F1i.com, 2016c. Renault facing tough decision on when to focus on 2017 car. http://en.f1i.com/news/60606-renault-facing-tough-decision-focus-2017-prost.html.

F1i.com, 2016d. McLaren working 50/50 on 2016 and 2017 F1 car [WWW Document]. http://en.f1i.com/news/57653-mclaren-working-5050-2016-2017-cars.html.

F1technical.net, 2014. Regulations [WWW Document]. http://www.f1technical.net/topics/30.

Ferrier, W.J., Smith, K.G., Grimm, C.M., 1999. The role of competitive action in market share erosion and industry dethronement: A study of industry leaders and challengers. Academy of Management Journal 42, 372–388.

Formula1.com, 2019. Andreas Seidl: The man tasked with leading McLaren's fightback [WWW Document]. https://www.formula1.com/en/latest/article.andreas-seidl-the-man-tasked-with-leading-mclarens-fightback.mgkJ4r1FNYnkz6fefcrnL.html.

Formula1.com, 2015. Pat Symonds Q&A: Williams can be champions again [WWW Document]. http://www.formula1.com/news/interviews/2015/2/16811.html.

Formula1.com, 2014. Moving McLaren forward - exclusive Ron Dennis Q&A [WWW Document]. http://www.formula1.com/news/interviews/2014/8/16267.html.

Fu, L., Liao, S., Liu, Z., Lu, F., 2021. An investigation of resource allocation mechanism for exploration and exploitation under limited resource. IEEE Trans Eng Manag 68, 1802–1812.

Gavetti, G., Levinthal, D.A., 2000. Looking forward and looking backward: Cognitive and experiential search. Adm Sci Q 45, 113–137.

Gersick, C.J.G., 1994. Pacing strategic change: The case of a new venture. Academy of Management Journal 37, 9–45.

Ghemawat, P., Costa, J., 1993. The organizational tension between static and dynamic efficiency. Strategic Management Journal 14, 59–73.

Gibson, C.B., Birkinshaw, J., 2004. The antecedents, consequences, and mediating role of organizational ambidexterity. Academy of Management Journal 47, 209–226.

Gilbert, C.G., 2005. Unbundling the structure of inertia: Resource versus routine rigidity. Academy of Management Journal 48, 741–763.

Gino, F., Pisano, G.P., 2011. Why leaders don't learn from success. Harvard Business Review2 89, 68–74.

Grant, R.M., 1996a. Toward a knowledge-based theory of the firm. Strategic Management Journal 17, 109–122.

Grant, R.M., 1996b. Prospering in dynamically-competitive environments: Organizational capability as knowledge integration. Organization Science 7, 375–387.

Gulati, R., 1998. Alliances and networks. Strategic Management Journal 19, 293–317.

Gulati, R., Gargiulo, M., 1999. Where do interorganizational networks come from? American Journal of Sociology 104, 1439–1493.

Gupta, A.K., Smith, K.G., Shalley, C.E., 2006. The interplay between exploration and exploitation. Academy of Management Journal 49, 693–706.

Harrison, J.R., Lin, Z., Carroll, G.R., Carley, K.M., 2007. Simulation modeling in organizational and management research. Academy of Management Review 32, 1229–1245.

Helfat, C.E., Finkelstein, S., Mitchell, W., Peteraf, M.A., Singh, H., Teece, D.J., Winter, S.G., 2007. Dynamic Capabilities: Understanding Strategic Change in Organizations. Blackwell, London, UK.

Helfat, C.E., Peteraf, M.A., 2003. The dynamic resource-based view: capability lifecycles. Strategic Management Journal 24, 997–1010.

Helfat, C.E., Raubitschek, R.S., 2000. Product sequencing: co-evolution of knowledge, capabilities and products. Strategic Management Journal 21, 961–979.

Henderson, R.M., Clark, K.B., 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. Adm Sci Q 35, 9–30.

Hobday, M., Davies, A., Prencipe, A., 2005. Systems integration: a core capability of the modern corporation. Industrial and Corporate Change 14, 1109–1143.

