Real-Time Information Availability and Performance: Evidence from a Regulatory Shock

JACOBO GOMEZ-CONDE
Universidad Autónoma de Madrid
jacobo.gomez@uam.es

LAURA GOMEZ-RUIZ
Universidad Pablo de Olavide
lmgomrui@upo.es

CRISTINA GRANDE-HERRERA
Universidad Pontificia Comillas
School of Economics and Business Administration
cgrande@icade.comillas.edu

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Jacobo Gomez-Conde, Universidad Autónoma de Madrid, Accounting Department, C/ Francisco Tomás y Valiente, 5, 28760, Madrid, Spain; *Laura Gomez-Ruiz*, Universidad Pablo de Olavide, Financial Economics and Accounting Departament, Carretera Utrera km1, Sevilla (41013), Spain; *Cristina Grande-Herrera*, Universidad Pontificia Comillas, School of Economics and Business Administration, Financial Management Department, Madrid, 23 Alberto Aguilera Street, Spain.

Real-Time Information Availability and Performance: Evidence from a Regulatory Shock

Abstract. We analyze the effect of real-time information availability on performance in a high-pressure setting. An open question in management control is how the amount of real-time information provided during task execution influences decision-making. Using high-volume data from Formula One and a regulatory shock from a radio communication restriction, we test competing arguments about decision quality, autonomy, and information overload. Our findings indicate that, *on average*, increased real-time information availability does not necessarily enhance performance—drivers perform better with less real-time information. Yet the restriction also imposes costs, including larger within-team performance gaps, adjustments in pit stop strategies, and more unfinished races, accidents, and engine failures. Cross-sectional tests show that racetrack complexity, driver experience and prior performance influence these effects, while a matching analysis mitigates potential concerns about compositional biases. Collectively, our findings highlight the complexities of real-time information availability in decision-making, with implications for management control.

Keywords: Real-time information availability; Information restriction; Information overload; Individual performance.

JEL Classifications: M40; M41; D82.

1 INTRODUCTION

We examine how changes in real-time information availability on performance in a high-pressure, competitive environment. Typically, managing the flow of information to individuals can help correct decision-making errors, align the interests of principals and agents, and protect individuals from harms resulting from their choices (Bertomeu, 2024; Casas-Arce et al., 2017). Most of the literature examines how the provision of either more frequent information or information with different characteristics before and after task execution influences decision-making or performance (Abernethy et al., 2023; Casas-Arce et al., 2017; Sprinkle, 2003; van Veen-Dirks, 2010). In contrast, we focus on *real-time* operational information, which shapes decisions as they are made and directly supports task execution. Despite its central role in many organizational settings, little is known about how performance responds when such real-time guidance is removed—and whether removing information produces effects that differ from those associated with adding information.[1]

In management control, real-time information helps shape decision-making and performance (Casas-Arce et al., 2017; Johnson et al., 2025; Margolin et al., 2025). As technology enables faster access to data (Tong et al., 2021), organizations must determine whether more information always leads to better outcomes (Lipnowski et al., 2020). Too much feedback may overwhelm employees, shift attention away from the task at hand, or create dependency on external

[1] We argue that this is an important and timely question, as significant organizational resources are invested to increasingly incorporate information from, for example, big data or artificial intelligence to improve decision-making (Abernethy et al., 2023; Tong et al., 2021). However, some leading companies have circumscribed the availability of additional information of this sort to employees. Notable recent examples include Samsung Electronics (Bloomberg, 2023), Apple, JP Morgan Chase, and Verizon (The Wall Street Journal, 2023). This is a real-world issue, as "24/7/365 operations, global connectivity, and information overload are all conspiring to create the 'overwhelmed employee'" (Deloitte, 2015).

guidance (Abernethy et al., 2023; Johnson et al., 2025; Waddoups, 2022), making it an ongoing practical concern (Mosow, 2015).

Competing predictions arise regarding the effect of restricting information during task execution. On the one hand, information can enhance efficiency and improve decision-making, especially when individuals lack essential knowledge or face cognitive constraints. Without access to information in real time, decisions may suffer, impairing performance (Gibbs & Van der Stede, 2025). On the other hand, information is not free—it requires processing, and too much during task execution may overload individuals, reducing performance (Casas-Arce et al., 2022; Hartmann & Wießenberger, 2023; Iselin, 1996; Johnson et al., 2025). Additionally, continuous access to external inputs may hinder independent problem-solving and exploration, key means of learning and improvement (Goodman et al., 2004). Limiting real-time information may also encourage individuals to rely more on their own knowledge, intuitions, and decision-making skills, fostering autonomy and resilience. Given these competing arguments, whether restricting the real-time availability of information enhances or impairs performance remains an open empirical question.

The effects of real-time information availability are not static—individuals adjust as conditions change. While most research examines the benefits of providing more information, we additionally explore what happens when real-time information, once removed, is reintroduced. This process is not a simple reversal—reintroducing information forces individuals to recalibrate, potentially disrupting the adaptations they developed. Understanding these shifts is key to grasping how changes in real-time information shape decision-making and performance.

We exploit a regulatory shock in the Formula One (F1) World Championship, where a restriction on radio communication serves as a plausibly exogenous shift in drivers' real-time information availability. From September 2014 to July 2016, the FIA (Fédération Internationale de l'Automobile) prohibited virtually all real-time communication between drivers and their teams, allowing only safety-related messages. This policy removed the primary channel through which drivers receive live strategic guidance during a race—including updates on competitors' lap times, tire degradation, pit stop plans, and fuel or engine settings—and required drivers to make decisions independently and under extreme time pressure. Although the number of teams and drivers in F1 is limited, the setting provides a uniquely powerful environment for studying real-time information: performance is observable at a high frequency, decision-making is continuous and high-stakes, and the regulatory change is abrupt and externally imposed. These features mirror conditions faced in many modern organizational settings—such as emergency response, air traffic control, high-frequency trading, and logistics coordination—where workers rely on live data streams to guide immediate actions. Moreover, even small changes in lap times accumulate into economically meaningful differences over a race and season, often determining championship standings and the distribution of substantial financial rewards. Thus, the F1 context offers both exceptional internal validity and insights with broad relevance for understanding how real-time information affects performance.

We test our research question using a large dataset of 389,742 F1 race-driver-lap-year observations (118 different drivers) over the 1996–2021 period. We find that, *on average*, reduced real-time information availability (i.e., radio restriction) during races is significantly associated with better performance (as measured by fewer milliseconds per lap). To strengthen this result, we also incorporate *Race Pace*—a widely used metric that captures lap-time consistency—as an additional performance measure, finding similarly robust effects. While our primary interest lies in understanding how the availability of real-time information affects performance on average, the regulatory shock we examine—first restricting and then reintroducing team radio communication—offers a unique opportunity to study the dynamics of information availability. This sequential design allows us to explore two mechanisms. The initial restriction of real-time communication forces drivers to operate with greater autonomy, reducing external interruptions and encouraging reliance on internal heuristics. This adaptation may improve focus and streamline decision-making, which helps explain why performance does not deteriorate—and even improves—during this phase. In contrast, the subsequent reintroduction of radio communication does not simply restore prior conditions but disrupts these adapted routines. The sudden influx of external inputs introduces coordination frictions and cognitive switching costs, impairing the integration of new information into established strategies. Consistent with this view, we find that performance declines significantly when the restriction is lifted, indicating that the benefits of autonomy and routine stability can outweigh the nominal advantages of real-time information.

We conduct a placebo test using practice sessions, which are contemporaneous with the radio restriction, but focus less on competitive race outcomes. These sessions are primarily used for car setup and testing, and drivers typically operate under different strategic and performance constraints. As expected, we find no significant performance changes during this period, which helps to rule out the possibility that broader temporal trends or unobserved factors are driving our main results. In additional validation analyses, we show that the restriction of real-time communication had a tangible impact on race dynamics—widening performance gaps between teammates and altering pit stop timing, frequency, and duration. These results indicate that the radio restriction was not merely symbolic, but a substantive shock that significantly disrupted race management and strategy execution.

To better understand why performance changes, we conduct a series of cross-sectional analyses. First, racetrack complexity matters—restricted communication impairs performance particularly on complex tracks, where strategic adaptability is especially important. Second, drivers who debuted in 2015 or 2016 and never experienced unrestricted radio conditions (*newly treated drivers*) perform better under the restriction, while those accustomed to unrestricted radio face a steeper learning curve, leading to smaller gains. This analysis provides a particularly informative test of the treatment effect, as it isolates drivers whose baseline experience was shaped under the restriction. Third, the benefit of limiting real-time information strengthens for experienced drivers and those with longer team tenure, suggesting that familiarity with F1 dynamics and team strategies helps mitigate the challenges of reduced communication. Fourth, performance gains are less pronounced for lower-skilled drivers, who likely depend more on external guidance. Lastly, high-budget teams exhibit larger performance losses, which is consistent with their greater investments in real-time communication technologies. Because these teams rely more heavily on continuous data flows, the restriction curtailed a key source of their competitive advantage.

The increase in performance from the radio restriction is not without consequences. We observe a higher likelihood of early race dropouts, reflecting both driver errors and mechanical failures. This suggests that, while drivers may adapt more quickly with less real-time information, the reduced availability of data also limits their ability to manage the car, leading to a higher likelihood of unfinished races, accidents, and engine failures.

Despite extensive research on feedback and monitoring, the effects of information availability—particularly information restrictions—remain underexplored. The closest studies include the work of Abernethy et al. (2023), Eyring et al. (2021), and Margolin et al. (2025).

Abernethy et al. (2023) find that introducing an advanced monitoring system in the NBA enhances individual performance by providing more actionable data. Similarly, Eyring et al. (2021) show that, in football training, providing athletes with performance feedback—especially relative feedback—improves performance outcomes. Margolin et al. (2025) analyze real-time feedback in football through the introduction of the video assistant referee system, finding that, while experienced referees benefit, inexperienced ones increase effort without improving decision quality. Collectively, these studies illustrate how adding information can enhance decision quality, but far less is known about what happens when real-time information is removed, and whether the effects of removal differ from those of provision.

Our study differs in two key ways. First, rather than examining the introduction of new feedback or monitoring tools, we examine what happens when previously available real-time information is removed and later reintroduced. This distinction is theoretically important because removing information that individuals have come to rely on may disrupt routines, alter attention allocation, or require rapid adaptation—mechanisms not captured in prior work. Second, we focus on *truly* real-time information: data provided and acted upon at the very moment of task execution, rather than feedback that informs future decisions or corrects past ones. Our setting is a high-pressure environment where individuals rely on *live* information to make split-second decisions. The sudden restriction—and subsequent reintroduction—of this information creates a unique opportunity to observe how individuals adapt. Our findings challenge conventional wisdom by examining whether having less real-time information available can sometimes be beneficial.

We contribute to the literature on information availability and decision facilitating by directly assessing a fundamental trade-off: whether more or less information enhances performance. The F1 racing is exceptionally demanding and offers a unique opportunity to study high-stakes decision-making in real time, precisely the kind of environment where information management matters most and where substantial financial interests are at play. The regulatory shock helps mitigate endogeneity concerns that challenge prior studies. While information systems and reporting structures are typically endogenous—firms continuously adjust the intensity and format of information flows to align with strategic objectives (Anderson & Kimball, 2019)—our setting benefits from a regulatory shock that is plausibly exogenous to teams and drivers. This allows us to better isolate the performance consequences of changing real-time information availability, rather than observing outcomes shaped jointly by performance needs and information design choices. More broadly, as the volume of data available to decision-makers continues to grow, so does the risk of information overload. Using this regulatory shock, we address recent calls for innovative approaches to understanding how information availability shapes decision-making under pressure (Breuer et al., 2024; Casas-Arce et al., 2022).

