# THÈSE

**En vue de l'obtention du**

## DOCTORAT DE L'UNIVERSITÉ DE TOULOUSE

**Délivré par :**

Université Toulouse 1 Capitole (UT1 Capitole)

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**Présentée et soutenue par :**

Vincent TENA

**le** 09/07/2021

**Titre :**

Three essays on the impact of exogenous and persistent changes on the provision of incentives

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**École doctorale et discipline ou spécialité :**

ED SG : Finance

**Unité de recherche :**
Toulouse School of Management - Research

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*"It is the interest of every man to live as much at his ease as he can; and if his emoluments are to be precisely the same, whether he does, or does not perform some very laborious duty, it is certainly his interest… either to neglect it altogether, or, if he is subject to some authority which will not suffer him to do this, to perform it in as careless and slovenly a manner as that authority will permit."*

– Adam Smith in *The Wealth Of Nations*

# REMERCIEMENTS

La rédaction de ces quelques mots clôt mes années toulousaines, et je m'apprête maintenant à poursuivre ma carrière en “montant à la capitale” comme aurait dit ma très chère grand-mère. Je souhaite tout d'abord remercier mon directeur de thèse, le professeur Stéphane Villeneuve, qui avait su voir en moi dès la licence un potentiel que j'ai longtemps ignoré. Sans son soutien sans faille et ses nombreuses marques de confiance, je n'aurai peut-être pas débuter ce voyage à la fois difficile et captivant.

Je tiens également à remercier les professeur.e.s Sebastian Gryglewicz et Elisa Luciano pour l'honneur qu'ils me font d'être les rapporteurs de ce travail. Je remercie également les autres membres de mon jury, les professeurs René Aïd, Jean-Paul Décamps et Frank Moraux.

Merci aux professeurs Alexander Guembel et Matthieu Bouvard pour leurs relectures et leurs nombreux commentaires sur mon travail, et aussi aux professeur.e.s Sophie Moinas, Christophe Bisière, Sébastien Pouget, et Nour Meddahi pour m'avoir aidé à préparer au mieux ma recherche d'emploi sur le Job Market.

Merci aux membres du département de Finance de m'avoir si bien acceuilli toutes ses années, et j'addresse un grand merci aux professeur.e.s Catherine Casamatta, Silvia Rosetto, Christophe Bisière, et Ulrich Hege dont la marque d'attention à mon égard dans les moments les plus difficiles m'a beaucoup touché. Je remercie également le Laboratoire TSM-Research et tout particulièrement son directeur le professeur Karim Mignonac. Je souhaite remercier l'école doctorale de Toulouse School of Management (TSM), et les professeures Fany Declerck et Marion Fortin qui se sont succédées à sa direction durant mes années de thèse. L'école doctorale de TSM m'a fournit les moyens et les ressources qui m'ont permis de réaliser cette thèse dans des conditions idéales. Merci aussi à Valérie Placier qui a toujours été là pour m'aider à préparer les ateliers doctoraux.

J'adresse également mes remerciement à la professeure Nadine Galy, car c'est après qu'elle m'ait recruté à la Toulouse Business School que j'ai décidé de débuter un doctorat. Merci également à mes amis Dominique et Gilbert et à mes anciens collègues Anne, Kévin et Cameron.

Plus personnellement, je tiens à remercier tous mes collègues doctorants et anciens doctorants. Merci à mes amis Sarah, Grégoire, Maxence avec qui j'ai partagé bien plus qu'un bureau. Merci à Karen, Filip, Yifey, Hugues, Maxime, Clark, et Quentin car c'est aussi à leur côté que je me suis construit.

Merci à mes amis, et en particulier à Georges, Léonard, Pierre, Olivier, Marco, et Matthias pour leur présence réconfortante quand j'en avais le plus besoin. Je remercie aussi toute ma famille pour toutes ces années de soutien. Merci à mon père, à mon frère ainsi qu'à mon oncle et ma tante car ils sont toujours restés à mes côtés. Et merci à toi maman, qui n'aura pu me voir soutenir ma thèse mais qui sera toujours présente dans mes pensées.

Enfin, les mots me manquent pour remercier autant qu'elle le mérite celle qui a su/du partager mon quotidien au cours de toutes ces années de thèse. Merci à toi, Bertille, pour ton soutien de chaque instant.

