Paper to be presented at the DRUID 2011

on

INNOVATION, STRATEGY, and STRUCTURE -
Organizations, Institutions, Systems and Regions
at
Copenhagen Business School, Denmark, June 15-17, 2011

Adaptation at Full Speed - Regulatory Changes in Fast Moving Industries

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Abstract

Prior research provides rich insights into the mechanisms to enhance an organization?s ability to adapt. Even though human resources have been found to play a key role to enable organizations to reply to environmental opportunities and threats, evidence at the individual level is scarce. A comprehensive understanding of the determinants of adaptation is particularly important in fast moving industries, where organizations typically do not get a second chance to make up for a failure to adapt. This paper aims at filling this research gap. It uses a unique data set on Formula One motorsport constructors. A pre-post experimental design with exogenous regulatory change allows for the operationalization of adaptation as well as a causal interpretation of the results. The findings indicate that whereas domain-specific experience at the level of the individual decreases the adaptive ability of an organization, experience from moderately distant technological fields increases it. To exploit experience from more distant fields, absorptive capacity is needed. Additionally, results provide first evidence that learning matters with respect to the determinants of adaptation.

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1 INTRODUCTION

Although understanding the determinants of adaptation looks back on a long tradition, it is still in the focus of research (Lawrence and Lorsch, 1967; Chakravarthy, 1982; Meyer, 1982; Ginsberg and Buchholtz, 1990; Ganesh et al., 2004). This is particularly so as rapid advancement in technology and highly dynamic environments create the need for faster and flexible action of organizations in order to be successful or simply to survive (Ghemawat, 1991; Kessler and Chakrabarti 1996). Frequent and literally impossible to forecast changes repeatedly cancel out competitive advantages and organizations have to continuously innovate to maintain competitive (Eisenhardt and Tabrizi, 1995).

The existing literature contributes to a better understanding of the determinants of adaptation by providing new or extending existing theoretical frameworks of adaptation (e.g., Chakravarthy, 1982; Miles and Snow, 1978). Empirical evidence dealing with adaptation is scarce. Exceptions form a number of in part case study-based analyses dealing with the strategies of adaptation (Ganesh et al., 2004), predictors of adaptation (Meyer, 1982; Ginsberg and Buchholz, 1990), and the relationship between adaptation and innovativeness (Tuominen et al., 2004; Eisenhardt and Tabrizi, 1995) or survival of an organization (Bradley et al., 2011) as well as adaptation and firm success (Oktemgil and Greenley, 1996). So far, with the exception of Tuominen et al. (2004) and Eisenhardt and Tabrizi (1995) none of the studies have considered adaptation in the context of R&D.

Yet, despite the findings of these studies, a number of important questions still remain unanswered. Even though human resources have been found to play a key role to enable organizations to reply to environmental opportunities and threats (Andrews, 1971; Child, 1997), evidence on how individuals contribute to an organization's ability to adapt is scarce. The major part of the existing literature analyzes the determinants at the level of the organization (e.g. Meyer, 1982; Tuominen et al., 2004). However, a comprehensive understanding of the determinants of adaptation is of particular importance to organizations to enable them to accelerate decision-making processes and to learn how to effectively adapt in technologically dynamic environments. Typically, in those environments, organizations do not get a second chance to make up for a failure to adapt (D'Aveni and Thomas, 2004).

This study builds on the literature on organizational adaptation and knowledge recombination. Since adaptation is investigated in an R&D environment, the study focuses on resource-related determinants of adaptation, i.e. professional experience of key engineers in R&D and industry related experience of the organization. A unique dataset allows the operationalization of adaptation. The empirical setting, i.e. a pre-post design with an exogenous change of the environment (i.e., a regulatory shock) to which organizations have to adapt to enables causal interpretation of the results. Finally, the fact that the same regulatory change is observed twice over time, allows quantifying the effect of learning on the ability of an organization to adapt.

The empirical context of this study is Formula One motorsport. Exogenous regulatory changes introduced in the 1994 and 2008 Formula One seasons will be used to account for adaptation of the different Formula One constructors[1] (e.g., Ferrari, McLaren or Williams) to maintain or to become successful. The fact that Formula One data contains publicly available and rich information, recently resulted in a number of economic papers employing these data to examine knowledge spillover (Solitander and Solitander, 2010), agglomeration and cluster effects (Pinch and Henry, 1999; Tallman et al., 2004), the evolution of technology (Jenkins and Floyd, 2001), or competitive balance (Mastromarco and Runkel, 2009). However, none of these studies have considered adaptation.

Formula One motorsport creates a unique setting to analyze the determinants of R&D-related adaptation, since race car constructors require human, financial, and organizational resources to maintain their competitiveness, i.e. to construct competitive race cars to win races and finally the World Championship (Jenkins et al., 2007). Even though the motorsport industry is well defined, the constructors continuously innovate to adapt to the fast changing environment or to influence it. The latter, i.e. proactive innovations of one organization in an industry to which competitors have to respond, is not considered within this paper.

In Formula One, frequent and sudden rule changes, which affect all constructors at the same time, repeatedly change the balance of power of the constructors within the industry. Whereas some rule changes are caused by the dominance of one particular team (e.g., Ferrari’s and Michael Schumacher’s predominance in the early years of 2000), this study uses a rule change that was caused by safety requirements, i.e. driver aids were prohibited to reduce the speed of the cars. These rule changes force Formula One constructors to adapt their cars in order to stay competitive. This typically requires innovation. For instance, for Gordon Murray[2], a star designer at Brabham F1 and McLaren F1, sudden regulatory changes provided a stimulus to innovation. In the 1981 season, after the reduction of the

[1] According to Article 6.3 of the FIA Sporting Regulations, a Formula One constructor can be defined as an organization that builds engines or chassis for Formula One race cars. Within this paper, only the construction of the chassis is considered. This requirement distinguishes Formula One from other race series like, for instance, American IndyCar Series, which allows race teams to buy chassis (see http://argent.fia.com/web/fia-public.nsf/3C9E78D2AAE9B15DC1257617002CF08F/$FILE/Stable%20Sporting%20Regulations%20-%2024%20July%20-%20CLEAN.pdf, http://wapedia.mobi/en/Formula_One?t=13; accessed on October 9, 2010).

[2] Gordon Murray is responsible for four Formula One Word Championship cars (1981, 1983, 1988 & 1989) and a McLaren road-going “super-car” that won the Le Mans 24-hours race in 1995 (Cross and Clayburn Cross, 1996).

aerodynamic "ground effect", he invented the hydropneumatic suspension system[3] (Cross and Clayburn Cross, 1996), which bestowed the title Formula One World Champion to Brabham F1 in the very same year.

The findings of this study indicate that whereas domain-specific experience at the level of the individual decreases the adaptive ability of an organization, experience from moderately distant technological fields increases it. Experience from more distant fields does not significantly affect the ability of an organization to adapt. Additionally, results provide evidence that organizations can learn how to adapt to an exogenous regulatory change.

The remainder of this paper is structured as follows: Sections 2 and 3 discuss the theoretical background of the study, and develop the hypotheses to be tested. Section 4 describes the Formula One motorsport industry and the data. The empirical results are presented in Sections 5 and 6. Section 7 concludes.

2 THEORETICAL BACKGROUND

Adaptation is one of the primary goals of strategic management and is defined as preparing an organization to exist, i.e. to survive in a changing environment or to increase the fit between the organization and the environment to stay competitive (Chakravarthy, 1982). Cameron (1984) notes that adaptation is not the same as "planned change" or "organizational development", since adaptation is related to changes coming from the external environment, i.e. which are "environmentally dictated" (Goodman and Kurke, 1982: 4). Planned change, on the contrary, is initiated from within the organization.

The extant literature provides a number of theoretical frameworks dealing with the determinants of adaptation. In particular, adaptation is affected by a firm's strategy (Miles and Snow, 1978), structure (March and Simon, 1958; Levinthal, 1997), ideologies (Beyer, 1981), and slack resources (Bourgeois, 1981). One of the most frequently cited frameworks of adaptation was proposed by Chakravarthy (1982). The framework includes different strategies of adaptation. Depending on an organization's adaptive ability, it chooses between defensive, reactive, and proactive strategies of adaptation. Adaptive ability, in turn, is determined by organizational capacity, i.e. internal and external communication links and by material capacity, i.e. the extent and nature of an organization's material

[3] For the 1981 season, regulations required a minimum gap between the underbody of the car and the ground of 6 cm to reduce the speed. Gordon Murray invented a hydropneumatic suspension system for the Brabham BT49C. Compressed air acted as an air spring, which held the car at the regulation height for measurement while stationary. On the race track, where the ground clearance could not be measured, downforce compressed the car and it was stuck to the ground, allowing a higher speed. See http://www.histomobile.com/dvd_histomobile /fr/212/1979-Brabham-BT49-.asp?id1=28419844; accessed on August 16, 2010.

resources and human resources (Andrews, 1971). Child (1997) proposes that adaptive ability is determined by market-, technology-, and organization related factors.

Eisenhardt and Tabrizi (1995) argue that in highly dynamic environments innovation is the central path by which firms adapt. Therefore, organizational strategies and structures have to be oriented towards learning, flexibility, innovation, and cooperation. Whereas an innovation of one organization could also initiate change and, therefore, require action of the competitors, within this study a change is defined as an exogenous regulatory change and innovation[4] forms the mechanism of how organizations adapt to this change.

To enhance innovativeness, resources are needed (Cohen and Levinthal, 1990). Tangible resources of the organization, in particular financial resources, have already been extensively discussed in the literature. Results show that the relationship between slack financial resources and adaptation is two-fold. Generally, researchers agree that slack financial resources are an important determinant of adaptation. However, one group of researchers argues that slack financial resources foster adaptation, since it allows strategic flexibility and innovative experimentation without the expectation that all innovations pay off (Evans, 1991; Bourgeois, 1981). Another group of researchers points in the opposite direction and suggests that slack financial resources can also impede adaptation, since extensive financial resources could decrease the incentives to undertake change (Hedberg, 1981; Norita and Gulati 1996).