2 LITERATURE, SETTING, AND RESEARCH QUESTION

2.1 Theoretical Framework and Literature

We introduce a theoretical framework to understand agents' reactions to an information restriction during task execution. Providing information is a critical issue for organizations, as the employees (agents) do not always act in the best of the organization (principals) (Lipnowski et al., 2020; Narayanan & Davila, 1998) and, at times, even against their own interests (Bertomeu, 2024). Information control serves to align employees' goals with organizational objectives (Heese & Pacelli, 2025), a mechanism widely recognized as the *decision-influencing role* (Abernethy et al., 2023; Sprinkle, 2003; van Veen-Dirks, 2010). A substantial body of research in economics (Cookson, 2000; Lipnowski et al., 2020), finance (Bova & Yang, 2017; Goergen & Renneboog, 2011), and accounting (Hannan et al., 2013; Rowe, 2004; Towry, 2003) has explored how controls and incentives can mitigate misalignment. Yet far less attention has been given to how information systems should be designed to improve decision-making (Casas-Arce et al., 2022). Our focus shifts to this second role of feedback information—the *decision-facilitating role* (Casas-Arce et al., 2017; Luft, 2016)—which remains comparatively underexplored but is just as essential in shaping performance.

Information processing theory depicts actors as navigating decision-making challenges with incomplete information, making it crucial for them to effectively access, share, and interpret relevant, timely data (Fourné et al., 2023). The aim of the decision-support role of information is to increase knowledge, thereby improving agents' ability to make decisions. Employees, for example, require information that enhances their performance, particularly when faced with complex decisions (Chenhall, 2005; Grafton et al., 2010; Ittner et al., 2003). This decision-facilitating role aims to minimize uncertainty by providing information at different stages: before decisions are made (forward-looking information), during task execution (real-time information), and after decisions are made (backward-looking information) to enable learning and error correction (Johnson et al., 2025; Margolin et al., 2025). As technology expands the availability of real-time information,[2] firms are increasingly weighing the benefits and drawbacks of unrestricted information access versus selective restriction (Deloitte, 2015).

Increasing information availability for employees aligns with the concepts of reducing uncertainty (Tiessen and Waterhouse 1983), belief revision (Narayanan & Davila, 1998), and

[2] Examples include call centers where agents are given access to real-time customer data to enhance service but may be limited in their ability to act on certain information, stock trading environments where traders may receive real-time market data but with constraints to avoid manipulation or overreaction, and even logistics operations where truck drivers have real-time feedback on their fuel efficiency and driving patterns, which can be used to improve performance but may also influence behavior in unintended ways.

problem-solving (Simon et al., 1954).[3] If the purpose of decision-facilitating information is to enable employees to make better judgments and choices, restricting information could harm performance by diminishing decision quality. However, limiting information during task execution may also foster exploration and learning while mitigating the risk of overload. Without immediate access to guidance, agents must solve problems independently and adapt, which can enhance performance over time (Song et al., 2017).

The effectiveness of this learning process depends on maintaining an appropriate balance between the amount of information provided and the cognitive capacity of the decision-maker. A critical issue is the agent's ability to process information, as a misalignment between information demands and cognitive capacity can lead to information overload (Chong & Eggleton, 2003; Eyring et al., 2021). Overload occurs when individuals receive more data than they can absorb, process, and use, leading to cognitive fatigue, poor decisions, and diminished performance. Organizations therefore face a trade-off when designing information control systems: providing enough data to support decision-making while avoiding the harm of overload. Research suggests that even professional analysts—who are highly trained in processing complex information—often struggle to recall and appropriately respond to details in financial disclosures (Hirst & Hopkins, 1998; Peng, 2005). This underscores the substantial cognitive effort required to process information, reinforcing the notion that more data does not always lead to better decisions. Since information entails costs at every stage—acquisition, processing, and communication—organizations must carefully manage its flow. Reducing irrelevant data and structuring essential information in a clear and concise manner help mitigate information overload (Casas-Arce et al., 2022).

[3] See Sprinkle (2003) for an excellent review.

2.2 Research Setting

The Formula One (F1) World Championship involves open-wheel, single-seater racing cars, operating under the regulatory jurisdiction of the *Fédération Internationale de l'Automobile* (FIA). The first F1 race was in 1950. The word "formula" in its title signifies the specific set of regulations for all participating vehicles. Each F1 season comprises a series of races,[4] known as the Grands Prix, conducted across several countries. The season usually begins in March and ends in late November or early December. Every driver must possess a valid Super License, a racing credential issued by the FIA, while the races must take place on tracks holding a grade one rating, the highest classification for tracks. F1 races typically last from an hour and a half to two hours. The number of laps for each race is determined by the length of the circuit. The race distance is consistently set to be just beyond the minimum number of laps required to cover a distance exceeding 305 kilometers.[5] While there were times when more than 10 teams participated, the standard grid size for a modern F1 race is 20 cars (two cars per team at each race, one driver per car). A race director oversees the logistics of every F1 Grand Prix race, inspecting cars in the *parc fermé* pre-race, enforcing FIA rules, and managing the race start lights. Serving as the head of race officials, the race director has a significant role in resolving disputes between teams or drivers. In cases of rule violations, the director can impose penalties, such as drive-through or stop-and-go penalties, pre-race grid demotions, race disqualifications, and fines.

An F1 Grand Prix event extends over a weekend, starting with two free practice sessions on Friday and one on Saturday. Following the final free practice session, a qualifying session commences, establishing the starting order for Sunday's race. In that race, the drivers compete for

[4] The number of races per season is around 20. In the 2000s, it was slightly lower (17 or 18), while the number of races in more recent seasons, 2020 and 2021, was 22.
[5] The exception is Monaco, a street circuit with lower speeds, where the race length is about 260 km.

points[6] and to be on the podium. Before the race begins, drivers complete a warm-up lap. The cars then line up on the starting grid, according to their qualifying positions. The winner of the race is determined by the first driver to cross the finish line after completing the requisite number of laps, with lap times crucially determining overall performance and strategy. The driver who finishes first not only secures the victory but also earns the most points. The competition follows a tournament format. The driver gathering the most points by the end of the season wins the championship. The final ranking of drivers is determined based on the total points scored throughout the races.

Driving an F1 car is an intricate task, requiring precision, quick reactions, and endurance. The high-speed nature of the sport demands intense concentration. The driver must multitask, managing the car's controls, communicating with the team via radio, monitoring the status of the car and competitors, and making strategic decisions, all while hurtling around the track at high speeds. Overall, driving an F1 car entails a unique blend of physical and mental skills. During an F1 race, drivers can access an array of information to enhance their decision-making and performance. The steering wheel serves as a control hub, relaying real-time telemetry data encompassing speed, engine RPM, tire pressure, fuel levels, brake temperatures, and other important metrics. Drivers can adjust engine modes, fuel mix settings, and brake bias, enabling them to optimize power output, fuel efficiency, and braking performance. Continuous updates on time gaps to competitors, weather conditions, and race strategy are communicated to drivers, allowing for on-the-fly adjustments. This wealth of information empowers F1 drivers to navigate the complexities of each race with precision.

[6] The number of points awarded has varied. From 1991 to 2002, only the first six drivers received points. From 2003 to 2009, the first eight drivers received them, and since 2010, the first 10 have.

From September 11, 2014, to July 28, 2016, F1's regulatory body implemented radio communication restrictions (i.e., the type and amount of information was reduced) during races, aiming to increase the self-reliance of the driver.[7] The restrictions were intended to make races more challenging and enhance the driver's role in managing the car and race strategy. During this period, teams could convey only limited information to drivers over the radio. Banned information included details related to car performance adjustments, like precise instructions on aerodynamic settings and suspension tweaks. Additionally, guidance on driving techniques, such as braking points and racing lines, was restricted. Information on tire conditions, optimal strategies for tire management, and fuel management was also limited.

The communication restrictions also extended to teams providing specific information about competitors to their drivers during races. Teams were generally prohibited from sharing precise details regarding the strategies, lap times, or conditions of other competitors on the track. Teams were typically allowed to communicate essential information such as noting the gap between a driver and a competitor, indicating a competitor's pit stop, or providing general updates on the competitive landscape. However, the specifics of a competitor's strategy, tire conditions, or technical issues were typically off limits. For example, related to competitors, the following information was banned: comparative or absolute sector time detail of another driver, speeds in corners compared to another driver, or gear selection compared with another driver. Also restricted was information about how to improve lap times, including guidance on optimal driving lines, gear selection, and braking points. These restrictions were intended to ensure a more level playing field.

In 2016, the FIA reversed the radio communication restrictions introduced in 2014. While the rule was enforced from mid-2014 until mid-2016, it proved controversial and operationally

[7] See Appendix A for a detailed description.

challenging. Teams and drivers criticized the ban because it often prevented engineers from providing essential technical guidance during critical situations, raising safety and reliability concerns. Although the FIA monitored messages to enforce the rule, distinguishing between legitimate technical advice and prohibited 'driver coaching' created ambiguity and frequent disputes. Additionally, the restriction was perceived as detrimental to the fan experience, as it reduced the amount of strategic and technical content available in race broadcasts. Responding to these issues, and following discussions with the F1 Strategy Group and commercial stakeholders, the FIA decided to lift the restrictions mid-season, restoring full radio communication between teams and drivers.

Overall, we argue that our setting is appropriate for the current study for five main reasons. First, information is constant across the sample, i.e., all drivers receive the same type of information from their teams via radio communication during races. Second, the information is provided to improve driver performance. Third, all teams and drivers work under the same tournament incentive. Fourth, the sport's use of fine-grained measures (i.e., times per lap) allows us to evaluate the performance of the drivers. Finally, we can analyze an interrupted time series setting, where we can observe the impact on driver performance of the radio communication restriction. The restriction constitutes a plausibly exogenous shock.[8]

2.3 Research Question

We examine how the availability of real-time information during task execution affects performance. Specifically, we analyze whether drivers who rely heavily on real-time information achieve better or worse outcomes when they have more or less information available. While

[8] It is difficult to assume that there are ex ante effects, since the announcement of the restriction was made in the middle of the season and from one week to the next. This means that there was no pre-season to train for the restriction and the time to adapt, for example in training simulators, was very short.

research suggests that having more information improves decision-making (Fiolleau et al., 2018; Hall, 2010; Tucker & Alewine, 2023), competing arguments suggest that having less information available can enhance performance by encouraging exploration and mitigating overload (Goodman et al., 2004; Iselin, 1996). Anecdotal evidence from our research site (Appendix B) reflects these opposing perspectives. On the one hand, having less information available may hinder decision quality due to skill limitations (Abernethy et al., 2023; Casas-Arce et al., 2017). On the other, having less information can prompt agents to develop alternative strategies, fostering learning, enhancing performance (Goodman et al., 2004; Song et al., 2017), and reducing cognitive overload (Hartmann & Wießenberger, 2023; Iselin, 1996).

In high-pressure, competitive environments, real-time information is often critical for coordination, urgency management, and uncertainty reduction (Bisbe & Sivabalan, 2017). However, too much information can disrupt independent decision-making, creating dependency on external guidance (Gibbs & Van der Stede, 2025). This tension is illustrated by contrasting views from Formula 1. Lewis Hamilton, a seven-time world champion driver, criticized having less information available, stating, "I am just looking at my steering wheel for a large portion of the lap—all the way down the straight just looking at my wheel. All they can tell me is there is a switch error, so I am looking at every single switch thinking, am I being an idiot here?" (Reuters, 2016). Conversely, Nico Rosberg emphasized the benefits of operating with less real-time information, saying, "We are on our own now—we have to manage such situations ourselves—and that's a good challenge!" (FIA, 2016). Franco Colapinto, reflecting on his first Grand Prix experience (which was not impacted by the radio restriction), highlighted the difficulties he faced with managing information while driving. He described the overwhelming nature of receiving constant instructions over the radio, saying, "I had someone talking to me every five seconds, and at first, I couldn't even stay straight on the gray [track]; I was running off into the grass" (Marca, 2024). His struggle to focus on critical tasks, such as determining which buttons to press on his steering wheel at high speeds, underscores the potential for excessive feedback to hurt performance. Similarly, Mercedes team principal Toto Wolff supported the idea that having less information available promoted learning through experience, arguing, "Strategy, engine-mode deployment, tire choices, even up to a point pit stops, a lot will be down to the driver to decide. … It is an absolutely positive step" (Autosport, 2016).