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# Introductory Chapter (I)

# 1 Introduction

Modigliani and Miller's capital structure irrelevance principle states that financing decisions do not affect firm value in an idealized world without financial frictions. However, if we consider the real world, things are different. In particular, the separation of ownership and control may generate agency friction because the manager's objectives are not aligned with those of the owner. This observation is shared by Adam Smith – as the quote in the preamble to this thesis demonstrates – as well as by academics in the contemporary era. For instance, Nikolov et al. (2021) study different frictions generating financing constraints and find that moral hazard – the unobservability of the agent's decision – is the most prominent financial friction for private firms. As the Theory of incentives predicts: providing to the agent "skin in the game" may mitigate such a concern.

In standard principal-agent models over an infinite horizon, the provision of incentives is twofold: a performance-based compensation that divides cash flows between the principal and the agent, and the threat of dismissal. However, it is noteworthy that these elements have evolved over time (see, e.g., Murphy (2013), and Graham et al. (2020)) . While factors withing the relation (the nature of the relation, firm-specific factors, manager-specific factors) may explain such changes, there exists empirical evidence that other factors in the contractual environment induce them. The literature have found that factors at the industry level, at the market level, and at the regulatory level may affect the contractual relationship. In particular, empirical studies suggest that incentive contracts adapt to exogenous and persistent changes. For example, Bertrand and Mullainathan (2001) show that the principal ties the agent's incentives to both the firm performance and luck shocks beyond the agent's control. Hoffmann and Pfeil (2010) show that a dynamic contracting setting is a comprehensive theoretical framework to conciliate with such an empirical observation and explore how the incentives adapt to such shocks.

Lately, a new source of changes has emerged and has raised many concerns about the future of labor: the technologies of automation. While being often developed by third parties, there is a consensus that they are about to replace many workers in the years to come. Hence, we also expect that they may reshape the contractual relationship.

In the light of these observations, we explore in this thesis three complementary and original papers that study how exogenous and persistent shocks affect the provision of incentives.

The next steps of this introduction are, first, to provide an overview of the literature that explores the optimal provision of incentives in the presence of agency friction. We cover models both in static and dynamic cases and present the advantages of the method introduced by Sannikov (2008) that relies on the martingale method to provide tractable solutions.

Second, we present the evolution of the two typical contractual characteristics: the agent's compensation and dismissal. We discuss the main determinants of the changes in these characteristics, how new regulations impact them, and that, contrary to conventional wisdom, exogenous factors beyond the agent's scope also matter.

Third, we depart from the study of executives' contracts and investigate determinants of a change in the labor market. As technological change is considered the most prominent, we present an overview of the leading hypotheses to conceptualize its impact on labor. We continue with a discussion on one of its main effects, namely the hollowing-out of the employment distribution, and conclude this section with models embedding automation technologies to substitute for human labor.

Fourth, we state the main research question that guides this thesis, and we present our three articles. The fifth section concludes this introductory chapter.

# 2 The provision of incentives in the presence of agency friction

Our discussion begins with the problem of an entrepreneur who needs to raise money from a financier to launch a profitable project with random returns. The contractual delegation may be valuable for several reasons. First, the agent may not have sufficient wealth to finance up-front the firm himself. Second, it is valuable to attract outside investor when he has a higher discount rate than the market. However, an information asymmetry arises when only the agent observes his own actions. Consequently, an incentive contract is required to align both the entrepreneur's and the financier's objectives.

Townsend (1979), Gale and Hellwig (1985) analyze static models of risk-sharing with asymmetric information that can be used to study the problem aforementioned. Here, the principal can verify the firm's output at a cost to remove the uncertainty.[1] The revelation principle can be used to implement a contract that forces the agent to report the project's output truthfully, and the optimal contract relies on debt. The principal seizes the project if the up-front investment cannot be paid back, and the agent reimburses the principal otherwise. As Townsend says "one of the more interesting aspects of this [framework] is the attempt to explain the financial organization of firms by way of information asymmetries".

[1]The analysis excludes stochastic verification of the project's output.