Less frequently discussed in the literature is the link between intangible resources and adaptation. Existing research provides first indication that, the experience of an organization should impact adaptation. The literature argues that, over time, organizations accumulate knowledge and introduce routines but they also become increasingly bureaucratized (Inkson et al., 1970; Lawrence and Dyer, 1983). Additionally, established organizations suffer from cannibalization effects (Schumpeter, 1975). Consequently, those organizations often feel that they have more to lose than to gain from changes (Chattopadhyay et al., 2001). This may well lead to resistance against innovation or change and thereby constraints adaptation. Hanssen-Bauer and Snow (1996) as well as Bradley et al. (2011) point out that organizations - to be able to adapt - have to learn continuously and apply their knowledge rapidly, i.e. they must be able to introduce their knowledge quickly into their operational routines.

[4] In Formula One racing, innovation has always been a critical factor of success, in particular, standstill means finishing the next race at the end of the grid (Jenkins et al., 2007). However, innovation is associated with high risk. For the 2003 Formula One season, Ron Dennis, team principal of McLaren decided that a radical innovation was needed to be capable of competing against the dominant Ferrari team. Therefore, McLaren started the most expensive development program (25 million Euros) ever seen in F1 until then to develop the McLaren MP4/18. Unfortunately, the car never passed the FIA crash tests and had problems with cooling the engine down due to very narrow sidepods. Overall, the car never drove in a race in the 2003 season. Instead, the McLaren raced a developed version of the 2002 car, the McLaren MP4-17D, and developed the McLaren MP4/18 to the McLaren MP4/19 for the 2004 season. Also, in 2004, McLaren only finished 5th in the Constructor's Championship. See http://www.f1technical.net/features/689, accessed on August 10, 2010.

Even though human resources (Andrews, 1971, McKee et al., 1989) have been found to play a key role to enhance innovativeness and thereby adaptation, surprisingly, the existing literature hardly provides evidence of their importance. Human resource management literature points at the importance of human resource flexibility, which is defined as the human resource-related capacity to facilitate effective and timely adaptation to changing demands from the environment (Milliman et al., 1991). Additionally, individuals that dispose of heterogeneous skills are found to be highly flexible and, therefore, may well positively contribute to adaptation (Sanchez, 1995; Eisenhardt and Tabrizi, 1995; Ordónez de Pablos, 2005). With the exception of Chattopadhyay (2001) and Hambrick and Mason (1984), who analyze the role of executives influencing their organization's action by making the relevant decisions to respond to environmental changes, the contribution of individuals to organizational adaptation has so far escaped systematic analysis.

The existing literature provides a number of indications that intangible resources, in particular, experience of individuals and of organizations may impact adaptation. However, additional research is needed to cover several important, yet largely neglected micro-level relationships to arrive at a more comprehensive picture of adaptation in fast moving industries. It has to be noted that experience of organizations is not just the sum of the individuals' experience employed with the organization. Whereas experience at the level of the individual is defined as a high level of domain-specific knowledge in a certain field (Benner, 1984; Dreyfus and Dreyfus, 1986), experience at the level of the organization comprises the whole knowledge base of the organization. Although some overlap might exist between the experience of the organization and its employees, since organizational learning is mutual, i.e. part of the organizational knowledge is diffused to individuals but organizations also adjust to individual beliefs and opinions. However, the knowledge base of the organization is subject to permanent change due to labor turnover or changes in the relationships to suppliers or other partners (March, 1991). As mentioned in the introduction, Formula One motorsport is characterized by high labor turnover rates. Hence it is reasonable to assume that the experience of the constructors and of the engineers forms two different determinants of adaptation.

The next section develops a set of hypotheses exploring the relationship between individual experience and organizational experience and adaptation. The derivation of the hypotheses is based on the literature on adaptation and is supplemented with literature on knowledge recombination.

3 HYPOTHESES

Individual experience

Innovations, which exhibit a possible answer to a changing environment, often result from combining technological components in a novel manner (e.g., Nelson and Winter, 1982; Weitzman, 1996).[5]

[5] For the 1992 Formula One season, Patrick Head (a successful car designer, co-founder and today Engineering Director of the Williams Formula One team) designed the Williams FW14B, a very successful

Fleming and Sorenson (2004) argue that innovation requires some experience with the technology that should be developed. According to Katila and Ahuja (2002), domain-specific experience is in the following referred to as "depth of experience". Altschuler (1998) as well as Goldenberg et al. (1999) suggest searching previous inventions to identify possible applications to future contexts is a fruitful way to create innovations. Combining familiar components (local search) is characterized by a lower uncertainty, since R&D personnel, typically engineers, can learn from past failure and, thus, can select more appropriate components (Fleming, 2001; Vincenti, 1990). Additionally, the repeated use of the same knowledge components facilitates the development of routines, which, in turn, increase search reliability (Levinthal and March, 1981). Given this literature, one could assume a positive relationship between the depth of experience in a certain technical domain and adaptation, since experience should not only allow innovation in general but should also facilitate the application of existing components in new contexts.

However, research in strategic management as well as in psychology suggests that whereas experience might contribute to effective decision making and job performance (Sonnentag, 1998; Kahnemann and Klein, 2009; Salas et al., 2010), it may also be harmful, since domain experts may have difficulties to adapt to new conditions within their field of expertise (Cañas et al., 2003; Sternberg and Frensch, 1992). Furthermore, Chi (2006) and Sternberg (1996) propose that an increase in domain specific expertise (depth of experience) typically leads to a decrease in the flexibility regarding problem solving and the generation of creative ideas. Too much experience in a certain domain could lead to rigidity with respect to change, i.e. experts may try to preserve the status quo (Argyris and Schön, 1978) or prevent just following intuition. The latter turned out to accelerate adaptation (Eisenhardt and Tabrizi, 1995). Overall, it is assumed that whereas depth of experience may be beneficial in rather stable environments it is assumed to impede adaptation in rapidly changing and highly dynamic environment. Therefore, the paper follows the second argumentation. Consequently, it is proposed that an organization's ability to adapt decreases with the depth of experience of R&D personnel.

H.1: A negative relationship exists between the depth of experience of R&D personnel and the ability of an organization to adapt.

Over time engineers may gradually exhaust the possible combinations in their limited knowledge space (Kim and Kogut, 1996). Hence, the development of new components, based on the same knowledge elements, becomes increasingly expensive or complicated (Katila and Ahuja, 2002). Consequently, over time, engineers' search has to turn to more distant sources (distant search). However, the recombination of distant knowledge domains can only occur in case an engineer

car by effectively combining existing innovations, i.e. the carbon-composite monocoque invented by McLaren, the semi-automatic gearbox invented by Ferrari, and the active suspension invented by Lotus. In 1992, Williams F1 won the first 5 races and, finally, won the Formula One World Championship in the very same year (Jenkins et al., 1997).

disposes of experience in different technical domains or in case the members of an engineering team contribute their experience of different technical fields (Fleming et al., 2007; Taylor and Greve, 2006; Hargadon and Sutton, 1997), in the following referred to as "scope of experience" (Katila and Ahuja, 2002).[6] A first indication of the importance of recombinant experience to adapt to a continuously and rapidly changing environment is provided by Sanchez (1995), Eisenhardt and Tabrizi (1995) and Ordónez de Pablos (2005), who find that the heterogeneity of individual skills available to an organization is positively related to its flexibility and speed of adaptation.

One example of the importance of experience from different domains to be able to adapt can be derived from cognitive psychology. In particular, cognitive psychology proposes the process of "reasoning by analogy", i.e. individuals apply analogies from other (or perhaps simpler) situations to complex problems to reduce the complexity and uncertainty of a situation. Existing research has shown that reasoning by analogy is an effective mean to generate creative and quick solutions to problems (Huff, 1980; Schön, 1983; Schwenk, 1984). Therefore, it is proposed that

H.2: *A positive relationship exists between the <u>scope of experience of R&D personnel</u> and the ability of an organization to adapt.*

Experience of the Organization and Learning

The existing literature points out that experienced organizations could have difficulties in adapting to a changing environment. As organizations age, they become increasingly bureaucratized (Inkson et al., 1970; Lawrence and Dyer, 1983). Once these bureaucratic structures have been established it is difficult to remove or change them (Ginsberg and Buchholtz, 1990). Additionally, a turbulent environment may render existing assets of these firms obsolete (Levinthal, 1997). In particular, those organizations often feel that they have more to lose than to gain from changes (Chattopadhyay et al., 2001). This phenomenon called "creative destruction" (Schumpeter, 1975) may lead to resistance against innovation or change. Therefore, experienced organizations tend to invest in existing routines rather than create new ones. The fact that these organizations are generally tightly coupled in their social and ecological environments (Weick, 1979) and are involved in resource dependence relationships (Aldrich and Auster, 1986) further complicates navigating the changing environment.[7]

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[6] Jenkins et al. (2007: 44) confirm that in Formula One motorsport "innovation is often about reconfiguring and rearranging ideas from both within and outside the industry". For instance, at the end of the 1970s, Colin Chapman, a very successful race car (Lotus 87) constructor, made the path breaking invention of the ground effect, i.e. the opposite of aerodynamic lift, sucking the car to the track, allowing to corner at a much higher speed. This innovation enabled Lotus to win the Formula One World Championship in 1978 (Jenkins and Floyd, 2001). See http://www.autoevolution.com/news/ground-effects-in-formula-1-6717.html; accessed on August 8, 2010.