While we are primarily interested in the average effect on performance of having less real-time information available, the regulatory shock we study also allows us to examine the dynamics of information availability, as the shock first reduces and then reintroduces real-time information. This sequential change enables us to test two mechanisms. The initial reduction in available information enables assessment of the information quality mechanism, as it forces individuals to rely on their own judgment, potentially fostering learning and adaptation. The subsequent reintroduction of previously removed information then allows us to examine information overload, as the abrupt increase in information may disrupt decision-making or overwhelm cognitive capacity. Research suggests that adjustments to changing information availability are not always symmetrical (Goodman et al., 2004), making it critical to explore whether performance effects stem primarily from improved decision-making with less information or from cognitive strain when more information becomes available again.

In summary, rather than assuming a directional effect, we examine the relationship between information availability and performance as an empirical question. The primary effect we analyze is whether, *on average*, less information leads to better or worse performance. However, the research design—based on the restriction and subsequent reintroduction of team radio communication—also enables the examination of how changes in information availability influence established decision-making processes.

3 METHOD, SAMPLE, AND DATA

3.1 The Model

We analyze our research question using data from the F1 between the years 1996 and 2021.[9] The first year for which the FIA officially reports all lap times for each race is 1996. Our identification strategy exploits a regulatory change introduced by the FIA that temporarily restricted real-time radio communication between drivers and their teams from September 2014 to July 2016. This setting provides a unique opportunity to observe how individuals perform under different information regimes within a stable competitive environment, enabling within-driver and within-team comparisons before, during, and after the restriction while holding individual ability constant. We estimate the effect of the reduction in real-time information using the following specification:

$$\textit{Milliseconds per Lap}_{r,d,l} = \beta\ \textit{Radio Restriction}_{r,d,l} + \delta' \textit{Controls}_{r,d,l} + \varphi_t + \delta_c + \lambda_{co} + \alpha_d + \varepsilon_{r,d,l}, \qquad (1)$$

where the dependent variable is milliseconds per lap (i.e., more milliseconds, less performance), the main independent variable of interest is the radio restriction (i.e., the real-time restriction of information availability), and subscripts *r*, *d*, and *l* correspond to race, driver, and lap, respectively. *Milliseconds per Lap* corresponds to the total milliseconds used by each driver to finish each lap.[10]

[9] Due to data availability, the 2001 season is incomplete. Our results remain consistent when the sample is restricted to start in 2002 instead of 1996.

[10] To finish each race, drivers need to run a certain number of laps. Milliseconds are log-transformed for statistical reasons, to address skewness and heteroscedasticity, and multiplied by 100 for easier interpretation in percentage terms. In untabulated tests, we also estimate the model without the log transformation, and the results are consistent, indicating that the transformation does not drive the findings.

It provides a direct and continuous measure of speed and efficiency, isolating the driver's and car's fundamental pace.

Anecdotical evidence from the research site suggests that lap time is the most important KPI for driving success. As an example, Amazon Web Services (2025), the official partner for F1 data analytics, states: "Driver Performance highlights which drivers are pushing their car to the absolute limit of performance, … Three parameters will be shown to highlight three key areas of driver performance that have a major effect on *the ultimate goal—lap time* [emphasis added]: Acceleration, Braking, Corners." Similarly, data science consulting firms emphasize the centrality of lap times in assessing performance. According to Ludis (2023), "Lap times encapsulate the essence of Formula 1 racing, providing a direct measurement of a car's speed and performance on the track. They represent the culmination of the car's capabilities, driver skill, and team strategy."

To further validate this measure and address concerns about its ability to capture performance, we conduct additional untabulated tests. We correlate *Milliseconds per Lap* with other potential performance metrics: (i) *Points* (Corr = -0.015; $p < 0.01$; fewer milliseconds per lap, more points achieved in the race), (ii) *Position Order* at the end of the race (Corr = 0.080; $p < 0.01$; fewer milliseconds per lap, better race position),[11] and (iii) *Race Progression*, that is the difference between the initial position in the race (*Grid*) and the position in each lap (Corr = -0.026; $p < 0.01$; more milliseconds per lap, fewer positions gained).[12] These untabulated results provide additional evidence that milliseconds per lap reliably proxies for performance. Additionally, in the results section, we conduct several tests using additional important

[11] *Position Order* is not inverted, meaning lower values (e.g., 1, 2, 3) indicate better finishing positions.
[12] Again position is not inverted, meaning higher values indicate more positions gained. For example, a driver starting in fourth and finishing first will have a value of +3, while a driver starting fourth and finishing second will have a value of +2.

performance outcomes, such as race pace (the driver's ability to maintain consistent and competitive lap times throughout a race, reflecting overall performance and efficiency) as well as unfinished races, accidents, and engine failures.

φ_t, δ_c, λ_{co}, and α_d are year, circuit, car constructor, and driver fixed effects, respectively. For completeness, we also add engine fixed effects to control for both the team and the motor used in the car. As controls, we add the following variables: *Lap*, *Pit Stop*, *Position Order$_{t-1}$*, *Points$_{t-1}$*,[13] and *Grid*.[14] We include the control variables *Position Order* and *Points* at period *t-1* to avoid potential serial correlations with our dependent variable, *Milliseconds per Lap*. Models are run clustering standard errors at the driver level. The coefficient of interest is β, as it shows the relationship between the radio restriction and drivers' performance. A negative coefficient indicates that performance *improves* as milliseconds per lap decrease due to the real-time information restriction.

3.2 Descriptive Statistics

Table 1 Panel A shows the descriptive statistics for the main variables used in our regression models. In our sample, drivers finish their lap using, on average, 96,644.55 milliseconds. This is equivalent to 1.61 minutes, on average.[15] In our sample, races have a maximum of 87 laps (this corresponds to the 2020 race in Sakhir, Bahrain), with an average of 62 laps per race. On average, each driver completes 30 laps per race, reflecting dropouts, pit stops, and classification rules. Table 1 Panel B shows driver characteristics. Our sample contains a total of 118 drivers of 32 different

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[13] *Position Order$_{t-1}$* is the position obtained by each driver in the previous race of the current year. *Points$_{t-1}$* also corresponds to the points obtained by each driver in the previous race of the current year. In untabulated results our findings remain the same when *Position Order$_{t-1}$* and *Points$_{t-1}$* are calculated as (i) the final position and points obtained in the last race of the previous year, (ii) the previous year's average final position and points at the driver and year level, or (iii) the current year average final position and points at the driver and year level, excluding the final race of the year. Our results also hold when we do not include both control variables.
[14] Variables definitions can be found in Appendix C.
[15] Tables show the descriptives for *Milliseconds per Lap* as the natural logarithm multiplied by 100.

nationalities. Their ages range from a minimum of 18 years to a maximum of 43 (with an average of 28). The most common nationality in the sample is British, followed by Brazilian, German, and French. Table 1 Panel C shows the 37 circuits (and 394 races) included in our sample and the location/country distribution. In the circuits included in our data, 76 car constructors participate, with the most common being Ferrari followed by McClaren Mercedes, Mercedes and Renault.[16] Finally, Table 1 Panel D shows the correlation matrix.

4 RESULTS AND DISCUSSION

4.1 Main Results

We start our analysis by examining our research question: how information availability affects individual performance, proxied by the radio communication restriction and milliseconds per lap, respectively. Table 2 shows our main results. The coefficient for *Radio Restriction* shows a negative and significant relationship with *Milliseconds per Lap* in all columns. Columns (1) and (2) include year, circuit, car constructor and driver fixed effects. Column (3) also includes engine fixed effects. Overall, these results suggest that, on average, drivers perform better when real-time information is limited.

We conduct a series of (untabulated) sensitivity analyses to assess the robustness of our results across different model specifications. First, we create a race-specific trend variable (*Time Trend Race*) that equals 1 for the first race in the sample, 2 for the second race, and so on. This variable accounts for any gradual improvements in lap times over the years. The results show that the estimated effect of the radio restriction remains significant. Second, we create a driver-race

[16] Appendix D shows the sample distribution of the 76 different car constructors included in our sample.

specific trend variable (*Time Trend*)[17] and use it as the alternative year fixed effects. Since each driver's performance may improve or decline over time, we replace year fixed effects with the individualized trend, ensuring that changes in a driver's skills do not confound the estimated effect. Our findings endure. Third, we restrict the sample to 2009–2021 (five years before and after the restriction starts in 2014) to reduce the potential influence of long-term trends. Again, our results hold. Fourth, we only consider drivers who participated in at least one race before, after, and during the radio restriction period.[18] Our findings remain largely unchanged.[19] Fifth, we restrict our sample to drivers who competed during the restriction period and who also participated either before *or* after the policy change. Our main findings remain statistically significant and directionally consistent.[20] Sixth, we apply winsorization to mitigate the influence of extreme outliers in lap times. We perform winsorization on both the upper and lower extremes, though low outliers are conceptually less plausible, as they would suggest excessively fast, unrealistic lap times. Our inferences remain unchanged when applying winsorization at the (i) 99%, (ii) 1% and 99% levels, and (iii) 5% and 95% levels. These consistency checks confirm that our conclusions are not driven by a few extreme observations or local maxima in the data but rather reflect a broader and more generalizable effect.

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[17] This variable that starts at 0 in the year 1996 and increases by 1 each year, reaching 25 in 2021, and then we interact it with a driver identifier.

[18] Ten drivers are present at least once before, during, and after the radio restriction: D. Ricciardo, F. Massa, F. Alonso, K. Räikkönen, L. Hamilton, N. Hülkenberg, R. Grosjean, S. Vettel, S. Pérez, and V. Bottas.

[19] To assess whether our main findings are sensitive to clustering choices, we re-run this test using (i) standard errors clustered at the car constructor level and (ii) Huber-White robust standard errors. The results remain qualitatively unchanged across specifications, suggesting that our findings are not driven by the few drivers in the restricted sample.

[20] Thirty-two drivers meet this condition. Given that 32 is still a relatively small number, we run our main regression using (i) car constructor-clustered standard errors and (ii) Huber-White robust standard errors. Untabulated results remain qualitatively the same, mitigating concerns that the sample restriction influenced estimates.

4.2 Matching Analysis

To mitigate concerns that drivers competing during the radio restriction period may systematically differ from those who only raced before or after this period, we conduct a matching analysis. Specifically, we form all possible driver pairs between *treated drivers*—those affected by the communications restriction—and *untreated drivers*, ensuring that the analysis does not rely on selective or arbitrary pairings. Matches are based on three key criteria: *Years in the Same Team*, *Driver Age*, and *Position in the Season*. By using the full set of feasible pairs that satisfy these criteria, we ensure that comparisons are drawn across drivers with identical levels of team familiarity and tenure, experience, and competitive standing, thereby minimizing potential bias from variation in driver characteristics across periods.

Our results remain robust, even when using this reduced, carefully matched sample. Columns (1) and (2) in Table 3 show that drivers competing during the radio restriction time are, on average, faster than drivers who competed always before or after the restriction period (never treated). These results suggest that the observed performance differences are not simply due to changes in driver characteristics or historical performance trends but rather are linked to the restriction itself.