In Holmstrom and Milgrom (1987), the principal's problem is to provide incentives to an agent with constant absolute risk aversion over a finite time horizon. The contract runs until the project's end, and the principal only incentives the agent through a final compensation. The authors solve for both the optimal effort level and the optimal compensation and find that the latter is linear in the project's output. Furthermore, they establish the equivalency of the optimal contract in a single-period static problem and a problem in continuous time. The assumption on the agent's exponential utility function is crucial here because it abstracts from wealth effects. Williams (2015) extends the paper aforementioned to study a broader environment (intermediate consumption, a natural state variable and private savings) with different assumptions (among others risk-averse principal and separable utility). The author shows that private savings reduce the optimal level of effort and that with exponential utility, the optimal contract is still linear. He and Zhu (2017) also extend Holmström and Milgrom's paper to study the effect of learning. It creates an informational rent that is taken as the state descriptor of the model.

In a dynamic capital-structure model, Leland (1994) extends Merton (1974)and Black and Cox (1976) and investigates the trade-offs between the tax advantages of debt and bankruptcy costs. Assuming time-independent debt coupon and infinite maturity debt, the author derives closed-form solutions for the debt value and the optimal firm's capital structure.

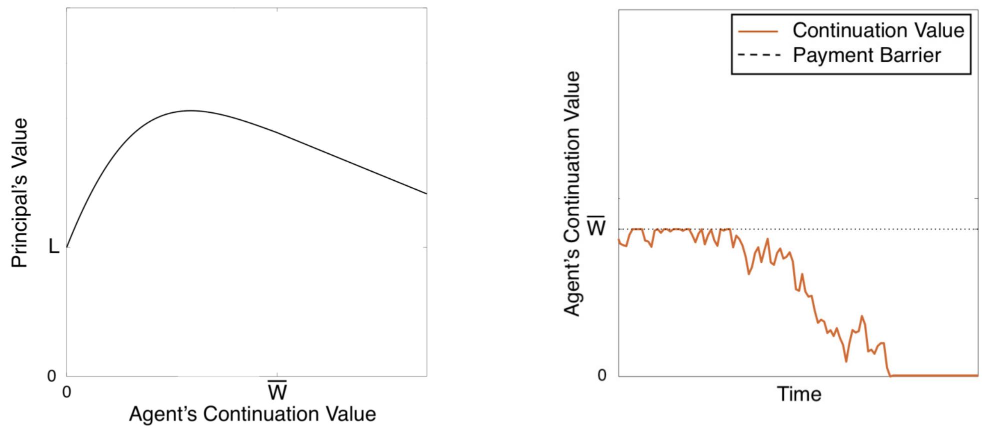
Biais et al. (2007) connect both discrete-time and continuous -time frameworks. They explore the problem of an agent who is protected by limited liability and needs to raise money from a principal to start an everlasting project. In addition, the agent can divert cash flow out of the principal's sight. The authors show that the discrete-time optimal contract that relies on cash reserves, debt, and equity converge towards the optimal contract in continuous time.

Discrete-time models can be tedious to solve, and the contribution of Sannikov (2008) to the literature is seminal to that extent. The author analyses a model where a risk-neutral principal delegates the management of a firm to a risk-averse agent protected by limited liability. While agency friction arises as a Brownian motion hides the agent's action, the drift of the firm's cash flow depends on the level of effort exerted at a cost by the agent. The author introduces a novel methodology to solve principal-agent models in continuous time able to depict the employment and wage dynamics in an extended framework. Indeed, continuous-time models offer computational advantages, and the method developed in Sannikov (2008) uses martingale theory and differential equations to derive a solution for the optimal contract. For instance, the method introduced by Phelan and Townsend (1991) to derive an optimal long-term contract in discrete time is more computationally intensive, so it is difficult to produce in-depth insights on how the contract characteristics change when a richer environment is considered (e.g., in the presence of an outside opportunity, with costly replacement, with promotion opportunities). Consequently, the solution presented by Sannikov offers tractability even when it results in a sophisticated and non-linear compensation scheme and effort strategy. Here, the optimal contract relies on a mix of short-term incentives (wages) and long-term incentives (increases in the continuation value $W$, golden parachutes, and the threat of termination after a poor performance).