[7] In Formula One Racing, experienced constructors also suffer from "creative destruction". For instance, historically, Ferrari focused on engine power as the critical factor of race performance. In the mid of the 1970s, Ferrari developed the Flat-12 engine, a 12 cylinder engine (competitors used the 8 cylinder Ford DFV V8 engine) with a very low center of gravity leading to an improvement of the handling of the car. The Flat-

However, Levinthal (1991), for instance, suggests that the age of an organization can be interpreted as accumulated competence. In frequently changing environments, experience of an organization may even be beneficial to adaptation, since industry-specific experience also means experience with dealing with exogenous shocks. In particular, Hanssen-Bauer and Snow (1996) argue that organizational adaptation requires continuous learning to be able to introduce knowledge quickly into operational routines. Organizational learning is defined as "encoding inferences from history into routines that guide behavior" (Levitt and March, 1988: 320). Routines thereby include, e.g., rules, conventions, strategies or technologies through which organizations operate. The importance of learning for an organization to adapt is confirmed by Lounamaa and March (1987). The authors argue that organizations best adapt to a changing environment slowly by revising their routines and changing unsuccessful action, i.e. by "trial-and-error". Meyer (1982) finds that organizations can learn from environmental jolts. In particular, these jolts lead to enduring organizational changes in the routines.

Transferring the existing literature to the underlying context would mean that organizations as they age accumulate experience in (successfully) surviving environmental changes. This should enable them to adapt to regulatory shocks more successfully. Learning from exactly the same regulatory shock should even better enable organizations to adapt. This leads to the last two hypotheses:

H.3a: *A positive relationship exists between the experience of an organization and its ability to adapt.*

H.3b: *In case an environmental change re-occurs, learning from the first change positively affects the relationship between the experience of an organization and the ability to adapt.*

4 THE FORMULA ONE MOTORSPORT INDUSTRY

Formula One motorsport is a car race series (like American IndyCar series) governed by the FIA (the Fédération Internationale de l'Automobile) that consists of a number of race teams (referred to as constructors; i.e. Ferrari, McLaren or Williams) that "design, manufacture and race a highly specialized single seat race-car" (Jenkins, 2004: 13). Formula One constructors are medium sized companies located in Europe, mainly in the region around Oxford in the UK (the so called Motorsport Valley), who compete for the Formula One World Championship. The first Formula One World

12 engine enabled Ferrari to win the Constructors' World Championship in 1975, 1976, 1977, and 1979. At the end of the 1970s, Lotus founder and engineer Colin Chapman invented the ground effect, a technology borrowed from aircraft technology that allowed higher speeds (see footnote 6). However, Ferrari could not use the new ground-effect technology, since their Flat-12 engine (in contrast to the narrow Ford DFV V8) did not leave enough space for the venturi. Ferrari appeared to ignore the new technology and went on developing their engine. Consequently, Ferrari lost their dominant position and Ferrari cars became completely uncompetitive against cars using the ground effect (Tallman et al., 2004; Jenkins and Floyd, 2001).

Championship was held in 1950. In 1968, the FIA allowed unrestricted sponsorship on Formula One cars[8]. Starting from that year, sponsorship money from multinational organizations became a major source of income for Formula One constructors. The second major source of income comprises TV revenues which are paid out to the constructors according to the scored championship points (Solitander and Solitander, 2010; Khanna et al., 2003). Today, Formula One is a global industry, generating 4.6 billion US $ revenues. About 600 million unique viewers watch the up to 19 fortnightly races held in more than 15 countries between March and November each year. This makes Formula One motorsport the most widely watched sport event after the Olympic Games and the Soccer World Cup (Pinch and Henry, 1999; Khanna et al. 2003; Jenkins, 2004; Jenkins et al., 2007; Sylt and Reid, 2009).

The term "formula" in the name of the motorsport series refers to a set of rules[9], established by the FIA, to which all race cars must comply to. In order to take part, all participants (i.e., drivers, manufacturers, constructors, race officials, organizers, race tracks etc.) require a Super Licence[10], the highest class racing license issued by the FIA. A Formula One season consists of up to 19 races, referred to as Grand Prix, held on purpose-built race tracks (circuits) or public roads. Each constructor is allowed to compete with two cars. At the end of each season, the drivers and constructors who scored the most points are awarded the Drivers' and Constructors' Championship title by the FIA.[11]

What makes Formula One motorsport particularly attractive to analyze adaptation processes is the fact that according to Article 6.3 of the FIA Formula One Sporting Regulations, constructors have to build the chassis of their race cars. In contrast to other race series, like for instance American IndyCar or GP2[12], constructors are not allowed to purchase the chassis from third parties.[13] Hence, the constructors produce a relatively homogeneous 'product'. Additionally, the assignment of a technical achievement to responsible engineers or "head-designers" is possible (Solitander and Solitander, 2010: 44). In Formula One motorsport, teams of designers (R&D teams) dispose of key personnel, i.e. decision makers, who have personal responsibility and who act as "champions" to persuade other team members of the value of an idea (Pinch and Henry, 1999; Cross and Clayburn Cross, 1996). The key decision makers as regards to the design of the car are three individuals: the technical director, the

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8 See International Sporting Code of the FIA: http://www.onf1.co.uk/about/history.html#sa; accessed on August 13, 2010.

9 See http://argent.fia.com/web/fia-public.nsf/130A104E1769D120C1257617002D4CAE/$FILE/Stable%20Technical %20Regulations%20-%2024th%20July%20-%20CLEAN.pdf; accessed on August 15, 2010.

10 See http://www.fia.com/sport/regulations/common/sporting_code/full_doc.html; accessed on August 15, 2010.

11 See http://www.formula1.com/inside_f1/rules_and_regulations/sporting_regulations/8681/; accessed on August 15, 2010.

12 The GP2 race series was introduced in 2005. Compared to Formula One, it is characterized by similar rules but a downsized technology, resulting in a lower speed of the race cars. GP2 forms an important stepping stone for young drivers to Formula One. See http://gp2series.com/; accessed on August 15, 2010.

13 See http://argent.fia.com/web/fia-public.nsf/3C9E78D2AAE9B15DC1257617002CF08F/$FILE/Stable%20Sporting%20Regulations%20-%2024%20July%20-%20CLEAN.pdf; accessed on October 9, 2010).

chief designer and the chief aerodynamicist (Solitander and Solitander, 2010). In case of fully integrated teams, so called works teams, who do not only build the chassis but also the engines, the chief engine designer is also one of the key engineers.[14]

The use of a car in a race provides the missing link between technology creation, i.e. invention and putting it into effect, i.e. innovation. The racing teams have only one goal in mind: to finish a race first and to finally win the championship. As described above, the two major sources of income of Formula One constructors are sponsorship money and TV revenues. Sponsors (e.g. Philip Morris' Marlboro) use Formula One cars to expose their brands. Due to the fact that only the successful, i.e. the cars leading a race, are traced with TV cameras and consequently shown on TV, competitive cars form more attractive "billboards" and generate more sponsorship revenues. The distribution of TV revenues is directly related to performance, since these revenues are shared among the constructors according to their scored championship points. Consequently, success (= winning races and finally the World Championship) is defined consistently across the various racing constructors and over time - thus, success is observable and quantifiable (Jenkins et al., 2007).

In Formula One motorsport, continuous innovation plays a decisive role. First, the FIA consecutively changes regulations to reduce speed in order to increase safety but also to balance competition among constructors, i.e. to make race events more attractive for the viewers (Mastromarco and Runkel, 2009). Second, a high visibility of the technology on the race track makes it difficult to protect innovation (on the outer face of the car) against imitation. Third, Formula One motorsport is characterized by high labor turnover rates, which lead to a sustained dissemination of knowledge between the constructors. Finally, although constructors largely design their race cars in-house, due to the complexity of the technology, they are highly dependent on their network of suppliers. Large constructors have up to 750 suppliers and many of these suppliers also produce components for competitors. Therefore, even though unwillingly, informal knowledge transfer can occur.

Overall, strong competition, regulatory constraints and changes, high labor turnover, knowledge spillovers, and the risk of imitation force Formula One constructors into continuous and rapid innovation to adapt and to remain competitive (Henry and Pinch, 2000; Blitz, 2007; Jenkins et al., 2007; Solitander and Solitander, 2010; Cross and Clayburn Cross, 1996).

5 METHODS

5.1 Empirical Setting

To avoid endogeneity problems due to a two-sided relationship between the resources a constructor has at its disposal and its ability to adapt, a pre-post design is employed. In particular, the ability of

[14] Since this paper focuses on the design and construction of the chassis, the technical director, the chief designer and the chief aerodynamicist are included in the analysis. The chief engine designer is not considered.