4.3 Validation Analyses

To further validate the effectiveness of the radio restriction, we examine its impact on two key areas that depend heavily on real-time communication: (i) intra-team performance consistency and (ii) pit stop decisions. If the restriction limited teams' ability to relay strategic guidance, we would expect greater performance variability between teammates and changes in pit stop frequency, both of which would indicate a disruption in information flow.

First, we analyze whether the restriction influenced performance consistency within teams by examining the milliseconds difference between two drivers of the same team for each lap.[21] This measure captures the extent to which teammates—who typically operate under similar car conditions and strategic direction—diverge in their lap times. The results in Table 4 Panel A show a significant increase in *Milliseconds Difference* during the restriction period, suggesting that reduced communication led to greater intra-team performance dispersion. This finding supports the notion that the policy constrained real-time coordination, inhibiting teams from synchronizing race execution strategies between teammates.

Second, we assess whether the radio restriction affected pit stop frequency and execution, as pit stops require precise coordination between drivers and engineers to manage tire strategy, fuel consumption, and race positioning. Under normal conditions, teams use real-time data and direct communication to determine the optimal timing for pit stops, ensuring strategic alignment with race conditions and minimizing unnecessary stops. However, with restricted communication, drivers had to rely more on pre-established strategies or personal judgment. The results in Table 4 Panel A show that the number of pit stops increased during the restriction period, indicating that teams faced greater uncertainty in managing race strategy. Additionally, we find that the first pit stop occurred earlier in the race under the restriction, suggesting that, without real-time guidance, drivers were more conservative in their tire management, opting for earlier stops to mitigate potential performance risks.

[21] To calculate this variable, we exclude observations where only one driver from a team is present for a given lap. This typically occurs when the teammate has exited the race.

4.4 Placebo Tests

We also conduct two placebo tests. First, we use data from practice sessions. Conceptually, the effect of the information restriction should not matter for drivers in the first practice session, when the goal is to test the track and car settings, with lap times being less important. In this one-hour free practice, teams and drivers typically finetune their setups before *parc fermé* conditions begin and most work on the car is banned. We find support for this argument, as the radio restriction is not significantly associated with better performance using the sample of practice sessions (Table 4 Panel B). Second, we rerun regression (1) but over a different period of radio restriction, from 11 September 2014 to 28 July 2016. Thus, we randomly select races from 4 September 2005 to 22 July 2007, which also represent around 23 months in the pre-restriction period. In untabulated results, we find that the estimated coefficient is statistically insignificant, suggesting that the observed effects in our main analysis are not driven by underlying time trends.[22]

4.5 Information Dynamics

Our primary analysis examines the effect of radio restrictions on driver performance. Beyond assessing whether information availability improves outcomes, we analyze how changes in real-time information influence decision-making over time. We analyze a restricted sample covering 2014–2016. The introduction of the restriction in 2014 and its removal in 2016 allow for within-driver comparisons across regulatory changes, substantially reducing concerns about differences in driver composition. By focusing on drivers present under both conditions (i.e., from with to

[22] We also run this test using the number of races instead of the dates. The radio restriction ranges from 11 September 2014 to 28 July 2016, which represents 37 races in total. Thus, we randomly select a period including 37 races: from 4 September 2005 to 16 September 2007. This corresponds to five races in 2005, 18 in 2006, and 14 in 2007. All these races are in time order in our sample (i.e., we start selecting the race from 4 September 2005 and the following 36 races). Again, the untabulated estimated coefficients are statistically insignificant, further supporting our identification strategy.

without radio restriction in 2014; and from without to with the radio restriction in 2016), we obtain a cleaner assessment of how restricting and reintroducing real-time information affects performance. Hence, Table 5 focuses on the within-season effects of the radio restriction, examining separately the period when it was first imposed (second half of 2014) and when it remained in place prior to its mid-2016 removal. This separation allows us to observe immediate reactions to the policy change as well as performance under sustained exposure to limited information, isolating adaptation effects within the same racing season.

The coefficient for the second half of 2014, when the restriction was first imposed, is small and statistically insignificant. This indicates that drivers maintained performance despite losing access to real-time information, and it is consistent with the patterns observed in our main results. In other words, drivers adapted quickly, demonstrating the ability to compensate for the withdrawal of external guidance. By contrast, the coefficient for early 2016—when the restriction remained in place prior to its mid-season removal—is negative and highly significant, indicating faster lap times under prolonged restricted communication. This pattern suggests that sustained exposure to limited information not only offset potential disadvantages but may have enhanced performance over time, as drivers and teams developed more autonomous decision-making routines.[23] Taken together, these results highlight an asymmetry: the introduction of the restriction does not harm performance, whereas its sustained application leads to measurable improvements, setting the stage for the subsequent deterioration observed once real-time information was reintroduced later in 2016.

[23] It is important to note that 2015 does not appear in the regression, because the restriction was in force for the entire season, and its effect is fully absorbed by the year fixed effects. Our identification strategy leverages within-season changes in 2014 (introduction of the restriction) and 2016 (removal), allowing comparison of the same set of drivers before and after the regulatory change. The absence of a separate coefficient for 2015 reflects collinearity with the year fixed effects and does not compromise the validity of our results.

4.6 Additional Results: Cross-Sectional Analyses

We conduct cross-sectional tests to further investigate the mechanism for our main findings, identifying contexts where the radio restriction is expected to have varying effects. In cases where the restriction is anticipated to have a weaker impact, these contexts operate as natural benchmarks.

4.6.1 Circuit Complexity

Circuits with complex layouts, more corners, and greater technical demands typically require more real-time strategic adjustments, making radio communication more valuable. In contrast, simpler circuits should demand less from drivers and thus be less sensitive to restrictions on communication. If the performance effects we identify are indeed driven by the lack of real-time guidance, we expect to find stronger negative effects on complex circuits. This approach is motivated by the theoretical tension highlighted earlier: real-time information can improve decision quality by reducing uncertainty, but it can also create cognitive overload and dependency, impairing autonomous decision-making.

First, we identify typically complex circuits within our sample.[24] To validate this classification, we conduct several tests. Untabulated descriptive evidence shows that, on average, complex circuits differ from simpler ones. The former features more pit stops, accidents, collisions, retirements, gearbox use, or tire issues. On average, complex circuits have more corners and higher downforce levels. They also require more gear changes per lap and impose a greater time penalty

[24] The complex circuits we identify are the following: Monaco Circuit, Suzuka Circuit, Marina Bay Street Circuit, Circuit de Spa-Francorchamps, Hungaroring Circuit, Circuit of the Americas, Baku City Circuit, Barcelona-Catalunya Circuit and Silverstone Circuit. Anecdotical evidence can be found at: *https://www.cmcmotorsports.com/blogs/the-drift/4-most-difficult-f1-tracks*; and *https://www.newcarsonline.co.uk/blog/the-top-ten-formula-1-circuits-to-experience/*

per lap due to fuel load. Additionally, drivers spend less time at full throttle on these tracks, further emphasizing their technical demands.

Second, we run our main regression with complex and noncomplex circuit subsamples (Table 6 Panel A). The results show that drivers competing during the radio restriction period are slower on complex circuits, where strategic adaptability, technical precision, and real-time decision-making are especially demanding. This aligns with the expectation that drivers who previously relied on real-time guidance struggle more when facing harder tracks without real-time feedback. Conversely, in simpler circuits, we observe a better performance. This suggests that, in simpler track configurations, the absence of real-time communication is beneficial, as drivers might experience fewer distractions and more autonomous decision-making. Overall, these findings reinforce the idea that the impact of the radio restriction is not uniform but rather context-dependent, being most detrimental where external guidance plays a critical role in optimizing lap times.

We also exploit the regulatory reversal to study how performance responds when information flows change (Table 6 Panel B). When the restriction was first imposed, performance deteriorated on complex circuits but improved on simpler ones, reflecting initial adjustment costs and the benefits of reduced overload. By early 2016—after drivers had adapted to limited communication—the negative effect on complex circuits diminished, while the positive effect on non-complex circuits persisted. This asymmetry highlights two mechanisms: initial withdrawal of information imposes costs on tasks requiring high adaptability, whereas sustained restriction fosters routines that enhance autonomy. Crucially, when unrestricted communication was reintroduced mid-2016, these gains were reversed, suggesting that sudden increases in information availability can disrupt established heuristics and impose cognitive switching costs. Overall, these dynamics highlight that the performance effect of information availability is both contingent and dynamic, shaped by task complexity and the stability of information flows.

4.6.2 Newly Treated Drivers

We run a subsample analysis considering drivers who started competing in 2015 or 2016—after the radio restriction was already in place—since they never experienced an F1 environment with unrestricted radio communication. As shown in Table 6, Panel C, these "*newly treated*" drivers perform significantly better under the restriction, recording lap times almost 3 milliseconds faster per lap relative to drivers who had previously raced with full radio communication. This suggests that these drivers developed their decision-making processes in an environment with fewer real-time inputs, which may have encouraged greater autonomy, faster internal information processing, and greater reliance on personal situational judgment. With fewer external cues, these drivers may have avoided the distraction or cognitive load associated with constant incoming guidance, leading to more efficient decision execution under pressure. By contrast, drivers accustomed to continuous radio support may have initially developed routines that depend on frequent team feedback. For them, the restriction removes a familiar input channel and requires behavioral and cognitive adjustment, which may explain the more modest performance gains in this group.

4.6.3 Driver Experience

We examine subsamples based on driver experience, as less experienced drivers are expected to rely more on radio guidance. In contrast, highly experienced drivers should better handle the radio restriction on account of their accumulated knowledge and intuitive racecraft. Just as managers draw upon experiences and knowledge to inform their decisions (Hall 2010), F1 drivers rely on their skills and familiarity with different track conditions, car setups, and racing strategies.

We create variable *Experience in F1* that ranges from 1 to 22 (mean of 6.58 years), according to the years that have passed since the first year each driver competed in F1.[25] We classify drivers as highly experienced if the number of years they have competed exceeds or equals the annual average. The results in Table 6 Panel D indicate that the radio restriction improves performance for all drivers, but the effect strengthens for more experienced ones. Experienced drivers likely benefit from the restriction because they have more autonomy in decision-making, a better understanding of strategy, and better adaptability to changing conditions. In contrast, less experienced drivers rely more on real-time team guidance for optimizing times, tire management, and in-race adjustments.

4.6.4 Prior Performance

To further examine the role of skills in adapting to the radio restriction, we use past performance as an alternative proxy. Specifically, we rely on $Points_{t-1}$ (points earned in the last race of the current season), $Position\ Order_{t-1}$ (finishing position in the last race of the current season),[26] and *Accumulated Points* (total points accumulated by each driver, in each year, up to the current race). We classify drivers into annual terciles based on these measures, where better finishing positions and more accumulated points indicate stronger past performance and greater competitiveness in prior races. Consistent with the results based on F1 experience, these findings suggest that radio restriction benefits the best drivers. Those with stronger prior results experience a greater reduction in lap times, indicating a greater ability to adapt without real-time guidance. In contrast, drivers

[25] The driver with 22 years of experience is Michael Schumacher, as he started competing in F1 in 1991.

[26] $Position\ Order_{t-1}$ is an inverse measure of performance, where lower values indicate better past results (e.g., a position of 1 corresponds to a race win, while higher values reflect poorer finishes). To ensure clarity and avoid misinterpretation, we inverted this variable for this analysis and the corresponding table.

with weaker past performance appear to depend more on team instructions, meaning they are hurt more by restricted communication (see Table 6 Panel E).

4.6.5 Driver Team Tenure

A driver's ability to cope with limited real-time communication may depend not only on experience in Formula One generally, but also on the extent to which routines and shared decision processes have developed within the driver–team relationship. From a management control perspective, long-standing working relationships support the development of tacit coordination mechanisms, mutual knowledge, and pre-aligned decision rules that reduce the need for continuous, externally supplied guidance. This logic aligns with the idea that familiarity and accumulated shared knowledge can mitigate the risks of information overload and improve performance under greater autonomy.