DeMarzo and Sannikov (2006) use the method of Sannikov (2008) to characterize an optimal security design in the presence of moral hazard in an infinite horizon. The cash flow is driven both by the agent's strategy and by a Brownian motion that adds uncertainty. The authors considers both cash-flow diversion and hidden effort and show that both situations require the same kind of incentives. They derive an optimal contract that ties the agent's expected wealth – defined as the agent's continuation value – with the firm performance. Such a mechanism introduces volatility in the agent's expected wealth, which is now correlated with the movements of the cash flow's Brownian component. As the principal's value turns out to be concave, tying the agent's continuation value to realizing the cash flows is costly for the principal. The principal provides incentives to the agent both (i) by deferring compensation, so lump-sum payments are given only when the firm has performed sufficiently well, and (ii) by the threat of terminating the contract after the observation of too many bad outcomes. Figures 2a and 2b illustrates this result. When the firm performs sufficiently well, it drives the agent's continuation upwards. Then, payments occur at an upper boundary (that is denoted $\bar{W}$ on the figure). We note that if at any instant the agent were endowed with a continuation value larger than this upper threshold, then by construction, the principal would simply give to the agent a lump-sum payment such that the agent is moved to the payment boundary. Finally, the agent's continuation value may go down to a lower boundary, where the termination occurs because the agent cannot be incentivized anymore in the absence of renegotiation.

He (2009) builds on DeMarzo and Sannikov (2006) but specifies that the cash-flow process follows a geometrical Brownian motion, so changes in firm size generate incentives. In Gryglewicz et al. (2017), the firm is managed by a risk-averse agent and where the principal holds a growth option. The agent's risk aversion implies compensation for bearing risk.

This section has provided an overview of the literature on the optimal provision of incentives when the goal is to mitigate moral-hazard friction. However, other factors beyond the control of both the principal and the agent may impact the firm. Consequently, we will broaden the scope of our discussion to factors that affect the




(a) The principal's value as a function of the agent's continuation value.

(b) An illustration of the agent's continuation value as a function of time.

compensation and dismissal decision and then present how the theoretical literature embedding these factors may shed new light on these concerns.

# 3 The evolution of executive pay and dismissal

We begin with the observation that both the manager's compensation and the risk of dismissal – the two typical contractual characteristics described in agency theory – have been subject to change over time.

First, we present the figure 2 – extracted from Murphy (2013, Figure 5, p. 227) – that depicts the evolution of CEO compensation and supports this idea. It covers CEOs managing firms that were in the S&P 500 universe in 1992.[2] First, we remark the striking increase in pay levels (+ 165%) over that period. This observation is consistent with Bebchuk and Fried (2003), who find that the increase in CEO pay accelerates since 1995. We also note that the financial crisis of 2007-2008 has seen a reduction in pay level of 18.7% (2009 pay levels vs. 2006 pay levels), mainly due to the drop in value of the stock and restricted options. Then, compensation has returned to the pre-crisis level since 2010.

Second, we observe that the executive compensation packages have become increasingly sophisticated over time. Indeed, while the salary of the median CEO remains constant over time (around $ 1 million per year), the share of salary in

[2]We note that only half of the SP 500 firms in 1992 were still publicly traded in 2011.