Formula One constructors to adapt is compared in the season before and the season following an exogenous regulatory change.[15]

In Formula One motorsport, rule changes are introduced by the controlling organization FIA. The FIA generally introduces symmetric rule changes, i.e. the rule changes do not discriminate the stronger or advantage the weaker teams. The reason for this is that asymmetric rules would probably be considered unfair by the viewers leading to a decrease in the fan interest and, hence, to a decrease in broadcasting revenues. However, this does not mean that rule changes are always made for safety reasons. Rule changes can also be caused by the predominance of one team. For instance, for the 2003 season the qualifying rules were changed in order to overcome the long lasting predominance of Ferrari and Michael Schumacher.[16] Within this study, a rule change is considered that was introduced twice over time for pure safety reasons, i.e. to keep the speed of the cars within a certain limit:

From 1994 and from 2008, auxiliary driving aids such as traction control, ABS, power-assisted brakes and automatic transmissions were prohibited. The rule changes for the 1994 season were announced at the 1993 Canadian Grand Prix, which was held in Montréal on June 13th, 1993. The Canadian Grand Prix was the 7th out of 16 races, i.e. almost at half-time of the 1993 season.[17] For the 2001 season, traction control was again legalized, since the teams had started to surreptitiously use the technology in their cars. It was again banned for the 2008 season, again for safety reasons. The rule changes for the 2008 season were announced by the FIA already on March 30, 2007.[18]

What makes these two rule changes appropriate for statistical analysis is that, first, the rule changes applied to all constructors and the constructors got to know about the final decision to introduce these regulatory changes at the same time. Second, none of the constructors would have turned down auxiliary driving aids voluntarily or started building a car without these aids before the final decision about the rule changes of the FIA was disclosed. The constructors would not even have experimented with technologies that replaced driver aids before they were forced to do so by a rule change. These aids lead to a considerable improvement of the handling of the car, which resulted in higher average speeds. Hence, since the rule changes were introduced due to safety reasons, they can be considered as exogenous as regards the performance of the constructors. Finally, the fact that the same rule change

15 In Formula One, it is sufficient, just to consider one season prior and one season after the rule change. (1) A failure to adapt is observable from the first race. In case the constructors do not adapt by building a competitive car prior to the start of the season, they perform badly right in the first race. (2) The competitive balance in Formula One can change even within one season. Innovations introduced by competitors are imitated very quickly. (3) Analyzing longer time periods (two or more seasons prior to and after a rule change) would lead to biased results. Frequent rule changes would prevent assigning the performance of a constructors to the adaptation to a particular rule change.

16 From the start of the 2003 season, only one flying lap for grid position was allowed and refueling between qualifying and the start of the race was prohibited. See http://www.f1fanatic.co.uk/ 2008/03/29/f1-gets-8th-qualifying-change-since-2003/; accessed on August 22, 2010.

17 See http://sidepodcast.com/2009/02/13/days-that-shook-the-f1-world-traction-control-banned; accessed on August 27, 2010.

18 See http://www.formula1.com/news/headlines/2007/3/5857.html; accessed on September 12, 2010.

was introduced twice allows examining possible learning effects in technologically dynamic environments. In particular, over time, the constructors might have learned how to adapt to this particular rule change.[19]

Typically, a pre-post design would have called for a difference-in-differences approach. However, since the regulatory changes "hit" all constructors at the same time, the lack of a control group prevented the use of a difference-in-differences design. In the following, an empirical setting will be described that was developed to quantify adaptation by comparing the performance of the constructors that would have been expected without a rule change with the actual performance after the regulatory change.[20]

The empirical setting follows three steps. In a first step, the performance of the constructors in the seasons before the particular rule changes (i.e. 1993 and 2007) is estimated as a function of a number of explanatory variables and control variables:

$$p_t = \beta_0 + \sum_k \beta_{1k} \cdot x_{k,t} + \sum_m \beta_{2m} \cdot c_{m,t} + \varepsilon_t \quad (1)$$

where p_t refers to the performance in the 1993 and the 2007 season, i.e. the Formula One season before the regulatory change took place. $x_{k,t}$ refers to the different explanatory variables and $c_{m,t}$ to the control variables factored into the regression.

In a second step, the estimated coefficients are used to predict the performance of the constructors for the season after the rule change (i.e. 1994 and 2008):

$$\hat{p}_{t+1} = \hat{\beta}_0 + \sum_k \hat{\beta}_{1k} \cdot x_{k,t+1} + \sum_m \hat{\beta}_{2m} \cdot c_{m,t+1} \quad (2)$$

where $\hat{p}_{t+1}$ refers to the predicted performance of the constructors for the 1994 and the 2008 season based on the estimation of model (1). $\hat{p}_{t+1}$ can be interpreted as what would have happened in season 1994 and 2008 assuming the same dependencies as in 1993 and 2007, i.e. a situation without a change of the rules.

In a third step, the resulting errors or residuals R_{t+1} (3) are regressed on the explanatory variables and the control variables of the 1994 and the 2008 season (equation (5)).

$$-R_{t+1} = p_{t+1} - \hat{p}_{t+1} \quad (3)$$

19 One could argue that differences in the performance of the constructors between the season prior and after the rule change may have been caused by other effects (e.g., the drivers) or additional rule changes. In order to avoid biased results, the regression models will control for other influences, like, e.g. the quality of the driver, the size of the budget, etc. Additionally, the underlying seasons have been selected in a way that the considered rule changes were the only major changes.

20 Special thanks go to Jerry Thursby for his support regarding this empirical setting.

$$R_{t+1} = \begin{cases} < 0 & performance\ \underline{worse}\ than\ expected \\ = 0 & performance\ \underline{as}\ expected \\ > 0 & performance\ \underline{better}\ than\ expected \end{cases} \quad (4)$$

In case R_{t+1} becomes smaller than zero, the performance of the constructors in the season after the rule change is worse than expected[21], in case R_{t+1} is larger than zero, the performance is better than expected. Whereas the constructors' ability to adapt can be assumed to be low in the first case, it is high in the latter case. The coefficients of the model displayed in equation (5) can then be interpreted as the determinants of adaptation.

$$R_{t+1} = \gamma_0 + \sum_k \gamma_{1k} \cdot x_{k,t+1} + \sum_m \gamma_{2m} \cdot c_{m,t+1} + \upsilon_{t+1} \quad (5)$$

The original performance measure, i.e. the position of a car in the starting grid[22], is a count variable. Consequently, a Poisson regression model is used to estimate equation (1). Adaptation (3) is a continuous variable. Therefore, an OLS regression model is used to estimate equation (5).

The two regression models are calculated at the level of the engineer. Figure 1 displays the construction of the sample. In particular, for each race per season, the dataset contains one observation per engineer and per car. The observations for the two seasons (1993 and 1994 as well as 2007 and 2008) are matched according to the constructor, the race calendar of the season, and the quality of the driver. Using the latter criteria is necessary, since each constructor competes with two cars piloted by two different drivers. The performance of the more (A) and the less (B) successful drivers (assessment based on the results in the Driver World Championship at the end of each season) is displayed in Tables 1a and 1b. Not matching over the different constructors allows for mobility of the engineers between teams at the beginning of the seasons 1994 and 2008. It can be assumed that the error terms are independent across different races. However, we allow for correlation within engineers (technical director, chief designer, and chief aerodynamicist). In order to accommodate the correlation, a cluster regression is used. The cluster estimator adjusts the variance-covariance matrix to account for observations for the same engineer to be correlated (Wooldridge, 2002). To account for learning effects, in a second step, the explanatory variables are interacted with the year of the rule change.

[Please insert Figure 1 about here]
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21 Race performance is operationalized as the outcome of a competition. Hence smaller values mean higher performance. In case the predicted performance is 3rd position, but the actual position turned out to be 5th place, the performance is worse than expected and $-R_{t+1}$ equals 2 (5 – 3 = 2 > 0).

22 The cars' position in the starting grid is determined by qualifying times. On the day before the race, the drivers compete in a knock-out session. The driver who drives the fastest lap during this session starts the race from the pole (1st) position, see http://www.formula1.com/inside_f1/glossary.html#Q, accessed on June 2, 2011.

5.2 Data Source and Sample

To be able to analyze the determinants of adaptation, in particular, to get a better understanding of the intangible resource – adaptation link, data on Formula One motorsport constructors, the key engineers, the drivers, and on the performance of the race cars (race classification) are needed. Additionally, information about regulatory changes is required to be able to identify a set of appropriate exogenous rule changes needed for the empirical setting.

Since no publicly available database or dataset contained all of the information required for this study, the dataset was constructed by combining different electronic and paper-based sources. The main data source used was the electronic database "motorsportarchiv"[23]. Data on race classification, the assignment of race cars to engineers, and the driver were extracted from this database. The data were than supplemented with bibliographic and job-related information on the key engineers for the years 1970 until 2008, obtained through extensive search of the web. For the years 1993 and 1994, information on the budget the constructors had at their disposal was obtained from Formula One year books (Knupp, 1993; 1994). For the years 2007 and 2008, budget data were drawn from Formula One financial reports (Sylt and Reid 2008; 2009). Finally, information about regulatory changes was received from the official Formula One homepage[24].

Dependent Variables

Performance – For each Formula One race (Grand Prix) in 1993 and 1994 as well as in 2007 and 2008, the performance of the constructors is measured by the start position a driver has achieved during the qualifying session. The qualifying position is a better indicator for performance as compared to the actual race outcome, since during the qualifying session, each driver has a certain number of trials (1993/1994: 3 trials; 2007/2008: 1 trial) to determine the grid position of the car (pole position at the best). During these so called flying laps, the cars carry only the fuel necessary to finish the lap and other cars typically do not block them from driving as fast as possible. Additionally, during the race, constructors try to improve the position of the cars by applying the optimal strategy as regards refueling and changing tyres. Consequently, the qualifying positions of the race cars optimally reflect the technological performance of the car and thereby the merits of the engineers. A correlation amounting to 0.78 between the qualifying positions of the cars and the outcome of the Formula One Constructor World Championship proves evidence that the qualifying position provides a good proxy for the overall performance of the Formula One constructors. Performance is a count variable. Therefore, a Poisson regression model will be used to estimate the determinants of performance. Since counting should start at zero one will subtracted from the performance variable.

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23 See, http://www.motorsportarchiv.de; accessed on August 19, 2010.

24 See http://www.formula1.com/inside_f1/safety/history_of_f1_safety,http://www.formula1.com/ inside_f1/rules_and_regulations; accessed on August 19, 2010

Adaptation – The ability of a constructor to adapt is defined as the residual R_{t+1} of the performance of the constructors in season *t+1*. As described in the last section, it is calculated as the difference between the actual performance p_{t+1} and the predicted performance $\hat{p}_{t+1}$ based on the coefficients of season *t*, i.e. assuming a season without any rule changes (equation 3).