Building on this, we examine whether the effect of the radio restriction varies depending on how long a driver has raced for the same team. We measure *Driver Team Tenure* as the number of consecutive seasons a driver has competed with the same team. Average tenure in our sample is 2.55 years, with a range from one to twelve seasons. Table 6 Panel F shows that drivers with longer team tenure experience stronger performance improvements under the radio restriction. This is consistent with the idea that well-established relationships allow drivers and engineers to internalize communication routines, enabling drivers to make better autonomous decisions when real-time instructions are limited. Interestingly, we also find a statistically significant effect for drivers with short tenure. This suggests that even recently assigned drivers benefit from the reduction in real-time communication. Our interpretation is that removing radio input reduces cognitive load, freeing attentional resources for core driving tasks even among drivers who have not yet developed deep shared routines with their new teams. Related to the non-result for the midtenure drivers, a plausible explanation is that they face a different set of incentives and adaptation constraints compared to newcomers and veterans. Mid-cycle drivers are often in phases where contract renewal, internal role consolidation, and performance pressure are most salient. This may encourage more cautious or risk-averse driving, potentially limiting the benefits of reduced real-time guidance. At the same time, while these drivers have begun to rely on continuous radio feedback, they may not yet have developed the tacit coordination, mutual understanding, and decision routines that long-tenure drivers build with their engineers. As a result, they may bear both costs—loss of information without yet having fully internalized substitute processes—leading to smaller observed performance gains than in the other groups.

4.6.6 Resources: Team Budget

We also analyze the impact of team budget, as it captures the varying resource levels available to teams, which can significantly influence their reliance on real-time strategy inputs such as radio communication. Big-budget teams usually have more advanced technology, better data analytics, and more sophisticated strategies, making their feedback more valuable and technically superior to that of low-budget teams. This may increase their dependence on constant feedback during the race. On the other hand, low-budget teams may have less access to such resources, meaning their performance will rely less on radio communications, and they may therefore experience greater improvements under the radio restriction. By testing this, we assess how the restriction affects teams differently based on their resource capabilities, illuminating a potential mechanism driving performance changes.

The results in Table 7 indicate that the impact of radio restriction varies significantly depending on team budget. The coefficient for *Radio Restriction* is negative and highly significant across all specifications, confirming that reduced real-time communication is associated with faster lap times. As expected, the negative and significant coefficient for *Teams Budget 2014*[27] suggests that, in the absence of the restriction, big-budget teams generally achieve faster lap times. However, the interaction term *Radio Restriction* × *Teams Budget 2014* is positive and significant, suggesting that the performance improvements due to the restriction are smaller for these teams. This finding aligns with the argument that well-funded teams, which rely more on real-time strategy adjustments, are more harmed when this information is restricted. In contrast, low-budget teams, which already operate with less strategic guidance, experience greater performance gains under the restriction. These results are consistent with the regulation's intended goal of increasing competitiveness across the field.

4.7 Additional Results: Additional Consequences

4.7.1 Race Pace

As an additional analysis of alternative performance consequences, we examine race pace, a key performance indicator in F1 that captures a driver's ability to maintain consistent and competitive lap times throughout a race. Race pace isolates pure driving performance by filtering out external factors, such as starting positions, race incidents, and team strategies. This measure directly assesses a driver's ability to manage critical factors like tire degradation, fuel consumption, and overall race conditions. A strong race pace indicates sustained high performance. Race pace is widely used to evaluate both driver skill and car performance beyond race-day contingencies.

Our proxy for *Race Pace*[28] captures consistency relative to a driver's evolving performance. The results show a significant reduction in race pace, indicating that, under reduced

[27] This is the budget from when the regulation initially came into effect. The variable *Teams Budget 2014* ranges from 11 (teams with the highest budgets) to 1 (teams with the lowest budgets) in year 2014.
[28] *Race Pace* is the absolute value of the difference between milliseconds per lap and the mean of all previous laps of the same race. A higher value indicates greater inconsistency, suggesting difficulties in maintaining a stable pace as the race progresses. To ensure comparability and avoid distortions, the measure excludes the first lap (which often

real-time information availability, drivers achieve lap times that are closer to their evolving race average (Table 8). This suggests that, on average, rather than being hindered by the lack of immediate guidance, drivers improve their performance by maintaining a continuous and more controlled pace.

4.7.2 Failures

To further explore the impact of reduced real-time information on performance, we also analyze its effect on the probability of not finishing the race, having an accident, or suffering an engine failure. We argue that the lack of real-time information can also lead to suboptimal decision-making, which in turn increases the risk of such incidents. For example, drivers might push their cars to their mechanical limits, increasing the likelihood of engine failures, or exceed the driving limits, leading to a higher probability of run-offs and accidents. This aligns with the idea that even top professionals can err under pressure (Apesteguia & Palacios-Huerta 2010). Results in Table 8 confirm this view: the coefficient of *Radio Restriction* on *Unfinished Race* is positive and significant, indicating that limiting real-time communication increased the likelihood of drivers not finishing a race. Similarly, the probability of accidents and engine failures also increased under the restriction, suggesting that reduced information availability impaired drivers' ability to monitor critical elements, such as the engine, brakes, and tires. Overall, while reducing real-time information can enhance performance (i.e., lower milliseconds per lap), it also introduces trade-offs, including a higher likelihood of race retirements, accidents, and mechanical failures.

differs due to race start dynamics) and any laps involving pit stops. For the regressions, it is shown as natural logarithm and multiplied by 100.

5 CONCLUSION

We examine the effect of reduced real-time information on individual performance using the Formula One radio restriction. On average, drivers perform better with less real-time guidance, as shown by faster lap times. These results suggest that limiting external input can foster autonomous decision-making and adaptive learning while mitigating the risks of information overload—particularly in high-pressure environments. However, our results also show that this improvement is not immediate and depends on the dynamics of adaptation. When the restriction is first introduced, drivers maintain their performance despite losing live guidance. Over time, performance improves, suggesting that drivers and teams develop internal routines that substitute for real-time communication. Conversely, when full communication is reintroduced, performance declines, indicating that switching information regimes imposes cognitive and coordination costs.

The study offers relevant implications for managers operating in dynamic, data-rich environments. While real-time feedback can support performance, more information is not always better, and stability in the information environment matters. Striking the right balance is essential to enhance decision quality without overwhelming individuals. Although Formula One presents a unique context, the findings raise broader questions about feedback design and cognitive load. Future research could further explore how information dynamics affect performance in other settings with lower pressure and different incentive structures.

Appendix A: Radio Restriction. Regulation of Information Allowed and Not Allowed.

Message types allowed	Message types not allowed
Acknowledgement that a driver message has been heard.	Sector time detail of a competitor and where a competitor is faster or slower.
Lap or sector time detail.	Adjustment of power unit settings.
Lap time detail of a competitor.	Adjustment of power unit setting to de-rate the systems.
Gaps to a competitor during a practice session or race.	Adjustment of gearbox settings.
“*Push hard*”, “*push now*”, “*you will be racing xx*” or similar.	Learning of gears of the gearbox.
Helping with warning of traffic during a practice session or race.	Balancing the SOC [state-of-charge of batteries] or adjusting for performance.
Giving the gaps between cars in qualifying so as to better position the car for a clear lap.	Information on fuel flow settings (except if requested to do so by race control).
Puncture warning.	Information on level of fuel saving needed.
Tyre choice at the next pit stop.	Information on tyre pressures or temperatures.
Number of laps a competitor has done on a set of tyres during a race.	Information on differential settings.
Tyre specification of a competitor.	Start maps related to clutch position, for race start and pit stops.
Indication of a potential problem with a competitor's car during a race.	Information on clutch maps or settings, e.g. bite point.
Information concerning a competitor likely race strategy.	Burn-outs prior to race starts.
Yellow flags, blue flags, Safety Car deployment or other cautions.	Information on brake balance or BBW (brake-by-wire) settings.
	Warning on brake wear or temperatures.
	Selection of driver default settings (other than in the case of a clearly identified problem with the car).
	Answering a direct question from a driver, e.g. “*Am I using the right torque map*”?
	Any message that appears to be coded.

Source: FIA (2014)

Appendix B: Anecdotal Evidence from the Research Site

With arguments for and against, the impact of taking information away from drivers (and team) on their performance is an open research question. Anecdotal evidence from drivers and team managers indicates that these both potential sides are present at the research site. Red Bull boss Christian Horner, whose team had to send messages to Daniel Ricciardo to deal with a failed battery, suggested it would be wrong not to allow teams to help when problems arise:

> *"I think these cars are so bloody complicated and there's an awful amount going on. I completely support getting rid of driver coaching through the radio. It's not the engineers' job to tell them where they need to brake later, or whatever. But in terms of managing the actual power unit; they're so complicated that from a reliability and safety point of view, I think it's important. And I think for the show it's good [to speak to them]. At least we can tell them their brakes are getting hot and that they have to pull out of the slipstream, for example." (Autosport, 2014).*

Some drivers also argued that the lack of information caused them to get lost or compete in worse conditions. Hamilton (Mercedes driver and multiple world champion) commenting on the radio restriction, said he had spent much of the race distracted and struggling with his car's engine settings while engineers were unable to help him. The driver summed up the situation in one word: "*dangerous*," and suggested the rules should be reconsidered:

> *"I am just looking at my steering wheel for a large portion of the lap – all the way down the straight just looking at my wheel. All they can tell me is there is a switch error, so I am looking at every single switch thinking am I being an idiot here? Have I done something wrong? I hadn't. I looked time and again at the different switch positions and there was nothing that looked irregular. The radio ban, as far as I am aware was supposed to stop driver aids, but it wasn't a driver aid, it was a technical issue. Today would have added to the spectacle if I had full power because I would have been more in the race fighting with the guys up ahead... maybe the rule needs to be looked at again because it is a technical issue." (Reuters, 2016)*

Conversely, other protagonists argue that the restriction of radio communication could yield positive outcomes, enabling them to focus more effectively on their tasks. For instance, Nico Rosberg, a world champion driver, highlighted the radio regulations as a challenge for drivers, illustrating the potential benefits:

> *"It is a challenge for us drivers because it is new and different. Up until now much a lot of what we do on track is what they tell us to do: drive faster, drive slower, take care of the tyres, look after the fuel – now you can use more fuel and so on. Now we are on our own out there! From now on it will be very different. It's a great challenge and it is definitely the way to go as it is now much more pure racing. For example a few races ago I was second trying to overtake Lewis and his engineers did a great job: whenever I increased my electronic boost power – which I can only do for a couple of corners of laps – his engineers saw it and told him to do the same, so I never was able to create a difference between the two of us and never got the opportunity to have an advantage. Such situations are a thing now the past. From now on the other car will never know what I am doing – if I attack or defend. Now we are on our own! It will be much more exciting." (Formula One, 2014)*

Some team managers at the time also pointed to the potential positive effect on competitiveness. Toto Wolff (Mercedes executive director) approved of the new regulations:

> *"It is an absolutely positive step. The target was to make things less predictable, more variable, and this is what's going to happen. […] create more error, therefore more variability in the result, which is important for the sport." (Autosport, 2016)*