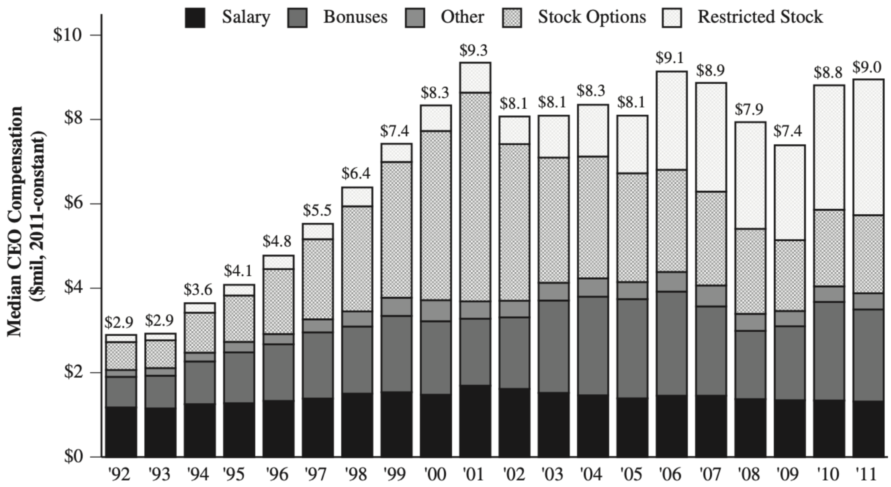



Figure 2: **Median Grant-date Compensation for CEOs in Firms Included in the 1992 S&P 500 – from Murphy (2013).**
This figure depicts the evolution of CEO grant-date pay over the 1992-2011 period. It includes cash pay (salary and bonuses), payouts from long-term pay programs, and the grant-date value of stock and option awards. For more details about the construction of the figure, please refer to Murphy (2013).

the total compensation of executives has fallen. This may reflect larger monetary incentives, as they are provided through bonuses and other compensations related to the firm's performance. While cash pay (salary and bonuses) represented about two-thirds of the total pay of CEOs in the early 1990s, options accounted for more than half of the compensation in 2001. The author adds that "by 2011, options fell to only 21% of pay, as many firms switched from granting options to granting restricted stock (which swelled to 36% of pay)". Jensen et al. (2004) document a similar trend over a more extended period and show that CEOs pay increases since the 1970s.

Concerning CEO dismissals, Graham et al. (2020) provide insights on their evolution over almost a century. The authors examine CEO-board dynamics for all firms in the NYSE and Amex universe from 1920 to 2011. They show that the propensity of CEO dismissal was low from the 1920s to the 1940s, increased over the period 1950-1970, and then decreased starting 1970. After a high CEO dismissal rate from 1990 to 2006, it dropped significantly from 14% to 8% in the last portion of their sample.

As the threat of dismissal also strongly incentivizes agents, it is important to distinguish between forced dismissals and voluntary dismissals. Forced CEO dismissal decision occurs when the CEO is "fired, forced out, or retires or resigns due to policy differences or pressure" (Parrino (1997)). Hence, this is closely related to the contract termination that occurs after a poor performance in agency theory.

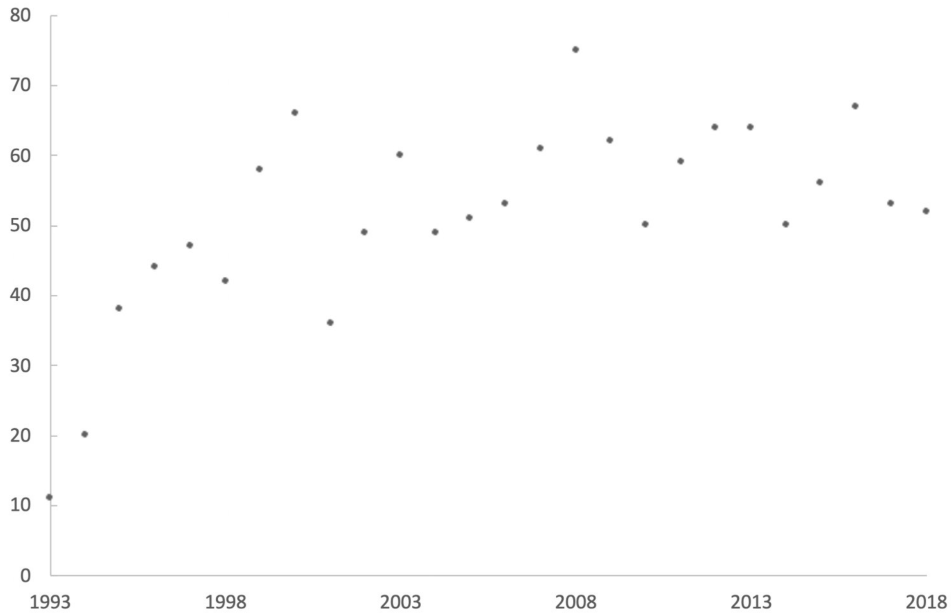



Figure 3: **Forced CEO Dismissal for Firms in the S&P ExecuComp Universe.**
We are grateful to Dirk Jenter, Alexander Wagner, and Florian Peters, who provided the data. Following the definition of Parrino (1997), a forced dismissal occurs when the CEO is "fired, forced out, or retires or resigns due to policy differences or pressure".