Explanatory Variables

As proposed by the existing literature, the key engineers responsible for the design of the race car comprise the technical director, the chief designer, and the chief aerodynamicist (Cross and Clayburn Cross, 1996; Pinch and Henry, 1999; Solitander and Solitander, 2010). The three positions are characterized as follows:

The *technical director* is the head of research and development division and is generally responsible for the design, development and deployment of race cars and, in addition, for performance and reliability of the cars. His duty is to ensure overall functioning of the cars, i.e. to bring together cassis, engine, drivers, and tyres, etc. but also to review actual technical or regulatory developments.[25]

The *chief designer* is responsible for designing the race car, i.e. for transforming single components with potentially conflicting requirements like chassis, suspension, gearbox, engine, aerodynamics, transmission, and brakes into a competitive car.[26]

The *chief aerodynamicist* is the head of the aerodynamics division. Aerodynamics has to create downforce in order to keep the car onto the track and to increase cornering speed. At the same time aerodynamics has to minimize air drag that would slow the car down. To fulfill this almost impossible task, aerodynamicists use full-sized wind tunnels and enormous computing power for simulation purposes.[27]

Depth of experience – To capture the depth of experience of the key engineers in Formula One, the number of prior employers in Formula One between 1970 and 1993/1994 as well as between 1970 and 2007/2008 was calculated. This variable captures the experience gained by working for different Formula One constructors. The measure "number of employers in Formula One" was preferred over the "number of years employed in Formula One", since the number of moves within an industry is typically positively related to the years employed in a certain industry. However, since mobile engineers have been exposed to a larger number of research processes and approaches and also have encountered different thought worlds than non-mobile engineers (Fleming et al., 2007), the "number of employers in Formula One" should provides a more comprehensive proxy for the accumulation of domain-specific experience.

[25] See http://forums.s2kca.com/showthread.php?t=3456; accessed on August 12, 2010.
[26] See http://www.f1technical.net/articles/1271; accessed on August 12, 2010.
[27] See http://www.formula1.com/inside_f1/understanding_the_sport/5281.html; accessed on August 12, 2010.

Scope of experience – Two dummy variables were constructed capturing the scope of experience of the key engineers in other fields between 1970 and 1993/1994 as well as between 1970 and 2007/2008. In particular, information was collected whether the key engineers were previously employed in sports car racing[28] or in other formulas like, e.g., Formula 2, Formula 3, Formula 3000 or IndyCar. Two dummy variables were created taking the value one in case the engineers dispose of work experience in (i) sports car racing or (ii) other formulas and zero otherwise.

Experience of the organization – The experience of the constructors was measured using the years of experience in Formula One, i.e. the number of years they have been competing in Formula One since the first championship was held in 1950.

Control Variables

Age of the engineers – A variable was built that controls for the age of the engineers, since one might assume that flexibility or the ability to adapt decreases with age (Weiss, 2001).

Slack financial resources – To measure slack financial resources, this study follows George (2005), who operationalizes resource slack as the resource availability – resource demand ratio. Since the costs of a Formula One constructor are, generally, a well kept secret, the average seasonal budget of all constructors is used as a proxy for financial demand. Consequently, slack financial resources of a particular constructor are calculated as the deviation of its seasonal budget from the average seasonal budget of all constructors. Generally, the budget comprises the money a constructor has at its disposal for drivers, engineers and support staff, the engine, the chassis (R&D, material, wind tunnel), tyres, fuel, transportation, and public relations[29]. For comparability reasons, the underlying study uses budgets without engine costs. Some teams buy engines from engine constructors or works teams, others develop their own engines and a third group gets engines for free (Khanna et al., 2003).

Works team - To distinguish between works teams, i.e. fully integrated teams that build not only the chassis but also the engines (e.g., Ferrari or Toyota) and pure chassis constructors (e.g., McLaren or Williams), a dummy variable is created taking the value one in case the team is a works team and zero otherwise. This variable is factored into the regression to control for possible variation in the performance that was caused by an insufficient fit between the engine and the chassis.

Two measures of recent success for both, the constructors and the drivers, are further added to capture other potential sources of heterogeneity. The variable controlling for recent success of the constructor is again a dummy variable that equals one in case the constructor was awarded the title Constructor World Champion during the 5 years prior to the seasons under considerations (1993/1994 or

[28] Sports car racing events take place on purpose built race tracks. In contrast to Formula One, the cars have two seats and enclosed wheels. The cars may also be purpose built but also rebuilt to road-going sports cars. The most famous sports car event is the Le Mans 24 Hours race. Other race series comprise the Super GT (JP) or the FIA GT Championship. See, e.g. http://gt1world.com/; accessed on August 24, 2010.

[29] See http://www.f1technical.net/articles/31, accessed on November 23, 2008.

2007/2008). The variable controlling for the success of a driver is constructed as a dummy equaling one in case the driver had already won the Driver Word Championship.[30] Finally, a control variable was added controlling for the year under consideration, i.e. for the first (1993/1994) versus the second (2007/2008) regulatory change.

6 RESULTS

The data used comprise information about 10 constructors per Formula One season. The constructors and the drivers, running the two race cars for the constructors, are summarized in Table 1a (seasons 1993 and 1994) and Table 1b (seasons 2007 and 2008). For 1993/1994, the data contain 23 key engineers, for 2007/2008, 26 key engineers holding the positions technical director, chief designer, or chief aerodynamicist. Due to the fact that, particularly in the earlier years, not all constructors employed a chief aerodynamicist, we do not observe 30 key engineers per season (10 times the three positions). Since 5 engineers built cars in 1993/1994 as well as in 2007/2008, the cluster regression described in the next section is based on 44 different engineers (clusters).

[Please insert Tables 1a and 1b about here]

Tables 2a and 2b provide information about the differences in the yearly World Championship ranking of the constructors in the sample. Results show that, first, there is variation in the positions of the teams over the two seasons 1993/1994 and 2007/2008. Second, the tables indicate that both, the experienced teams (e.g., Willimas) and the more recently founded teams (e.g., Red Bull Racing) change their positions in the World Championship. Additionally, the tables show that performance is not just a matter of budget. In particular, constructors with large budgets (e.g., McLaren) can perform worse and constructors with low budgets (e.g., Jordan) can perform better after a rule change.

[Please insert Tables 2a and 2b about here]

The distribution of adaptive capacity[31] is displayed in Figure 2. A negative value means a performance

[30] Defining a certain period to construct this variable was not necessary, since the number of years a driver has the chance to become Driver Championship is generally very limited. In particular, drivers start their career in Formula One in the early twenties. Then they have to gain the necessary experience and, typically, end their career in the late thirties at the latest. Stadelmann (2006) shows for 300 Formula One drivers - competing between 1950 and 2005 - that the average age at which the drivers start their careers amounts to 28.9, the age at which the drivers end their career amounts to 34.4.

[31] The dependent variable was centered at the mean. A deviation from a zero mean can be explained as follows: (1) the prediction of the post-rule change period does not provide a count variable varying between 1 and 20. (2) The performance of 20 cars (10 constructors) instead of 26 cars (1993/1994) or 22 cars (2007/2008)

worse than expected and a positive value can be interpreted as a performance that is better than expected. The figure shows considerable variation in the variable. Interestingly, the constructors in 2008, i.e. after the second rule change, perform slightly better than those after the first rule change (1994). This finding could point at a learning effect. In particular, the fact that the rule change occurred for the second time, could mean that constructors learned how to adapt to this change.[32]

[Please insert Figure 2 about here]

Descriptive statistics for the four different years (1993, 1994, 2007, and 2008) are reported in Table 3a. First, the table shows that whereas in 1993 and 1994, 26 cars competed in a race, only 22 cars competed in 2007 and 2008.[33] Adaptation varies between -14.7 and 10.5 in 1994 and between -10.1 and 10.3 in 2008. Whereas the share of engineers having prior experience in sports car series (scope of experience) does not differ distinctly between the two periods, there is considerable variation between the two periods as regards experience in other formulas. This difference may be explained by a change in the way engineers start their career in Formula One. In the earlier years, engineers often worked their way through lower formulas (e.g., Formula Ford, Formula 3, Formula 3000) before reaching Formula One. Nowadays, Grand Prix mechanics often start working in Formula One immediately after finishing college. Particularly in the UK, universities offer very specialized degrees in aerodynamic engineering or design engineering (Matchett, 2002). Experience of the constructor, measured as the number of years the constructors have been competing in Formula One since 1950, is also higher in the later period. However, this is not surprising, given that constructors like Ferrari, Williams, or McLaren never backed out of Formula One. Finally, the average budget spent by the constructors increased by the factor 4.5 between the earlier and the later seasons.

[Please insert Tables 3a and 3b about here]

Table 3b reports the correlation matrix. Correlations are relatively low, indicating that collinearity should not be a concern. The only exception forms a high correlation (r = 0.71) between budget and

competing in the two seasons is observed (see footnote 33). Hence, these 20 cars can, in both periods (pre and post rule change), hold positions between 1 and 26. (3) The empirics are calculated at the level of the engineer and the car, i.e. the sample includes two observations per engineer per race (see Figure 1 for the construction of the sample).

32 It is important to note that learning is also possible even if the constructors have not been involved in Formula One in the earlier periods (1993/1994). This is particularly so, since Formula One is characterized by high labor turnover, which leads to a dissemination of knowledge. Additionally, high visibility of the technology on the race track facilitates imitation.

33 Three constructors racing in the seasons 1993/1994 (Lola, Footwork, and Larrousse) and one constructor racing in 2007/2008 (Torro Rosso) are not represented in the dataset; either because the teams have not competed in each race per season or due to a lack or data.

slack financial resources. However, only slack financial resources will be used in the regression model.