Appendix C: Variables Definitions

Variable Name	Variable Description
Milliseconds per Lap	Milliseconds used by each driver to finish each lap. For the regressions, it is shown as natural logarithm and multiplied by 100.
Radio Restriction	Dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise.
Radio Restriction_2014	Dummy variable that equals 1 if races are between 11th September 2014 (i.e., radio restriction starting time) to the end of year 2014; 0 otherwise.
Radio Restriction_2016	Dummy variable that equals 1 if races are between the beginning of the 2016 season until 28 July 2016 (the date when the restriction was lifted); 0 otherwise
Milliseconds Difference	Milliseconds difference of the two pilots of the same team for each lap. Observations where only one driver is competing in the race are dropped.
Lap of the First Pit Stop	Lap at which the first pit stop of the race occurs for each driver.
Milliseconds Practice Session 1	Milliseconds used by each driver to the first training session. For the regressions, it is shown as natural logarithm and multiplied by 100. Data from: *https://pitwall.app/races/archive/2021*
Accumulated Points	Number of points accumulated by each driver (in each year) up to the current race.
Race Pace	Absolute value of the difference between milliseconds per lap and the average of all previous laps within the same race. The measure excludes the first lap and any lap involving pit stops. For the regressions, it is shown as natural logarithm and multiplied by 100.
Unfinished Race	Dummy variable that equals 1 if the driver did not finish the race, including lapped drivers; 0 otherwise.
Accident	Dummy variable that equals 1 a driver had an accident in a race; 0 otherwise.
Engine Failure	Dummy variable that equals 1 a driver had an engine failure in a race; 0 otherwise.
Team Budget 2014	Rank (from 1 to 11) of teams by budget in the year 2014 (inverted, where 11 is the team with the highest budget). Data from: *https://chispasf1.wordpress.com/2015/04/28/presupuestos-y-personal-de-los-equipos-de-la-f1-en-el-ano-2014/*
Lap	Lap number of the race.
Pit Stop	Dummy variable that equals 1 if there is a pit stop in each lap; 0 otherwise.
Position Order$_{t-1}$	Position order in at the end of the previous race of the current year.
Points$_{t-1}$	Points achieved in the previous race of the current year.
Driver Age	Age of the driver.
Grid	Race position in starting grid.

Appendix D: Constructors/Teams Characteristics

Constructor/Team	N	%	Constructor/Team	N	%
Alfa Romeo Racing Ferrari	6,301	1.62	Minardi Fondmetal	220	0.06
Alphatauri Honda	3,806	0.98	Minardi Ford	352	0.09
Alpine Renault	2,322	0.60	MRT Mercedes	2,000	0.51
Arrows	151	0.04	Prost Mugen Honda	1,108	0.28
Arrows Supertec	107	0.03	PROST Peugeot	586	0.15
Arrows Yamaha	606	0.16	Racing Point Bwt Mercedes	3,899	1.00
Aston Martin Mercedes	2,322	0.60	RBR Cosworth	1,532	0.39
Bar Honda	4,993	1.28	RBR Ferrari	1,595	0.41
Benetton Playlife	974	0.25	RBR Renault	3,712	0.95
Benetton Renault	1,285	0.33	Red Bull Racing Honda	6,251	1.60
Brawn Mercedes	1,805	0.46	Red Bull Racing Renault	10,171	2.61
Caterham Renault	5,204	1.34	Red Bull Racing Tag Heuer	6,015	1.54
Ferrari	41,119	10.55	Red Bull Renault	3,014	0.77
Footwork Hart	123	0.03	Renault	24,203	6.21
Force India Ferrari	1,374	0.35	Sauber Bmw	7,174	1.84
Force India Mercedes	18,772	4.82	Sauber Ferrari	16,572	4.25
Haas Ferrari	11,923	3.06	Sauber Ford	484	0.12
Honda	5,196	1.33	Sauber Petronas	6,479	1.66
HRT Cosworth	4,953	1.27	Scuderia Toro Rosso Honda	4,275	1.10
Jaguar Cosworth	3,357	0.86	Spyker Ferrari	1,248	0.32
Jordan Ford	2,670	0.69	Stewart Ford	453	0.12
Jordan Honda	90	0.02	STR Cosworth	1,787	0.46
Jordan Mugen Honda	786	0.20	STR Ferrari	11,743	3.01
Jordan Peugeot	1,060	0.27	STR Renault	3,634	0.93
Jordan Toyota	1,924	0.49	Super Aguri Honda	2,932	0.75
Ligier Mugen Honda	572	0.15	Toro Rosso	972	0.25
Lotus Cosworth	1,642	0.42	Toro Rosso Ferrari	2,010	0.52
Lotus Mercedes	1,533	0.39	Toyota	12,547	3.22
Lotus Renault	7,299	1.87	Tyrrell Ford	619	0.16
Marussia Cosworth	4,036	1.04	Tyrrell Yamaha	281	0.07
-Marussia Ferrari	3,168	0.81	Virgin Cosworth	3,286	0.84
Mclaren Honda	5,284	1.36	Williams BMW	5,414	1.39
Mclaren Mercedes	26,655	6.84	Williams Cosworth	4,884	1.25
Mclaren Renault	5,993	1.54	Williams Mecachrome	576	0.15
Mercedes	25,320	6.50	Williams Mercedes	16,556	4.25
MF1 Toyota	1,605	0.41	Williams Renault	5,323	1.37
Minardi Asiatech	65	0.02	Williams Supertec	99	0.03
Minardi Cosworth	3,993	1.02	Williams Toyota	5,348	1.37

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Table 1: Descriptive Statistics

Panel A: Sample Characteristics

	N	Mean	SD	Min	p25	Median	p75	Max
Milliseconds per Lap	389,742	1,144.51	19.36	1,092.24	1,131.27	1,142.88	1,154.60	1,583.14
Radio Restriction	389,742	0.10	0.30	0	0	0	0	1
Lap	389,742	30.18	18.36	1	14	29	45	87
Pit Stop	389,742	0.02	0.14	0	0	0	0	1
Position Order$_{t-1}$	389,742	10.49	6.06	1	5	10	16	24
Points$_{t-1}$	389,742	4.05	6.54	0	0	0	6	125
Grid	389,742	10.62	6.19	0	5	10	16	24

Panel B: Driver Characteristics

	Mean	SD	Min	p25	Median	p75	Max
Driver Age	28.10	4.90	18	24	28	31	43

Driver Nationality	N	%	Driver Nationality	N	%
American	2	1.69	Indonesian	1	0.85
Argentine	2	1.69	Irish	1	0.85
Australian	2	1.69	Italian	8	6.78
Austrian	4	3.39	Japanese	8	6.78
Belgian	2	1.69	Malaysian	1	0.85
Brazilian	11	9.32	Mexican	2	1.69
British	15	12.71	Monegasque	1	0.85
Canadian	3	2.54	New Zealander	1	0.85
Colombian	1	0.85	Polish	1	0.85
Danish	3	2.54	Portuguese	1	0.85
Dutch	5	4.24	Russian	4	3.39
Finnish	5	4.24	Spanish	6	5.08
French	10	8.47	Swedish	1	0.85
German	11	9.32	Swiss	1	0.85
Hungarian	1	0.85	Thai	1	0.85
Indian	2	1.69	Venezuelan	1	0.85

Panel C: Circuit Characteristics

Country	Location	Number of Races	Country	Location	Number of Races
Argentina	Buenos Aires	3	Japan	Oyama	2
Australia	Melbourne	22	Korea	Yeongam County	4
Austria	Spielberg	12	Malaysia	Kuala Lumpur	16
Azerbaijan	Baku	5	Mexico	Mexico City	6
Bahrain	Sakhir	18	Monaco	Monte-Carlo	20
Belgium	Spa	18	Netherlands	Zandvoort	1
Brazil	São Paulo	22	Portugal	Portimão	2
Canada	Montreal	17	Qatar	Al Daayen	1
China	Shanghai	16	Russia	Sochi	8
France	Magny Cours	7	Saudi Arabia	Jeddah	1
France	Le Castellet	3	Singapore	Marina Bay	12
Germany	Hockenheim	13	Spain	Montmeló	21
Germany	Nürburg	10	Spain	Valencia	5
Hungary	Budapest	19	Turkey	Istanbul	9
India	Uttar Pradesh	3	UAE	Abu Dhabi	13
Italy	Monza	19	UK	Silverstone	23
Italy	Imola	10	USA	Indianapolis	6
Italy	Mugello	1	USA	Austin	9
Japan	Suzuka	17			

Panel D: Correlation Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Milliseconds per Lap	1							
(2) Radio Restriction	**0.056**	1						
(3) Lap	**-0.244**	**0.005**	1					
(4) Pit Stop	**0.098**	**0.042**	**-0.038**	1				
(5) Position Order$_{t-1}$	**0.053**	**-0.009**	**-0.019**	**0.011**	1			
(6) Points$_{t-1}$	**-0.007**	**0.064**	**0.017**	**0.021**	**-0.728**	1		
(7) Driver Age	**-0.014**	**-0.049**	0.005	**-0.009**	**-0.091**	**0.099**	1	
(8) Grid	**0.073**	**-0.013**	**-0.029**	**0.009**	**0.532**	**-0.482**	**-0.120**	1

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. Panel A shows the descriptive statistics. Panel B shows the driver's characteristics. Panel C shows the circuit characteristics. Panel D shows the Pearson correlation coefficients. Bold numbers indicate statistical significance at 1% level. All variables are defined in Appendix C.

Table 2: Radio Restriction and Race Speed

		Full sample	
	(1)	(2)	(3)
		Milliseconds per Lap	
Radio Restriction	-1.389***	-1.444***	-1.432***
	(-4.589)	(-4.878)	(-4.728)
Controls			
Lap		-0.146***	-0.145***
		(-49.793)	(-50.017)
Pit Stop		8.774***	8.781***
		(27.096)	(27.004)
Position Order$_{t-1}$		-0.022	-0.027
		(-0.860)	(-1.044)
Points$_{t-1}$		-0.016	-0.022
		(-0.798)	(-1.079)
Grid		0.060***	0.051***
		(4.103)	(3.321)
Year FE	YES	YES	YES
Circuit FE	YES	YES	YES
Car Constructor FE	YES	YES	YES
Driver FE	YES	YES	YES
Engine FE	NO	NO	YES
Observations	389,742	389,742	389,742
Adj. R-sqr.	0.436	0.459	0.460

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and total milliseconds per lap (*Milliseconds per Lap*) completed. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. Column (1) does not include control variables. Columns (2), and (3) include the control variables (*Lap*, *Pit Stop, Position Order$_{t-1}$, Points$_{t-1}$* and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1 and 2) and also engine fixed effects (Column 3). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 3: Matching Analysis. Radio Restriction and Race Speed

	(1)	(2)
	Milliseconds per Lap	
Radio Restriction (*Matched*)	-1.760*	-1.789*
	(-1.995)	(-2.040)
Controls		
Lap		-0.144***
		(-8.901)
Pit Stop		8.935***
		(8.588)
Position Order$_{t-1}$		0.032
		(0.519)
Points$_{t-1}$		0.061
		(0.601)
Grid		0.180
		(1.635)
Year FE	YES	YES
Circuit FE	YES	YES
Car Constructor FE	YES	YES
Driver FE	YES	YES
Engine FE	NO	YES
Observations	22,016	22,016
Adj. R-sqr.	0.455	0.480

The sample comprises 22,016 race-driver-lap-year observations for the matched years between 1996 to 2021. The table shows the relationship between radio restriction, and total milliseconds per lap (*Milliseconds per Lap*) completed for a matched sample of drivers in terms of years in the same team, age and average position in the season. *Radio Restriction (Matched)* is a dummy variable that equals 1 if races are between 11th September 2014, and 28th July 2016, for drivers who were subject to the radio restriction and matched with a comparable driver—one who was not subject to the restriction but had a similar profile in terms of years with the same team, age, and average seasonal position; 0 otherwise. Column (1) does not include control variables. Column (2) includes the control variables (*Lap*, *Pit Stop, Position Order$_{t-1}$, Points$_{t-1}$* and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1 and 2) and also engine fixed effects (Column 2). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 4: Validation Analysis and Placebo Test.