Homer, J., 2019. A comment on John Sterman's "system dynamics at sixty: the path forward." Syst Dyn Rev 35, 5–7.

Iansiti, M., 1995. Technology integration: Managing technological evolution in a complex environment. Res Policy 24, 521–542.

Iansiti, M., Clark, K.B., 1994. Integration and dynamic capability: Evidence from product development in automobiles and mainframe computers. Industrial and Corporate Change 3, 557–605.

Jansen, J.J.P., Van Den Bosch, F.A.J., Volberda, H.W., 2006. Exploratory innovation, exploitative innovation, and performance: Effects of organizational antecedents and environmental moderators. Manage Sci 52, 1661–1674.

Jansen, J.J.P., Vera, D., Crossan, M., 2009. Strategic leadership for exploration and exploitation: The moderating role of environmental dynamism. Leadersh Q 20, 5–18.

Jenkins, M., 2014. Innovate or imitate? The role of collective beliefs in competences in competing firms. Long Range Plann 47, 173–185.

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

Jenkins, M., Floyd, S., 2001. Trajectories in the evolution of technology: A multi-level study of competition in Formula 1 racing. Organization Studies 22, 945–969.

Jenkins, M., Pasternak, K., West, R., 2009. Performance at the Limit: Business Lessons from Formula 1 Motor Racing. Cambridge University Press, Cambridge, UK.

Judde, C., Booth, R., Brooks, R., 2013. Second place is first of the losers: An analysis of competitive balance in Formula One. J Sports Econom 14, 411–439.

Judge, W.Q., Miller, A., 1991. Antecedents and outcomes of decision speed in different environmental contexts. Academy of Management Journal 34, 449–463.

Karadag, R., Poppo, L., 2023. Strategic resource decay. Strategic Management Journal 44, 1534–1561.

Katila, R., Ahuja, G., 2002. Something old, something new: A longitudinal study of search behavior and new product introduction. Academy of Management Journal 45, 1183–1194.

Kauppila, O.-P., 2010. Creating ambidexterity by integrating and balancing structurally separate interorganizational partnerships. Strateg Organ 8, 283–312.

Kitaguchi, T., Uchihira, N., 2022. Resource allocation mechanism considering combination of exploitation and exploration in ambidexterity with external factors, in: 2022 IEEE Technology & Engineering Management Conference - Asia Pacific (TEMSCON-ASPAC). pp. 108–113.

Klepper, S., 2002. The capabilities of new firms and the evolution of the US automobile industry. Industrial and Corporate Change 11, 645–666.

Klepper, S., 1996. Entry, exit, growth and innovation over the product life cycle. American Economic Review 86, 562–583.

Klevorick, A.K., Levin, R.C., Nelson, R.R., Winter, S.G., 1995. On the sources and significance of interindustry differences in technological opportunities. Res Policy 24, 185–205.

Knott, A.M., 2003. Persistent heterogeneity and sustainable innovation. Strategic Management Journal 24, 687–705.

Knott, A.M., Posen, H.E., 2005. Is failure good? Strategic Management Journal 26, 617–641.

Kogut, B., Zander, U., 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. Organization Science 3, 383–397.

Lazonick, W., Prencipe, A., 2005. Dynamic capabilities and sustained innovation: strategic control and financial commitment at Rolls-Royce plc. Industrial and Corporate Change 14, 501–542.

Lee, J., Lee, J., Lee, H., 2003. Exploration and exploitation in the presence of network externalities. Manage Sci 49, 553–570.

Leo, E., 2020. Toward a contingent model of mirroring between product and organization: A knowledge management perspective. Journal of Product Innovation Management 37, 97–117.

Leonard-Barton, D., 1995. Wellsprings of Knowledge. Harvard Business School Press, Boston, MA, US.

Leonard-Barton, D., 1992. Core capabilities and core rigidities: A paradox in managing new product development. Strategic Management Journal 13, 111–125.

Levinthal, D., 1992. Surviving Schumpeterian environments: An evolutionary perspective. Industrial and Corporate Change 1, 427–443.

Levinthal, D.A., 1997. Adaptation on rugged landscapes. Manage Sci 43, 934–950.