Figure 3 presents the number of forced CEO dismissal observed for firms in the S&P ExecuComp Universe from 1993 to 2018, and constructed with data grateful provided by Dirk Jenter, Alexander Wagner, and Florian Peters. We observe that CEO turnover increased in the 1990s, which is consistent with the findings of Murphy and Zabonjik (2004), and Jensen et al. (2004). Warner et al. (1988) provide empirical evidence that CEO dismissal and the firm's stock returns are inversely related. Antle and Smith (1986) show that the contract efficiency increases when the principal compares the agent's performance with peer's performance because it permits filtering out common uncertainty. According to Kaplan and Minton (2012), who study large U.S. firms from 1992 to 2005, the average tenure as CEO is less than seven years, and both forced and unforced dismissals follow the same increasing trend over that period. They find that the increase in block shareholder ownership, board independence, and the introduction of new regulations (specifically, the Sarbanes-Oxley legislation) are among the main determinants of the CEO dismissal decision.

In the following section, we study the impact of new regulations on CEOs pay and dismissal.

## 3.1 The role of regulatory authorities to mitigate excessive executive pay

We claim that the compensation package decision is arguably the output of a non-cooperative game, where the executive pay becomes increasingly sophisticated to adapt to a changing regulatory environment and where regulators implement new rules to limit excessive pay. Hence, it is the ascertainment of abuses that urges new regulations. In line with this argument, Murphy introduces the chapter dedicated to executive compensation in the *Handbook of the Economics of Finance* with the following observation:

> The first decade of the new century brought significant changes to executive compensation in large U.S. companies. Rocked by scandals ranging from accounting fraud to option backdating – coupled with suspicions that Wall Street bonuses led to excessive risk-taking that triggered the financial crisis – compensation committees faced a plethora of new pay-related laws and tax, accounting, and disclosure rules designed to stem perceived abuses in executive pay.

While excessive executive pay is regularly at the heart of concerns, SEC Chairman Christopher Cox acknowledges that "the SEC lacks statutory authority to impose salary caps on corporate executives and we'd be out of bounds to attempt that through indirection".[3] Rather, regulatory authorities expand the disclosure requirements in attempts to mitigate abusive pay.

However, the literature shows that the expansion of mandatory compensation disclosure on executive pay may not achieve the intended result. Mas (2019) studies the impact of the 1934 SEC reform on the Ceo's compensation. The author finds that the reform has significantly decreased the compensation of CEOs above the $97^{th}$ percentile of the earnings distribution and that the rest of the CEOs benefited

[3] Speech by SEC Chairman. January 17, 2006. https://www.sec.gov/news/speech/spch011706cc.htm

from the reform. In Mas (2017), pay disclosure in the public sector has led to wages cut for managers above the mean of the earning distribution but does not affect the managers below, and conclude that pay disclosure leads to a compression of wages. Gipper (2021) finds that the 2006 Compensation Discussion and Analysis reform has increased the mean of CEO pay by 11%.

Hence, factors out the firm's scope – such as changes in the regulatory environment – impact executives' contracts. In the next section, we present evidence about this channel for many exogenous and persistent changes, and discuss dynamic contracting models that offer predictions in line with these observations.