Panel A: Validation Analysis. Radio Restriction, Intra-team Performance Consistency and Pit Stops

	(1) *Milliseconds Difference (Teammates)*	(2) *Pit Stop*	(3) *Lap of the First Pit Stop*
Radio Restriction	4.709***	0.006***	-0.029***
	(2.784)	(5.371)	(-3.743)
Controls	YES	YES	YES
Year FE	YES	YES	YES
Circuit FE	YES	YES	YES
Car Constructor FE	YES	YES	YES
Driver FE	NO	YES	YES
Engine FE	YES	YES	YES
Observations	332,680	389,742	389,742
Adj. R-sqr.	0.056	0.018	0.007

The table shows the relationship between *Radio Restriction*, intra-team performance consistency and pit stops from 1996 to 2021. The number of race-driver-lap-year observations are 332,680 for Column (1) as observations where only one driver is competing in the race are dropped; and 389,742 for Columns (2) and (3). *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. *Milliseconds Difference (Teammates)* is the milliseconds difference between the two pilots of the same team for each lap. *Pit Stop* is a dummy variable that equals 1 when there is a pit stop in each lap; 0 otherwise. *Lap of the First Pit Stop* is the lap at which the first pit stop of the race occurs for each driver. All columns include the following control variables: *Lap*, *Position Order*$_{t-1}$, *Points*$_{t-1}$ and *Grid*. Column (1) also includes *Pit Stop* as control variable. All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, and engine fixed effects. Column (1) does not include driver fixed effects. Standard errors are clustered by driver in Columns (2), and (3) and robust in Column (1), and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Panel B: Placebo Test. Practice Sessions

	(1) *Milliseconds* Practice Session 1
Radio Restriction	0.094
	(0.486)
Year FE	YES
Circuit FE	YES
Car Constructor FE	YES
Driver FE	YES
Engine FE	YES
Observations	296,881
Adj. R-sqr.	0.902

The sample comprises 296,881 race-driver-lap-year observations from 2006 to 2021. The table shows the relationship between radio restriction and milliseconds in the first practice session. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver, and engine fixed effects. No control variables included. Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 5: Radio Restriction and Race Speed. Information Dynamics.

	2014–2016: Restricted Sample to the Radio Restriction Period		
	(1)	(2) *Milliseconds per Lap*	(3)
Radio Restriction_2014	-0.279	-0.354	-0.355
	(-0.547)	(-0.707)	(-0.711)
Radio Restriction_2016	-2.641***	-2.717***	-2.727***
	(-9.751)	(-10.121)	(-10.104)
Controls			
Lap		-0.173***	-0.173***
		(-36.532)	(-36.538)
Pit Stop		6.968***	6.968***
		(21.695)	(21.695)
Position $Order_{t-1}$		-0.011	-0.015
		(-0.227)	(-0.296)
$Points_{t-1}$		0.002	0.003
		(0.028)	(0.050)
Grid		0.045	0.037
		(1.262)	(1.015)
Year FE	YES	YES	YES
Circuit FE	YES	YES	YES
Car Constructor FE	YES	YES	YES
Driver FE	YES	YES	YES
Engine FE	NO	NO	YES
Observations	61,548	61,548	61,548
Adj. R-sqr.	0.438	0.467	0.467

The sample comprises 61,548 race-driver-lap-year observations from 2014 to 2016. The table shows the relationship between radio restriction in 2014 and 2016, and total milliseconds per lap (*Milliseconds per Lap*). *Radio Restriction_2014* is a dummy variable that equals 1 if races are between 11th September 2014 (i.e., radio restriction starting time) to the end of year 2014; 0 otherwise. *Radio Restriction_2016* is a dummy variable equal to 1 for races between the beginning of the 2016 season until 28 July 2016 (the date when the restriction was lifted); 0 otherwise. All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1 and 2) and also engine fixed effects (Column 3). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 6: Radio Restriction and Race Speed by Subsamples

Panel A: Circuit Complexity Subsamples

	Complex Circuits			*Non-Complex Circuits*		
	(1)	(2)	(3)	(4)	(5)	(6)
	Milliseconds per Lap			*Milliseconds per Lap*		
Radio Restriction	4.360***	4.248***	4.238***	-6.811***	-6.805***	-6.812***
	(17.511)	(18.828)	(18.686)	(-16.012)	(-16.019)	(-15.917)
Controls						
Lap		-0.133***	-0.133***		-0.151***	-0.151***
		(-37.538)	(-37.416)		(-44.999)	(-44.964)
Pit Stop		8.300***	8.301***		9.111***	9.121***
		(20.929)	(20.913)		(28.683)	(28.541)
Position $Order_{t-1}$		-0.028	-0.024		-0.028	-0.038
		(-0.887)	(-0.755)		(-0.897)	(-1.196)
$Points_{t-1}$		-0.022	-0.016		-0.022	-0.032
		(-0.770)	(-0.562)		(-0.834)	(-1.199)
Grid		0.054***	0.054**		0.057***	0.044**
		(2.757)	(2.608)		(2.685)	(2.024)
Coefficients Difference	*(1)-(4)*	*(2)-(5)*	*(3)-(6)*			
Radio Restriction	11.171***	11.053***	11.050***			
Prob > F	0.000	0.000	0.000			
Year FE	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES
Engine FE	NO	NO	YES	NO	NO	YES
Observations	152,658	152,658	152,658	237,084	237,084	237,084
Adj. R-sqr.	0.457	0.477	0.478	0.419	0.444	0.445

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and milliseconds per lap (*Milliseconds per Lap*) for complex and non-complex circuits subsamples. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. *Complex Circuits* is a dummy variable that equals 1 if the circuits are Monaco Circuit, Suzuka Circuit, Marina Bay Street Circuit, Circuit de Spa-Francorchamps, Hungaroring Circuit, Circuit of the Americas, Baku City Circuit, Barcelona-Catalunya Circuit or Silverstone Circuit; 0 otherwise. Columns (1) and (4) do not include control variables. Columns (2), (3), (5) and (6) include the control variables (*Lap*, *Pit Stop, Position* $Order_{t-1}$, $Points_{t-1}$ and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1, 2, 4 and 5) and also engine fixed effects (Columns 3 and 6). Standard errors clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 6: Radio Restriction and Race Speed by Subsamples

Panel B: Circuit Complexity Subsamples and Information Dynamics

	2014–2016: Restricted Sample to the Radio Restriction Period					
	Complex Circuits			*Non-Complex Circuits*		
	(1)	(2)	(3)	(4)	(5)	(6)
	Milliseconds per Lap			*Milliseconds per Lap*		
Radio Restriction_2014	7.339***	7.094***	7.103***	-8.681***	-8.635***	-8.640***
	(11.202)	(10.692)	(10.641)	(-16.186)	(-16.434)	(-16.573)
Radio Restriction_2016	3.114***	2.945***	2.926***	-8.182***	-8.226***	-8.242***
	(7.685)	(7.653)	(7.576)	(-19.130)	(-18.945)	(-18.991)
Controls						
Lap		-0.218***	-0.218***		-0.136***	-0.136***
		(-26.414)	(-26.403)		(-34.083)	(-34.129)
Pit Stop		7.347***	7.348***		6.707***	6.706***
		(15.800)	(15.796)		(19.071)	(19.063)
Position Order$_{t-1}$		-0.050	-0.052		-0.016	-0.021
		(-0.635)	(-0.659)		(-0.215)	(-0.282)
Points$_{t-1}$		-0.011	-0.011		-0.010	-0.009
		(-0.166)	(-0.155)		(-0.156)	(-0.136)
Grid		-0.010	-0.015		0.059	0.048
		(-0.144)	(-0.207)		(1.193)	(0.981)
Coefficients Difference	*(1)-(4)*	*(2)-(5)*	*(3)-(6)*			
Radio Restriction_2014	16.020***	15.729***	15.743***			
Prob > F	0.000	0.000	0.000			
Radio Restriction_2016	11.296***	11.171***	11.168***			
Prob > F	0.000	0.000	0.000			
Year FE	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES
Engine FE	NO	NO	YES	NO	NO	YES
Observations	27,027	27,027	27,027	34,521	34,521	34,521
Adj. R-sqr.	0.327	0.369	0.368	0.502	0.524	0.524

The sample comprises 61,548 race-driver-lap-year observations from 2014 to 2016. The table shows the relationship between radio restriction in 2014 and 2016, and total milliseconds per lap (*Milliseconds per Lap*) for complex and non-complex circuits subsamples. *Radio Restriction_2014* is a dummy variable that equals 1 if races are between 11th September 2014 (i.e., radio restriction starting time) to the end of year 2014; 0 otherwise. *Radio Restriction_2016* is a dummy variable equal to 1 for races between the beginning of the 2016 season until 28 July 2016 (the date when the restriction was lifted); 0 otherwise. *Complex Circuits* is a dummy variable that equals 1 if the circuits are Monaco Circuit, Suzuka Circuit, Marina Bay Street Circuit, Circuit de Spa-Francorchamps, Hungaroring Circuit, Circuit of the Americas, Baku City Circuit, Barcelona-Catalunya Circuit or Silverstone Circuit; 0 otherwise. All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1, 2, 5 and 5) and also engine fixed effects (Columns 3 and 6). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 6: Radio Restriction and Race Speed by Subsamples

Panel C: Newly Treated Subsamples

	Subsample of Drivers who Started Competing in the Years 2015 or 2016			*Remaining Sample*		
	(1)	(2)	(3)	(4)	(5)	(6)
	Milliseconds per Lap			*Milliseconds per Lap*		
Radio Restriction	-3.564***	-3.603***	-3.622***	-1.057***	-1.109***	-1.077***
	(-6.327)	(-6.170)	(-6.586)	(-3.356)	(-3.615)	(-3.431)
Controls						
Lap		-0.171***	-0.171***		-0.144***	-0.143***
		(-17.425)	(-17.377)		(-49.548)	(-49.897)
Pit Stop		12.269***	12.273***		8.323***	8.331***
		(14.125)	(14.133)		(27.814)	(27.654)
Position Order$_{t-1}$		0.040	0.035		-0.029	-0.036
		(0.571)	(0.472)		(-1.040)	(-1.248)
Points$_{t-1}$		-0.010	-0.010		-0.019	-0.025
		(-0.353)	(-0.371)		(-0.722)	(-0.966)
Grid		-0.051	-0.055		0.065***	0.054***
		(-1.550)	(-1.609)		(4.411)	(3.424)
Coefficients Difference	*(1)-(4)*	*(2)-(5)*	*(3)-(6)*			
Radio Restriction	-2.507***	-2.494***	-2.545***			
Prob > F	0.000	0.000	0.000			
Year FE	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES
Engine FE	NO	NO	YES	NO	NO	YES
Observations	27,534	27,534	27,534	362,208	362,208	362,208
Adj. R-sqr.	0.455	0.491	0.491	0.435	0.457	0.459

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and milliseconds per lap (*Milliseconds per Lap*) for the subsample of drivers who started competing in the year 2015 or 2016 and the remaining sample. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. Columns (1) and (4) do not include control variables. Columns (2), (3), (5) and (6) include the control variables (*Lap, Pit Stop*, *Position Order$_{t-1}$*, *Points$_{t-1}$* and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1, 2, 4 and 5) and also engine fixed effects (Columns 3 and 6). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 6: Radio Restriction and Race Speed by Subsamples