The OLS regression models predicting adaptive capacity are reported in Table 4. A positive coefficient refers to a positive relationship between adaptation and the respective explanatory variable. Model 4.1 estimates a baseline model only containing the control variables. Model 4.2 adds the explanatory variables, i.e. human resources and experience of the organization. Model 4.3 adds quadratic terms of the depth of experience of the key engineers and the experience of the organization to account for non-linear relationships between these two explanatory variables and the dependent variable. Finally, Model 4.4 analyzes the importance of learning with respect to adaptation. To do so, the relevant variables are interacted with a dummy variable indicating the re-occurring rule change (i.e. the rule change in 2008).

[Please insert Tables 4 and 5 about here]

Hypothesis 1 proposed a negative relationship between the depth of experience (i.e., Formula One-specific experience) and adaptation. Model 4.2 shows that the effect is negative and significant at the 10% level. In particular, one more employer of a key engineer in Formula One decreases adaptation by 0.55. Model 4.3 includes the quadratic term of depth of experience. The results do not exhibit a nonlinear relationship between depth of experience and adaptation. Overall, the findings confirm hypothesis 1.

Hypothesis 2 suggested a positive relationship between the scope of experience (i.e., experience in other race series) and adaptation. Both coefficients ("experience in sports car series" and "experience in other formulas") have the expected positive sign. However, only the effect of a job in other formulas prior to moving into Formula One exhibits a significant effect (Model 4.2). In particular, "experience in other formulas" increases adaptation by 3.37. A possible explanation for the insignificant coefficient of "experience in sports car series" might be the following: Experience from moderately distant fields (other formulas) may be immediately applicable to design a new car and, hence, positively affects adaptation. Experience from too distant fields (sports cars) may not contribute to adaptation, either because the knowledge does not fit at all or because the application of the knowledge from very distant fields would require lengthy modification to become useful. These findings confirm hypothesis 2.

Model 4.2 shows that the experience of the constructor exhibits the expected positive sign but the coefficient is not significant at the 10% level. Model 4.3 includes the quadratic term of the experience of the constructor. Results show that a u-shaped relationship exists between the experience of the organization and adaptation. The minimum is reached at 26.1. This means that in case the experience of the constructor in Formula One amounts to 27 or more years, the effect of experience on adaptation becomes positive. Hence, industry-specific experience only increases the ability of an organization to adapt in case organizations are very established. This in part confirms hypothesis 3a.

Model 4.4 reveals a positive effect of learning. In particular, the interaction between experience in Formula One and the second rule change is small but positive (0.19). This finding confirms hypothesis 3b.

The control variables show the expected signs. Slack financial resources have the expected positive effect on the dependent variable (Model 4.2). Whereas the impact of "prior success of the driver" is significant in each specification, "prior success of the constructor" is not significant. The effect of the driver can be explained by the fact that prohibiting auxiliary driving aids such as traction control attach more importance to the skills of the driver. However, the coefficient of the driver's prior success is not interpreted causally, since it may well be the case that successful drivers select successful teams to work for. The year dummy is capable of controlling for unobserved heterogeneity across the two periods (1993/1994 vs. 2007/2008). However, only Model 4.3 exhibits a significant effect of the year dummy. Finally, the age of the engineers[34] as well as the variable that captures possible differences between constructors that build their own engine (works teems) and constructors that buy engines from third parties do not exhibit significant effects.

Due to the fact that in Formula 1 rules change occur very frequently, a reliable robustness check is difficult to conduct. One possibility could be to conduct the same analysis for the seasons *t-1* and *t*, i.e. using 1992 and 2006 as pre-seasons as well as 1993 and 2007 as post-seasons. Results show that the correlation between the predicted performance and the true performance is considerably higher for *t-1* and *t* than for *t* and *t+1* (the ban of driving aids came into effect in season *t+1*), i.e. 0.7 (*t-1* and *t*) vs. 0.6 (*t-1* and *t*). This is what one would have expected given that adaptation to a major rule change had not been necessary. The results apply to both Model 2 and Model 3. These results provide first evidence that the empirical setting works. However, it has to be mentioned that e.g. in 2006 tyre changes were again allowed. Even though the impact of this rule change on the construction of the chassis should not be as large as a ban of driving aids, it may well have influenced it.

Results of the auxiliary Poisson regression models[35] are provided in Table 5. Model 5.1 contains all explanatory variables. Model 5.2 adds the two quadratic terms of depth of experience of the engineers and Formula One experience of the constructor. Since the dependent variable (qualifying

[34] Due to the fact that the information about the year of birth was only available for 90% of the engineers, the missing values were replaced by the average age. As a robustness check, the regression was also estimated only considering engineers for whom the age was available. The results were robust and the age did also not exhibit a significant effect.

[35] As a robustness check, a Negative Binomial Regression (NBREG) model was estimated. NBREG led to exactly the same results as regards sign and significance of the coefficients of the explanatory and control variables.

performance) is operationalized as the outcome of a competition, smaller values mean higher performance. Therefore, coefficients with a negative sign have to be interpreted as positive effects on performance. Overall, the results are in accordance with the results of the OLS regression model (Table 4). Since the Poisson regression is only utilized as a basis for the simulation of the effects in the post-change period, the results are not discussed in further detail.

7 DISCUSSION

The aim of this paper was to get a better picture of the resource-adaptation link by analyzing the determinants of adaptation in fast moving industries considering the contribution of individual level and organizational level experience. Furthermore, this study improves on the existing literature by comparing the performance of organizations before and after exogenous regulatory changes. The chosen empirical design allows operationalizing adaptation and provides a way to deal with possible endogeneity problems allowing clear causal interpretation of the results. Finally, due to the fact that the same regulatory change is observed twice over time, the analysis can also provide first evidence on learning effects from a particular regulatory change.

The results of the empirical analysis indicate that whereas an increasing domain-specific experience at the level of the individual decreases the adaptive ability of an organization, experience from moderately distant technological fields increases it. Experience from more distant fields, however, does not affect adaptation. One group of researchers suggested that experienced organizations are characterized by accumulated capacities that enable them to adapt to a changing environment. Another group of researchers pointed in the opposite direction and argued that experienced organizations are characterized by bureaucratic structures impeding flexible adaptation (Inkson et al., 1970; Lawrence and Dyer, 1983; Ginsberg and Buchholtz, 1990). Results reveal a positive effect of organizational experience on adaptation for very established organizations. Possibly, experience in an environment characterized by frequent change can be interpreted as experience in surviving (i.e. adapting to) these changes. Finally, learning from the same regulatory changes positively affects the experience-adaptation relationship.

Slack financial resources positively affect adaptation, irrespective of any learning effects. A possible explanation for this finding is that in fast moving environments, competitive advantages are typically not sustainable, i.e. become obsolete very quickly. Additionally, in order to be successful, firms have to run the risk of a failure. However, willingness to take risk is easier if an organization is able to afford to gamble on a wrong innovation.

7.1 Implications

The above summarized results provide a number of theoretical and practical implications.

In particular, the results of this study contribute to the empirical literature on adaptation, by showing that an integrated approach has to take into account different levels of analysis. The level of the individual as well as the level of the organization matter with respect to adaptation. Empirical studies have to look beyond a single level mechanism to arrive at a more comprehensive picture of adaptation. This study also extends the theoretical frameworks of adaptation by providing a better understanding of the combination of different types of experience. The results show that a comprehensive framework of adaptation has to allow depth and scope of experience. Finally, results indicate that learning matters with respect to adaptation. Hence this study provides a first link between the literature on adaptation and the literature on organizational learning.

In the management literature, the trade-off between experience and flexibility has a long tradition (Dane, 2010). This study also makes an important contribution to this literature. It is shown that considering different types of experience as well as learning effects may provide a possible solution to this trade-off. Consider, for instance, depth of experience: whereas domain-specific experience at the level of the organization may be beneficial to enhance adaptation, an increase in the depth of experience at the level of the individual impedes adaptation. Whereas organizations may be able to use experience about how to deal with exogenous regulatory changes to develop routines, individuals have to remain open-minded and flexible to be able to find creative solutions to deal with regulatory changes.

Furthermore, the study provides a number of practical implications. First, dynamic environments and short technology life cycles need employees who come up with unconventional ideas or solutions (possibly from distant fields of expertise). However, organizations also have to be able to afford these unconventional solutions that typically exhibit a higher risk of failure. Therefore, a financially strong basis is needed. Let's again consider the example of Gordon Murray, star designer at Brabham F1 and McLaren F1. Whereas the development of the hydropneumatic suspension system (see footnote 3) enabled Brabham to win the Formula One World Championship in 1981, by far not all inventions made by Gordon Murray turned out to be successful. One of the largest and probably most expensive failures was the development of a "surface cooling" car. The aim of this project was to reduce the weight of the car and, at the same time, to increase driver safety. The idea was "instead to pass the water and oil through surface heat exchangers built integrally into the monocoque structure: the 'skin' of the car was both structure and radiator" (Cross and Clayburn Cross, 1996: p. 101). Trials soon proved that the surface cooling was not going to work. Even though Gordon Murray was able to learn from his failure (too many steps forward at the same time), Brabham F1 needed sufficient financial resources to survive the coming season even without a car capable of winning races.