## 3.2 The effect of exogenous changes on executive contracts

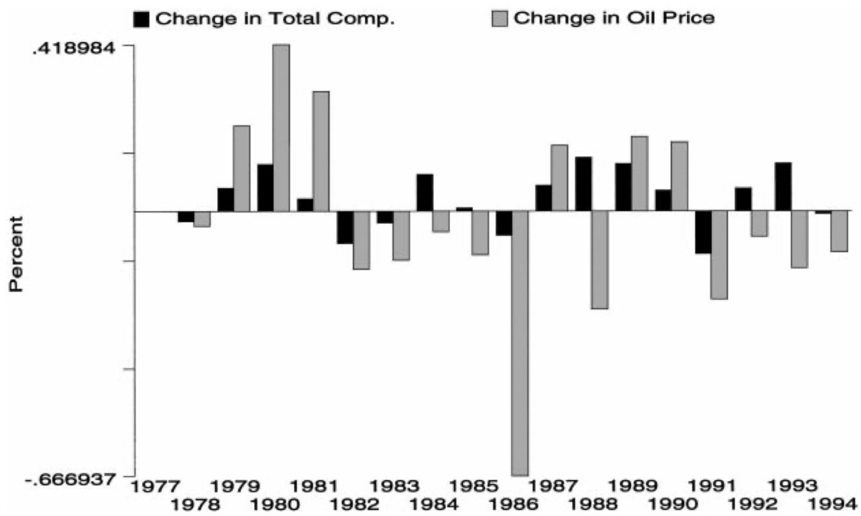



Figure 4: Oil Industry CEO Pay and Crude Oil Price – Extracted from Bertrand and Mullainathan (2001), Fig.3, p. 908.

In a standard contracting framework, the design of incentive contracts aims at mitigating agency friction. Hence, the contract purposely filters shocks in firm performance that are beyond the agent's control (Hölmstrom, 1979). However, there exists evidence that CEO compensation adapts to such exogenous and observable changes. Figure 4 extracted from Bertrand and Mullainathan (2001) presents the yearly change in oil price and the yearly change in CEO pay for oil firms in the Forbes 500 ranking. It shows remarkably how changes in CEO pay in the oil industry is correlated with movements in oil price. Indeed, they argue that shocks in oil price affect the firm performance in that industry. Then, they build a two-stage procedure to extract the impact of observable changes beyond the firm's scope on the firm performance and show that such "lucky events" impact CEO compensation significantly. There is no sufficient evidence to conclude that the general sensitivity of CEO pay to firm performance differs from the sensitivity of CEO pay for luck. Using several measures to assess a *lucky event*, they find that "CEO pay in fact responds as much to a lucky dollar as to a general dollar".

A closer observation of Figure 4 can provide another insight. While every positive yearly change in oil price has led to a positive change in CEO total compensation, only 6 out of 11 yearly decreases in oil price observe from 1977 to 1994 has led to a drop in CEO pay. Garvey and Milbourn (2006) confirm that "executives are rewarded for good luck but not penalized for bad". The authors suggest that the CEO pay sensitivity to bad luck is between 25% and 45% lower than the sensitivity to good luck. They present a potential channel that may explain this phenomenon. If we consider that pay is not entirely determined ex-ante, then the CEO may influence the compensation committee – that proposes, inspects, and approves executives' pay – to alleviate the effect of luck-based loss in compensation. Indeed, they find that weak corporate governance that would exacerbate the CEO's bargaining power intensified the asymmetry of luck on pay.

While previous empirical studies such as Barro and Barro (1990) and Gibbons and Murphy (1990) support that factors exogenous from firms are filtered from the CEO dismissal decision, Jenter and Kannan (2015) provide novel insights. The authors observe all firms in the S&P ExecuComp universe from 1993 to 2009. They find that CEOs are also dismissed based on factors beyond their control. Specifically, the authors show that negative performance shocks at the industry level significantly increases the probability of dismissal. They employ Cox hazard regressions rather than the usual probit model because it is better adapted to the study of firm's and manager's characteristics on the dismissal decision. They find that changes in the industry conditions also affect the risk of dismissal. Moreover, **?** finds a CEO dismissals are more likely to occur when the industry experience high volatility. They also suggest that CEOs receive a premium for bearing such a dismissal risk. Hence, the recent empirical literature supports that factors beyond the agent's control impact forced dismissal decision and compensation.

The work of Hoffmann and Pfeil (2010) conciliates optimal contracting with the empirical evidence that exogenous changes impact the executives' contract. The authors build upon DeMarzo and Sannikov (2006) and study an optimal dynamic contracting model where the agent can divert cash flows and consumes a fraction of the diverted cash flows out of the principal's sight. The novelty is to consider the occurrence of a persistent and observable shock on the mean of the firm's cash flows that is beyond the agent's control. They show that it is optimal to adopt the provision of incentives to the advent of such a shock. The intuition is that a positive shock on the firm's profitability makes the contract termination relatively less efficient, so it is optimal to lessen the threat of dismissal. Contrary to conventional wisdom, they show that firms should not hedge against these exogenous changes even if they worsen the firm's profitability. Rather, firms should smooth the changes from one state of the world to the other. This leads the agent to be rewarded when a positive shock occurs. From a methodological perspective, the agent's expected wealth is no longer the sole descriptor to entirely determine when the agent gets paid, when the contract terminates, and the firm value from the shareholders' perspective. Here, the jump process that persistently changes the mean of the firm's cash flow is also a relevant state descriptor.