Panel D: Driver Experience Subsamples

	High Experience = 1			*High Experience = 0*		
	(1)	(2)	(3)	(4)	(5)	(6)
	Milliseconds per Lap			*Milliseconds per Lap*		
Radio Restriction	-1.714***	-1.762***	-1.782***	-1.163**	-1.234***	-1.222***
	(-4.222)	(-4.270)	(-4.346)	(-2.570)	(-2.908)	(-2.812)
Controls						
Lap		-0.141***	-0.141***		-0.149***	-0.148***
		(-37.709)	(-37.527)		(-36.272)	(-36.427)
Pit Stop		8.500***	8.495***		8.953***	8.964***
		(18.000)	(17.939)		(17.420)	(17.381)
Position Order$_{t-1}$		-0.039	-0.041		-0.014	-0.019
		(-0.921)	(-0.952)		(-0.456)	(-0.614)
Points$_{t-1}$		-0.016	-0.008		-0.025	-0.035
		(-0.535)	(-0.293)		(-0.803)	(-1.108)
Grid		0.035**	0.023		0.071***	0.061**
		(2.256)	(1.354)		(3.000)	(2.466)
Coefficients Difference	*(1)-(4)*	*(2)-(5)*	*(3)-(6)*			
Radio Restriction	-0.551**	-0.528**	-0.560**			
Prob > F	0.030	0.024	0.008			
Year FE	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES
Engine FE	NO	NO	YES	NO	NO	YES
Observations	162,950	162,950	162,950	226,792	226,792	226,792
Adj. R-sqr.	0.434	0.456	0.456	0.437	0.461	0.463

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and milliseconds per lap (*Milliseconds per Lap*) for high and low experience drivers. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. *High Experience* is a dummy variable that equals 1 if drivers have been in F1 a number of years that is larger or equal than the annual average; 0 otherwise. Columns (1) and (4) do not include control variables. Columns (2), (3), (5) and (6) include the control variables (*Lap*, *Pit Stop, Position Order$_{t-1}$*, *Points$_{t-1}$* and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1, 2, 4 and 5) and also engine fixed effects (Columns 3 and 6). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 6: Radio Restriction and Race Speed by Subsamples

Panel E: Prior Performance

	Tercile 1—Top Performers			*Tercile 2—Mid-level Performers*			*Tercile 3—Low Performers*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	$Points_{t-1}$	Position $Order_{t-1}$	Accumulated Points	$Points_{t-1}$	Position $Order_{t-1}$	Accumulated Points	$Points_{t-1}$	Position $Order_{t-1}$	Accumulated Points
	Milliseconds per Lap			*Milliseconds per Lap*			*Milliseconds per Lap*		
Radio Restriction	-1.996***	-1.804***	-2.545***	-1.257	-1.388	-0.371	-1.006	-0.775	-0.164
	(-4.569)	(-2.931)	(-7.157)	(-1.201)	(-1.610)	(-0.466)	(-1.490)	(-0.639)	(-0.178)
Controls									
Lap	-0.139***	-0.142***	-0.139***	-0.153***	-0.147***	-0.144***	-0.145***	-0.143***	-0.149***
	(-28.740)	(-30.721)	(-25.212)	(-23.020)	(-30.177)	(-28.452)	(-33.524)	(-26.394)	(-29.719)
Pit Stop	7.744***	7.946***	7.511***	8.941***	8.721***	8.490***	9.295***	9.700***	10.038***
	(13.084)	(15.849)	(14.982)	(13.118)	(17.241)	(20.980)	(20.315)	(17.097)	(17.460)
Position $Order_{t-1}$			-0.021			-0.035			-0.020
			(-0.742)			(-0.972)			(-0.509)
Grid	0.020	0.030	0.067**	0.069*	0.049	0.000	0.064**	0.051	0.057*
	(0.669)	(0.961)	(2.130)	(1.672)	(1.499)	(0.011)	(2.518)	(1.295)	(1.783)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Engine FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	119,547	139,681	127,016	64,096	129,862	124,243	206,096	120,197	138,481
Ad. R-sqr.	0.452	0.454	0.473	0.479	0.469	0.465	0.467	0.476	0.454

The sample comprises race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and milliseconds per lap (*Milliseconds per Lap*) for previous performance annual terciles. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. *$Points_{t-1}$* and *Position $Order_{t-1}$* correspond to the number of points and position obtained in the previous race of the current year, respectively. *Accumulated Points* is the number of points accumulated by each driver (in each year) up to the current race. For each driver, the observation corresponding to their first race of the year is coded as missing. *Position $Order_{t-1}$* is an inverse measure of performance, where lower values indicate better past results (e.g., a position of 1 corresponds to a race win, while higher values reflect poorer finishes). To ensure clarity and avoid misinterpretation, this has been considered when creating the annual terciles. All columns include *Lap*, *Pit Stop,* and *Grid* as control variables. Columns (3), (6) and (9) also include *Position $Order_{t-1}$* as control variable. All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver and engine fixed effects. Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 6: Radio Restriction and Race Speed by Subsamples

Panel F: Driver Team Tenure Subsamples

	Highest Driver Teams Tenure			*Middle Drivers Teams Tenure*			*Lowest Drivers Teams Tenure*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Milliseconds per Lap			*Milliseconds per Lap*			*Milliseconds per Lap*		
Radio Restriction	-2.005***	-2.045***	-2.057***	-1.131	-1.201	-1.182	-1.061**	-1.161**	-1.134**
	(-3.906)	(-3.873)	(-3.926)	(-1.567)	(-1.656)	(-1.623)	(-2.076)	(-2.385)	(-2.311)
Controls									
Lap		-0.141***	-0.141***		-0.140***	-0.140***		-0.151***	-0.150***
		(-22.597)	(-22.593)		(-33.120)	(-33.091)		(-32.401)	(-32.276)
Pit Stop		8.085***	8.079***		8.996***	8.996***		9.033***	9.050***
		(16.419)	(16.364)		(14.545)	(14.557)		(17.533)	(17.554)
Position $Order_{t-1}$		0.014	0.012		0.001	-0.001		-0.067	-0.077*
		(0.392)	(0.335)		(0.032)	(-0.017)		(-1.485)	(-1.682)
$Points_{t-1}$		0.014	0.018		0.019	0.018		-0.052	-0.067
		(0.490)	(0.642)		(0.402)	(0.390)		(-1.024)	(-1.305)
Grid		0.089**	0.081**		0.025	0.022		0.049*	0.035
		(2.551)	(2.266)		(0.971)	(0.836)		(1.665)	(1.111)
Coefficients Difference	*(1)-(7)*	*(2)-(8)*	*(3)-(9)*						
Radio Restriction	-0.944*	-0.884**	-0.923**						
Prob > F	0.062	0.029	0.008						
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Engine FE	NO	NO	YES	NO	NO	YES	NO	NO	YES
Observations	89,865	89,865	89,865	111,662	111,662	111,662	188,215	188,215	188,215
Ad. R-sqr.	0.455	0.477	0.477	0.441	0.463	0.463	0.427	0.451	0.453

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction and milliseconds per lap (*Milliseconds per Lap*) by annual terciles of the number of years drivers have competed with the same team. *Radio Restriction* is a dummy variable that equals 1 if races are between 11^{th} September 2014 and 28^{th} July 2016; 0 otherwise. Columns (1), (4) and (7) do not include control variables. Columns (2), (3), (5), (6), (8) and (9) include the control variables (*Lap*, *Pit Stop, Position* $Order_{t-1}$, $Points_{t-1}$ and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1, 2, 4, 5, 7 and 8) and also engine fixed effects (Columns 3, 6 and 9). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 7: Radio Restriction and Race Speed interacted by Team Budget 2014

	(1)	(2)	(3)	(4)	(5)	(6)
		Milliseconds per Lap			*Milliseconds per Lap*	
Radio Restriction	-1.385***	-1.440***	-1.432***	-2.269***	-2.311***	-2.311***
	(-4.551)	(-4.838)	(-4.725)	(-5.498)	(-5.772)	(-5.664)
Teams Budget 2014	-0.050	-0.046	-0.022	-0.137***	-0.132***	-0.111**
	(-1.000)	(-1.055)	(-0.503)	(-2.905)	(-3.219)	(-2.515)
Radio Restriction × Teams Budget 2014				0.311***	0.307***	0.309***
				(5.182)	(5.234)	(5.235)
Controls						
Lap		-0.146***	-0.145***		-0.146***	-0.145***
		(-49.787)	(-50.022)		(-49.807)	(-50.047)
Pit Stop		8.774***	8.782***		8.773***	8.781***
		(27.097)	(27.005)		(27.081)	(26.989)
Position $Order_{t-1}$		-0.022	-0.027		-0.022	-0.027
		(-0.859)	(-1.046)		(-0.850)	(-1.035)
$Points_{t-1}$		-0.016	-0.022		-0.016	-0.022
		(-0.807)	(-1.082)		(-0.792)	(-1.069)
Grid		0.060***	0.051***		0.060***	0.051***
		(4.106)	(3.324)		(4.126)	(3.346)
Year FE	YES	YES	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES	YES	YES
Engine FE	NO	NO	YES	NO	NO	YES
Observations	389,742	389,742	389,742	389,742	389,742	389,742
Adj. R-sqr.	0.436	0.459	0.460	0.436	0.459	0.460

The sample comprises 389,742 race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and milliseconds per lap (*Milliseconds per Lap*) including the variable *Teams Budget 2014* and its interaction with *Radio Restriction*. *Radio Restriction* is a dummy variable that equals 1 if races are between 11^{th} September 2014 and 28^{th} July 2016; 0 otherwise. *Teams Budget 2014* ranges from 11 (teams with the highest budgets) to 1 (teams with the lowest budgets) in year 2014; 0 otherwise. Columns (2), (3), (5) and (6) include the control variables (*Lap*, *Pit Stop, Position* $Order_{t-1}$, $Points_{t-1}$ and *Grid*). All variables are defined in Appendix C. Models are estimated using year, circuit, car constructor, driver (Columns 1, 2, 4 and 5) and also engine fixed effects (Columns 3 and 6). Standard errors are clustered by driver, and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.

Table 8: Additional Consequences. Radio Restriction, Race Pace, Unfinished Race, Accident and Engine Failure

	(1) *Race Pace*	(2) *Unfinished Race*	(3) *Accident*	(4) *Engine Failure*
Radio Restriction	-6.631*	0.071**	0.002*	0.004***
	(-1.850)	(2.414)	(1.818)	(4.365)
Controls	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Circuit FE	YES	YES	YES	YES
Car Constructor FE	YES	YES	YES	YES
Driver FE	YES	YES	YES	YES
Engine FE	YES	YES	YES	YES
Observations	374,771	389,742	389,742	389,742
Adj. R-sqr.	0.139	0.408	0.040	0.094

The sample comprises race-driver-lap-year observations from 1996 to 2021. The table shows the relationship between radio restriction, and *Race Pace*, *Unfinished Race*, *Accident*, and *Engine Failure*. *Radio Restriction* is a dummy variable that equals 1 if races are between 11th September 2014 and 28th July 2016; 0 otherwise. *Race Pace* is the absolute value of the difference between *Milliseconds per Lap* and the average of all previous laps of the same race. It is calculated without considering the first lap and laps with pit stops. *Unfinished Race* is a dummy variable that equals 1 if the driver did not finish the race; 0 otherwise. *Accident* is a dummy variable that equals 1 a driver had an accident in a race; 0 otherwise. *Engine Failure* is a dummy variable that equals 1 a driver had an engine failure in a race; 0 otherwise. Columns (2), (3) and (4) include the following control variables: *Lap*, *Pit Stop*, $Position\ Order_{t-1}$, $Points_{t-1}$ and *Grid*. Column (1) includes the same control variables but excluding *Pit Stop* to avoid affecting previous lap averages. All variables are defined in Appendix C. All models are estimated using year, circuit, car constructor, driver, and engine fixed effects. Standard errors are clustered by driver in Columns (1) and (2) and robust in Columns (3) and (4), and t-statistics are in parenthesis. The superscripts *, **, and ***, respectively, indicate significance at the 10%, 5%, and 1% levels in a two-tailed test.