Results also provide an important implication for human resource management. Whereas moderately distant fields turned out to be beneficial for adaptation, experience from more distant fields does not contribute to adaptation. Hence, human Resources should refrain from hiring R&D personnel from too distant fields. Another possible implication can be drawn with respect to the educational system for R&D personnel. Results showed that experience in other fields (here: work experience in other formulas) positively affects adaptation. Not only in Formula One racing, university programs get more and more specialized. On the one hand, these specialized studies should optimally prepare students for future tasks. On the other hand, these highly specialized educational programs may prevent employees from choosing jobs in other, related but distant fields. Results of this study showed that more diverse backgrounds as regards work experience positively affect adaptation. In earlier years in Formula One, engineers had to work their way through lower formulas (e.g., Formula 2000, Formula 3) to finally reach Formula One. Today, specialized university studies prepare them for an immediate job in Formula One. An increasing share of engineers with a university degree is certainly advantageous, since earlier studies also show that a higher level of education is typically associated with an abstract understanding of the problem-solving process (Gibbons and Johnston, 1974), the ability to engage in meta-learning (Fleming and Sorenson, 2004) as well as a larger receptiveness toward innovation (Hambrick and Mason, 1984). However, employers should also profit from basic scientific education of their employees, i.e. degrees in physics or mechanical engineering, enabling them to collect work experience in diverse fields. To give an example, Rory Byrne, star engineer at Benetton F1 and Ferrari F1, after graduating with a BSc in engineering from Witwatersrand University, Johannesburg, worked as chief chemist at a polymer manufacturing plant. Afterwards, he, with three friends, set up a company importing performance car parts, called Auto Drag and Speed Den. Finally, at the age of 30 he started his career in Formula One and was able to draw upon his experience from earlier jobs.[36]

7.2 Limitations

Even though the data and the empirical setting provide major advantages compared to the existing literature, a few limitations have to be noted. As mentioned in the introduction, data from Formula One motorsport provide a well suited context for studying adaptation, since Formula One is a clearly defined highly competitive sector. In particular, the performance of all competitors is observable. However, the limited number of constructors also limits the sample size. Clustered standard errors lead to a further decrease of the number of degrees of freedom in the regression analysis. Additionally, as mentioned earlier, the regulatory changes “hit” all constructors at the same time. Therefore, it is not possible to employ a pre-post-design with a control group, like a difference-in-differences approach. Furthermore, the empirical setting chosen for this study requires a survival of the constructors for at least one more season after the regulatory change. This does not allow for analyzing the survival of the constructors. Additionally, the fact that regulatory changes are mandatory also does not allow resistance to adapt.

[36] See http://www.grandprix.com/ft/ft00223.html; accessed on September 26, 2010.

Another possible limitation is the transferability of the results to other industries. Formula One Racing may well be a unique industry. For instance, the race series is characterized by strong regulation and extremely short technology life cycles. The latter provides an advantage for empirical analysis. However, other industries with comparable product life cycles are rare. Possible examples for such industries are the software industry, the information & communication industry, and less technical industries like the music, movie, or apparel industries. Strong regulations comparable to Formula One racing may be observed in biotechnology and pharmaceuticals (e.g., clinical trials and drug approval) or in electricity and renewable energy markets as well as in industries were standards are of particular importance (e.g., the computer industry).

Finally, this study considers the contribution of three key engineers per constructor. Hence the study only considers the R&D stars. Even though existing studies provide evidence of the particular importance of key engineers or stars in science and technology (e.g., Zucker and Darby, 2006) information regarding other members of the engineering teams may provide interesting additional insights.

7.3 Conclusion

Although theoretical and empirical studies began analyzing the determinants of adaptation more than 30 years ago, the analysis of these determinants is still very much in the focus of research. In particular, a number of questions have, so far, remained unanswered. The underlying study provides one of the first large-scale empirical studies that are appropriate to operationalize adaptation in an environment characterized by rapid technological and regulatory change. Even though the environment of Formula One racing provides a number of advantages, further research should also look at other industries, e.g., characterized by a larger number of competitors or less regulation. The paper provides evidence that the micro-level, that is key employees in R&D as well as the level of the organization matter with respect to adaptation. However, the existing theoretical literature also points at further determinants of adaptation, e.g., ideologies (Meyer, 1982) or interactions with external parties (Andrews, 1971; Child 1997). Future studies should take these determinants into account to investigate the relative importance of the different determinants. Already in his seminal work, Chakravarthy (1982) distinguishes between defensive, reactive, and proactive adaptation strategies. These different types of adaptation could also be part of further empirical research. Future studies should also analyze different exogenous changes or jolts. Whereas this study focuses on regulatory changes, technology shocks, crises, or political changes may also provide a fruitful focus for further research. Finally, the analysis presents first evidence that learning matters with respect to the determinants of adaptation. Future studies should provide deeper insights into the ability of organizations and also of individuals to learn how to adapt to environmental changes.

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Table 1a: World Championship Results (Seasons 1993 and 1994)

Season 1993				
Driver WC	Prost	(Williams)		
Constructor WC	Williams			
Contructor	**Driver A**	**Driver B**	CWC	#D
Williams	Prost	Hill	1	B
McLaren	Senna	Andretti / Hakkinen	2	A
Benetton	M. Schumacher	Patrese	3	A
Ferrari	Alesi	Berger	4	A
Ligier	Brundle	Blundell	5	B
Lotus	Herbert	Zanardi / Lamy	6	A
Sauber	Wendlinger	Lehto	7	B
Arrows	Warwick	Suzuki	9	A
Jordan	Barrichello	Boutsen / Irvine / Apicella / Naspetti / Capelli	10	B
Tyrrell	de Cesaris	Katayama	11	A

Season 1994				
Driver WC	M. Schumacher	(Benetton)		
Constructor WC	Williams			
Contructor	**Driver A**	**Driver B**	CWC	#D
Williams	Hill	Senna / Coulthard / Mansell	1	A
McLaren	Hakkinen / Alliot	Brundle	4	B
Benetton	M. Schumacher	Lehto / Verstappen / Herbert	2	A
Ferrari	Berger	Alesi / Larini	3	-
Ligier	Panis	Bernard / Lagorce / Herbert	6	B
Lotus	Herbert / Salo / Bernard	Lamy / Adams /Zanardi	12	A
Sauber	Frentzen	Wendlinger / Lehto / de Cesaris	8	A
Arrows	Fittipaldi	Morbidelli	9	B
Jordan	Barrichello	Irvine / de Cesaris / Suzuki	5	A
Tyrrell	Blundell	Katayama	7	A

WC = World Championship / CWC = Constructor World Championship / #D: more successful driver(s)

Table 1b: World Championship Results (Seasons 2007 and 2008)

Season 2007				
Driver WC	Räikkönen	(Ferrari)		
Constructor WC	Ferrari			
Contructor	**Driver A**	**Driver B**	CWC	#D
Williams	Rosberg	Wurz	5	A
McLaren	Hamilton	Alonso	2[1]	A
Renault	Fisichella	Kovalainen	4	B
Ferrari	Räikkönen	Massa	1	A
Red Bull Racing	Webber	Coulthard	6	B
Toyota	Schumacher R.	Trulli	7	B
BMW Sauber	Heidfeld	Kubica	3	A
Super Aguri	Sato	Davidson	10	A
Spyker	Sutil	Albers	11	A
Honda	Button	Barrichello	9	A

1: later disqualified due to the McLaren - Ferrari espionage scandal (see http://www.f1fanatic.co.uk/2007/07/03/ mclaren-linked-to-ferrari-espionage-scandal; accessed on September 9, 2010)

Table 1b: World Championship Results (Seasons 2007 and 2008) (continued)

Season 2008				
Driver WC	Hamilton	(McLaren)		
Constructor WC	Ferrari			
Contructor	**Driver A**	**Driver B**	CWC	#D
Williams	Rosberg	Nakajima	8	A
McLaren	Hamilton	Kovalainen	2	A
Renault	Alonso	Piquet Jr.	4	A
Ferrari	Räikkönen	Massa	1	B
Red Bull Racing	Coultard	Webber	7	B
Toyota	Trulli	Glock	5	A
BMW Sauber	Heidfeld	Kubica	3	B
Super Aguri	Sato	Davidson	11	A
Force India	Sutil	Fisichella	10	B
Honda	Button	Barrichello	9	B

WC = World Championship / CWC = Constructor World Championship / #D: more successful driver(s)

Table 2a: Differences in the World Championship Ranking of the Constructors - Season 1994 compared to 1993 (i.e. prior and after the rule change)

Better than last season	**Equal** performance as last season	**Worse** performance than last season
Benetton **(+1)**	Williams	McLaren **(-2)**
Ferrari **(+1)**	Arrows	Ligier **(-1)**
Jordan **(+5)**		Sauber **(-1)**
Tyrrell **(+4)**		Lotus **(-6)**

Table 2b: Differences in the World Championship Ranking of the Constructors - Season 2007 compared to 2008 (i.e. prior and after the rule change)

Better than last season	**Equal** performance as last season	**Worse** performance than last season
Toyota **(+2)**	McLaren	Williams **(-3)**
Spyker/Force India **(+1)**	Renault	Red Bull Racing **(-1)**
	Ferrari	Super Aguri **(-1)**
	BMW Sauber	
	Honda	

Table 3a: Descriptive Statistics

	1993 (N = 568)				1994 (N = 568)			
Variable	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**
adaptive capacity* (based on Model 4.3)					0.00	6.51	-14.72	10.50
performance (qualifying position)	9.78	6.46	1	26	10.93	6.93	1	26
employers in F1	2.35	1.66	0	5	2.52	1.92	0	7
experience sports cars	0.38		0	1	0.38		0	1
experience other formulas	0.49		0	1	0.49		0	1
F1 experience constructor	18.54	13.58	0	43	19.71	11.55	1	44
age engineer	41.13	6.61	28	52	42.13	6.61	29	53
budget	64.08	28.96	20	100	54.15	32.63	20	100
slack financial resources	0.00	28.96	-44.08	35.92	0.00	32.63	-34.15	45.85
prior success driver	0.28		0	1	0.22		0	1
prior success constructor	0.23		0	1	0.23		0	1
works team	0.11		0	1	0.06		0	1