Levinthal, D.A., March, J.G., 1993. The myopia of learning. Strategic Management Journal 14, 95–112.

Levinthal, D.A., March, J.G., 1981. A model of adaptive organizational search. J Econ Behav Organ 2, 307–333.

Levitt, B., March, J.G., 1988. Organizational learning. Annu Rev Sociol 14, 319–340.

Lewin, A.Y., Volberda, H.W., 1999. Prolegomena on coevolution: A framework for research on strategy and new organizational forms. Organization Science 10, 519–534.

Louis, M.R., Sutton, R.I., 1991. Switching cognitive gears: From habits of mind to active thinking. Human Relations 44, 55–76.

Lovas, B., Ghoshal, S., 2000. Strategy as guided evolution. Strategic Management Journal 21, 875–896.

Lubatkin, M.H., Simsek, Z., Ling, Y., Veiga, J.F., 2006. Ambidexterity and performance in small-to medium-sized firms: The pivotal role of top management team behavioral integration. J Manage 32, 646–672.

March, J.G., 1991. Exploration and exploitation in organizational learning. Organization Science 2, 71–87.

March, J.G., Simon, H.A., 1958. Organizations. John Wiley & Sons, New York, NY, USA.

Marino, A., Aversa, P., Mesquita, L., Anand, J., 2015. Driving performance via exploration in changing environments: Evidence from Formula One racing. Organization Science 26, 1079–1100.

Markides, C., Charitou, C.D., 2004. Competing with dual business models: A contingency approach. The Academy of Management Executive 18, 22–36.

Markides, C., Geroski, P.A., 2004. Fast second: How smart companies bypass radical innovation to enter and dominate markets. Wiley, New York, NY, USA.

Martin, J.A., Eisenhardt, K.M., 2010. Rewiring: Cross business unit collaborations in multibusiness organizations. Academy of Management Journal 53, 265–301.

Mastromarco, C., Runkel, M., 2009. Rule changes and competitive balance in Formula One motor racing. Appl Econ 41, 3003–3014.

McCarthy, I.P., Lawrence, T.B., Wixted, B., Gordon, B.R., 2010. A multidimensional conceptualization of environmental velocity. Academy of Management Review 35, 604–626.

McCormack, A., Baldwin, C., Rusnak, J., 2012. Exploring the duality between product and organizational architectures: A test of the “mirroring” hypothesis. Res Policy 41, 1309–1324.

Mintzberg, H., Waters, J.A., 1985. Of strategies, deliberate and emergent. Strategic Management Journal 6, 257–272.

Murmann, J.P., Frenken, K., 2006. Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. Res Policy 35, 925–952.

Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Change. Belknap Press of Harvard University Press, Cambridge, MA.

Nickerson, J.A., Zenger, T.R., 2002. Being efficiently fickle: A dynamic theory of organizational choice. Organization Science 13, 547–566.

Noda, T., Bower, J.L., 1996. Strategy making as iterated processes of resource allocation. Strategic Management Journal 17, 159–192.

O’Reilly, C.A., Harreld, J.B., Tushman, M.L., 2009. Organizational ambidexterity: IBM and emerging business opportunities. Calif Manage Rev 51, 75–99.

O’Reilly, C.A., Tushman, M.L., 2013. Organizational ambidexterity: Past, present, and future. Academy of Management Perspectives 27, 324–338.

O’Reilly, C.A., Tushman, M.L., 2011. Organizational ambidexterity in action: How managers explore and exploit. Calif Manage Rev 53, 5–22.

O’Reilly, C.A., Tushman, M.L., 2008. Ambidexterity as a dynamic capability: Resolving the innovator’s dilemma. Res Organ Behav 28, 185–206.

O’Reilly, C.A., Tushman, M.L., 2004. The ambidextrous organization. Harv Bus Rev 82, 74–81.

Papachristos, G., 2012. Case study and system dynamics research: Complementarities, pluralism and evolutionary theory development, in: 30th International Conference of the System Dynamics Society, St Gallen, Switzerland Online Proceedings.

Patel, P., Pavitt, K., 1997. The technological competencies of the world's largest firms: complex and path-dependent, but not much variety. Res Policy 26, 141–156.