	2007 (N = 850)				2008 (N = 850)			
Variable	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**
adaptive capacity* (based on Model 4.3)					0.00	5.76	-10.12	10.32
performance (qualifying position)	9.99	6.24	1	22	11.10	6.15	1	22
employers in F1	2.91	1.79	0	7	3.03	1.85	0	7
experience sports cars	0.28		0	1	0.28		0	1
experience other formulas	0.13		0	1	0.13		0	1
F1 experience constructor	27.58	15.97	1	57	28.08	15.91	2	58
age engineer	44.07	6.40	28	56	45.07	6.40	29	57
budget	281.23	134.70	55	445	307.64	129.73	45	445
slack financial resources	0.00	134.70	-226.23	163.77	0.00	129.73	-262.64	137.36
prior success driver	0.12		0	1	0.12		0	1
prior success constructor	0.24		0	1	0.24		0	1
works team	0.40		0	1	0.44		0	1

* centered at the mean

Table 3b: Correlation Matrix

	Variables	1	2	3	4	5	6	7	8	9	10	11
1	performance	1										
2	employers in F1	-0.09	1									
3	experience sports cars	-0.20	0.14	1								
4	experience other formulas	0.05	0.36	0.23	1							
5	F1 experience constructor	-0.28	-0.002	0.01	-0.28	1						
6	age engineer	-0.17	0.49	0.11	0.03	0.03	1					
7	budget	-0.39	-0.22	-0.004	-0.41	0.48	0.35	1				
8	slack financial resources	-0.56	0.02	0.10	-0.17	0.39	0.28	0.71	1			
9	prior success driver	-0.53	0.09	0.10	0.02	0.21	-0.13	0.07	0.31	1		
10	prior success constructor	-0.41	-0.01	0.08	-0.11	0.35	-0.10	0.26	0.36	0.52	1	
11	works team	-0.19	-0.14	0.24	-0.16	0.39	0.22	0.52	0.43	-0.09	0.03	1

Pearson correlation coefficients (for two continuous variables) / Point biserial coefficient (for one continuous variable and one dummy variable) / Phi coefficient (for two dummy variables) (N = 1,418)

Table 4: Multivariate analysis of adaptation

	Model 4.1	Model 4.2	Model 4.3	Model 4.4
VARIABLES	Coeff. (S.E.)	Coeff. (S.E.)	Coeff. (S.E.)	Coeff. (S.E.)
depth of experience				
employers in F1	#	-0.554*	-0.678	0.121
		[0.312]	[0.653]	[0.338]
employers in F1 (squared)	#	#	0.049	#
			[0.098]	
scope of experience				
experience sports cars	#	0.931	0.667	-1.148
		[1.216]	[1.141]	[1.178]
experience other formulas	#	3.374***	3.202***	1.306
		[1.209]	[1.155]	[1.295]
F1 experence constructor	#	0.026	-0.209**	-0.085
		[0.045]	[0.097]	[0.056]
F1 experence constructor (squared)	#	#	0.004***	#
			[0.002]	
age of the enginner	0.018	0.038	0.033	0.020
	[0.095]	[0.106]	[0.100]	[0.082]
slack financial resources	0.023**	0.024***	0.028***	0.127***
	[0.010]	[0.009]	[0.008]	[0.021]
prior success driver	3.906***	3.994***	4.159***	2.568**
	[1.434]	[1.416]	[1.338]	[1.115]
prior success constructor	0.972	0.499	-0.076	-1.573
	[2.052]	[2.015]	[1.722]	[1.451]
works team	-0.497	-0.909	-2.305	-1.548
	[2.208]	[2.192]	[2.130]	[1.747]
year = 2008	0.531	2.020	2.330*	-2.210
	[1.634]	[1.478]	[1.368]	[2.038]
employers in F1 * year	#	#	#	-0.677
				[0.416]
experience sports cars * year	#	#	#	2.814
				[1.779]
experience other formulas * year	#	#	#	1.556
				[1.924]
F1 experence constructor * year	#	#	#	0.187***
				[0.065]
slack financial resources * year	#	#	#	-0.104***
				[0.020]
Constant	-1.839	-3.641	-1.180	0.096
	[4.230]	[4.018]	[3.730]	[3.221]
Observations	1,418	1,418	1,418	1,418
R-squared	0.286	0.355	0.388	0.451
F test	13.57	16.94	15.07	25.38
	p=0.000	p=0.000	p=0.000	p=0.000

OLS regression analysis, clustered standard errors in brackets (std. err. adjusted for 44 clusters in engineer_ID)
* significant at 10%; ** significant at 5%; *** significant at 1%; # not included

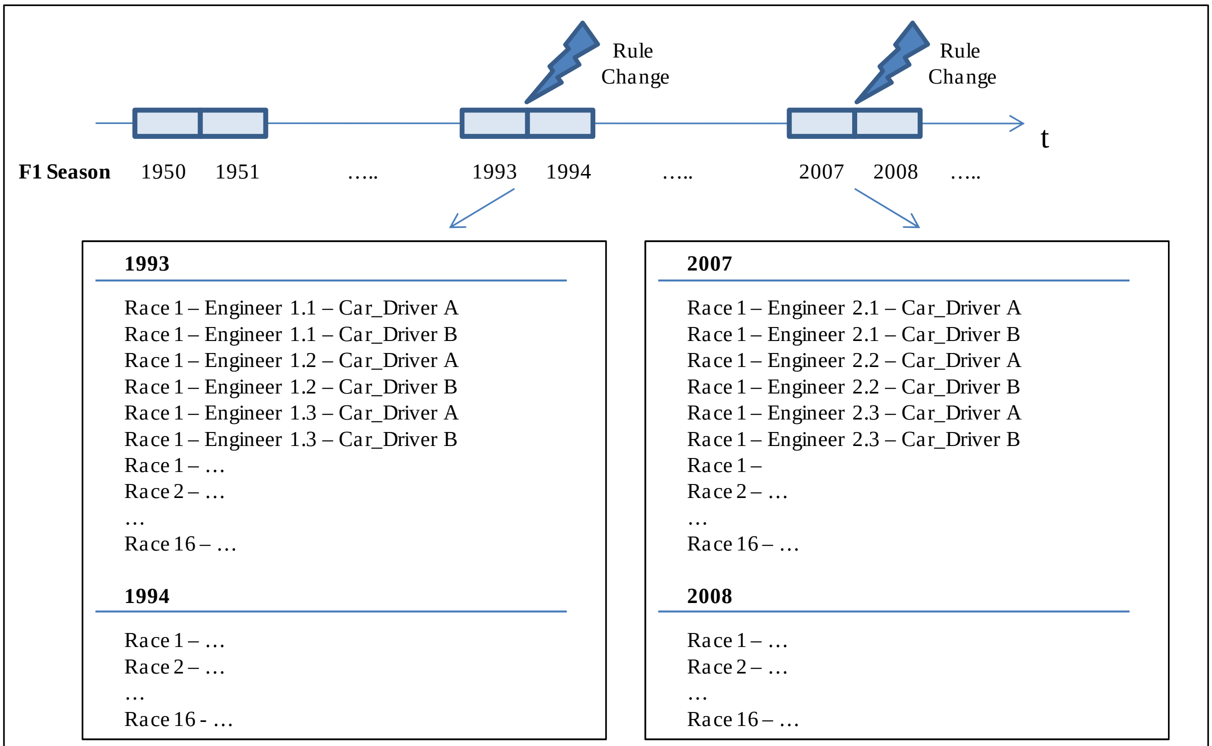
Table 5: Multivariate analysis of performance prior to a regulatory change (auxiliary regression)

	Model 5.1	Model 5.2
VARIABLES	Coeff. (S.E.)	Coeff. (S.E.)
depth of experience		
employers in F1	0.018	-0.037
	[0.033]	[0.077]
employers in F1 (squared)	#	0.007
		[0.009]
scope of experience		
experience sports cars	-0.177*	-0.164*
	[0.101]	[0.099]
experience other formulas	-0.038	0.008
	[0.080]	[0.089]
F1 experence constructor	-0.002	0.014
	[0.004]	[0.009]
F1 experence constructor (squared)	#	-0.000**
		[0.000]
age of the enginner	-0.011	-0.010
	[0.009]	[0.009]
slack financial resources	-0.002***	-0.002***
	[0.001]	[0.001]
prior success driver	-1.521***	-1.556***
	[0.221]	[0.228]
prior success constructor	-0.048	0.023
	[0.192]	[0.170]
works team	0.027	0.103
	[0.180]	[0.183]
year = 2008	-0.201	-0.223*
	[0.126]	[0.124]
Constant	2.914***	2.804***
	[0.349]	[0.365]
Observations	1,418	1,418
Pseudo R-squared	0.301	0.305
F test	228.37	283.99
	p=0.000	p=0.000
Log pseudolikelihood	-4298.51	-4273.12

Clustered standard errors in brackets (std. err. adjusted for 44 clusters in engineer_ID)

* significant at 10%; ** significant at 5%; *** significant at 1%; # not included

Figure 1: Construction of the Sample



The observations of the seasons 1993 and 1994 as well as the observations of the seasons 2007 and 2008 were matched according to the number of the race, the engineer and the driver. This leads to pre-post-data for two different rule changes. In the multivariate regression model the year of the rule change will be added as control variable to account for differences between 1993/1994 and 2007/2008.
Car_Driver A and Car_Driver B refers to the more (A) and less (B) successful driver per season. The assignment of the drivers to these groups is displayed in Table 1a (1993/1994) and Table 1b (2007/2008).

Figure 2: Distribution of adaptation; based on Model 4.3 ($N_{\text{full sample}}$=1,418/ N_{1994}=568/ N_{2008}=850; centered at the mean)