Pavitt, K., 1998. Technologies products and organization in the innovating firm what Adam Smith tells us and Joseph Schumpeter doesn't. Industrial and Corporate Change 7, 433–452.

Pennings, J.M., Harianto, F., 1992. Technological networking and innovation implementation. Organization Science 3, 356–382.

Perlow, L.A., Okhuysen, G.A., Repenning, N.P., 2002. The speed trap: Exploring the relationship between decision making and temporal context. Academy of Management Journal 45, 931–955.

Peteraf, M.A., 1993. The cornerstones of competitive advantage: A resource-based view. Strategic Management Journal 14, 179–191.

Posen, H.E., Levinthal, D.A., 2012. Chasing a moving target: Exploitation and exploration in dynamic environments. Manage Sci 58, 587–601.

Powell, W.W., 1990. Neither market nor hierarchy: Network forms of organization., in: Cummings, L., Staw, B.M. (Eds.), Research in Organizational Behavior, 12: JAI Press, Greenwich, CT, pp. 295–336.

Rahmandad, H., 2011. Impact of growth opportunities and competition on firm-level capability development trade-offs. Organization Science 23, 138–154.

Rahmandad, H., Repenning, N., 2016. Capability erosion dynamics. Strategic Management Journal 37, 649–672.

Raisch, S., 2008. Balanced structures: Designing organizations for profitable growth. Long Range Plann 41, 483–508.

Raisch, S., Birkinshaw, J., Probst, G., Tushman, M.L., 2009. Organizational ambidexterity: Balancing exploitation and exploration for sustained performance. Organization Science 20, 685–695.

Repenning, N.P., Sterman, J.D., 2002. Capability traps and self-confirming attribution errors in the dynamics of process improvement. Adm Sci Q 47, 265–295.

Repenning, N.P., Sterman, J.D., 2001. Nobody ever gets credit for fixing problems that never happened: creating and sustaining process improvement. Calif Manage Rev 43, 64–88.

Richardson, G.P., 2011. Reflections on the foundations of system dynamics. Syst Dyn Rev 27, 219–243.

Rogan, M., Mors, M.L., 2014. A network perspective on individual-level ambidexterity in organizations. Organization Science 25, 1860–1877.

Rosenbloom, R.S., 2000. Leadership, capabilities, and technological change: The transformation of NCR in the electronic era. Strategic Management Journal 21, 1083–1103.

Rosenbloom, R.S., Christensen, C.M., 1994. Technological discontinuties, organizational capabilities, and strategic commitments. Industrial and Corporate Change 3, 655–685.

Rosenkopf, L., Nerkar, A., 2001. Beyond local search: Boundary-spanning, exploration, and impact in the optical disk industry. Strategic Management Journal 22, 287–306.

Rothaermel, F.T., Deeds, D.L., 2004. Exploration and exploitation alliances in biotechnology: a system of new product development. Strategic Management Journal 25, 201–221.

Rumelt, R.P., 1991. How much does industry matter? Strategic Management Journal 12, 167–185.

Rumelt, R.P., Schendel, D., Teece, D.J., 1994. Fundamental issues in strategy. Harvard Business School Press, Cambridge MA.

Sahal, D., 1985. Technological guideposts and innovation avenues. Res Policy 14, 61–82.

Sanchez, R., 1995. Strategic flexibility in product competition. Strategic Management Journal 16, 135–159.

Sanchez, R., Mahoney, J.T., 1996. Modularity, flexibility, and knowledge management in product and organization design. Strategic Management Journal 17, 63–76.

Schilke, O., 2014. On the contingent value of dynamic capabilities for competitive advantage: The nonlinear moderating effect of environmental dynamism. Strategic Management Journal 35, 179–203.

Siggelkow, N., 2001. Change in the presence of fit: The rise, the fall, and the renaissance of Liz Claiborne. The Academy of Management Journal 44, 838–857.

Siggelkow, N., Levinthal, D.A., 2003. Temporarily divide to conquer: Centralized, decentralized, and reintegrated organizational approaches to exploration and adaptation. Organization Science 14, 650–669.

Siggelkow, N., Rivkin, J.W., 2005. Speed and search: Designing organizations for turbulence and complexity. Organization Science 16, 101–122.

Simon, H.A., 1991. Bounded rationality and organizational learning. Organization Science 2, 125–134.

Solitander, M., Solitander, N., 2010. The sharing, protection and thievery of intellectual assets: The case of the Formula 1 industry. Management Decision 48, 37–57.

Sterman, J.D., 2015. Stumbling towards sustainability: Why organizational learning and radical innovation are necessary to build a more sustainable world—but not sufficient. Leading Sustainable Change: An Organizational Perspective.

Sterman, J.D., 2000. Business dynamics: Systems thinking and modelling for a complex world. McGraw Hill, New York.

Sterman, J.D., Repenning, N.P., Kofman, F., 1997. Unanticipated side effects of successful quality programs: Exploring a paradox of organizational improvement. Manage Sci 43, 503–521.

Suarez, F.F., Utterback, J.M., 1995. Dominant designs and the survival of firms. Strategic Management Journal 16, 415–430.

Sylt, C., Reid, C., 2011. Formula money. Wyndeham Grange, Southwick, Sussex.

Teece, D.J., 2009. Dynamic Capabilities and Strategic Management: Organizing for Innovation and Growth. Oxford University Press, Oxford, UK.

Teece, D.J., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strategic Management Journal 28, 1319–1350.

Teece, D.J., 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Res Policy 15, 285–305.

Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18, 509–533.

TheRace.com, 2020. How Mercedes designed F1's best car but kept it secret [WWW Document]. https://the-race.com/formula-1/how-mercedes-designed-f1s-best-car-but-kept-it-secret/.

Trabesinger, A., 2007. Power games. Nature 447, 900–903.

Tripsas, M., 1997. Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry. Strategic Management Journal 18, 119–142.

Tripsas, M., Gavetti, G., 2000. Capabilities, cognition, and inertia: Evidence from digital imaging. Strategic Management Journal 21, 1147–1161.

Turner, S.F., Mitchell, W., Bettis, R.A., 2012. Strategic momentum: How experience shapes temporal consistency of ongoing innovation. J Manage 39, 1855–1890.

Tushman, M., Anderson, P., 1986. Technological discontinuities and organizational environments. Adm Sci Q 31, 439–465.

Tushman, M.L., O'Reilly, C.A., 1997. Winning through Innovation: A Practical Guide to Leading Organizational Change and Renewal. Harvard Business School Press, Boston, MA, US.

Tushman, M.L., O'Reilly, C.A., 1996. Ambidextrous organizations: Managing evolutionary and revolutionary change. Calif Manage Rev 38, 8–29.

Utterback, J.M., 1994. Mastering the Dynamics of Innovation. Harvard Business School Press, Boston.

Utterback, J.M., Suárez, F.F., 1993. Innovation, competition, and industry structure. Res Policy 22, 1–21.

Uzzi, B., 1997. Social structure and competition in interfirm networks: the paradox of embeddedness. Adm Sci Q 42, 35–67.

Verona, G., 1999. A Resource-Based View of product development. Academy of Management Review 24, 132–142.

Walker, G., Madsen, T.L., Carini, G., 2002. How does institutional change affect heterogeneity among firms? Strategic Management Journal 23, 89–104.

Wiggins, R.R., Ruefli, T.W., 2002. Sustained competitive advantage: Temporal dynamics and the incidence and persistence of superior economic performance. Organization Science 13, 82–105.

Winter, S.G., 2000. The satisficing principle in capability learning. Strategic Management Journal 21, 981–996.

Zahra, S.A., Sapienza, H.J., Davidsson, P., 2006. Entrepreneurship and dynamic capabilities: A review, model and research agenda. Journal of Management Studies 43, 917–955.

Zollo, M., Winter, S.G., 2002. Deliberate learning and the evolution of dynamic capabilities. Organization Science 13, 339–351.

Zott, C., 2003. Dynamic capabilities and the emergence of intraindustry differential firm performance: insights from a simulation study. Strategic Management Journal 24, 97–125.