Piskorski and Tchistyi (2010) offer the same insight than Hoffmann and Pfeil (2010) in the context of interest optimal mortgage design with rate jumps. Demarzo et al. (2012) also offers an interpretation of the reward for luck in the context of the firm's financial slack. When the shock occurs and the firm jumps in a *good state of the word*, it is optimal to raise the available slack. They find that the optimal contract is implemented with derivative instruments or convertible debt.

For now, we have mainly reviewed factors affecting CEOs and top executives, setting aside a large number of other factors affecting contractual relationships. In the following section, we present which factors impacting labor have been studied in the literature. Then, we will examine in detail technological change that appears to be the most prominent factor. Finally, we will discuss how the advent of automation technologies can studied in theoretical models.

# 4 The adaptation of labor to changes

According to the literature, there exist multiple factors that impact labor. First, the literature has investigated the consequences of globalization on the labor market (see Rama (2003) for an overview of the literature). While opening up to new markets and expanding new industries may bear prosperity in developing countries, offshoring has also been a source of much concern in developed countries. Wood (1995) shows that such a concern is justified and that the outburst in the offshoring decision has increased the inequality of the labor market in developed countries. However, it is noteworthy that cost reduction is not the sole reason for such a decision. In particular, Lewin et al. (2009) show that the scarcity of high-skilled workers is an important determinant of offshoring decisions in the U.S.

Second, the impact of labor market institutions on employment has also been studied extensively. According to Blau and Kahn (1996), "labor market institutions, chiefly the relatively decentralized wage-setting mechanism in the U.S. compared to other countries, appear to provide the most persuasive explanation for these international differences in [wages]". However, Nickell and Layard (1999) moderate the differences in labor market institutions across countries on employment. For instance, they find that stricter employment protection does not necessarily lead to higher unemployment. Also, generous unemployment benefits do not generate unemployment if active labor market policies move people from welfare to work.

Lastly, there is a consensus that technological change is the most prominent factor that affects labor (Goos et al. (2014)). This is not new and technological change has raised academic awareness for decades. Indeed, Keynes (1930) has foreseen that the adaptation of the labor market to technological progress would have negative consequences and claimed that "we are being afflicted with a new disease of which some readers may not have heard the name, but of which they will hear a great deal in the years to come – namely, technological unemployment". In 1952, Leontief shared Keynes' concerns, predicting that "more and more workers will be replaced by machines". While the worst is never certain, the impact of technological change over the last century has not been as tragic as these authors anticipated. However, labor will have to adapt to the recent advent of automation technologies in the near future. Such technologies able to enhance and to substitute worker has exacerbated political and social tensions recently.

## 4.1 Skill-biased and routinization-biased technological change

Tinbergen (1974, 1975) pioneering work on the "race between technological development and access to education" have paved the way for understanding how technological change has impacted workers heterogeneous in skill. His hypothesis of a *skill-biased technological change* (SBTC) is that the technological change increases the relative wages and demand for educated individuals – and so high-skill jobs – compared to the non-educated individuals. Numerous works test this hypothesis and show that it has a strong explanatory power in the U.S. job market (see Carneiro and Lee (2009), among others) and cross-country differences (Fitzenberger and Kohn in 2006 , Atkinson and Castro in 2008 , among others). This hypothesis is even confirmed by Goldin and Katz (2008) for the entire twentieth century in the U.S.

Nevertheless, Goos et al. (2014) state that "in spite of its success in explaining many decades of data, however, SBTC cannot explain the recent phenomenon of job polarization". Autor, Katz, and Kearney (2006,2008), Autor and Dorn (2013), and Goos and Manning (2007) document this phenomenon. Indeed, according to Acemoglu and Autor (2011), SBTC "treats technology as exogenous and typically assumes that technical change is, by its nature, skill-biased. The evidence, however, suggests that the extent of skill bias of technical change has varied over time and across countries".

Then, Autor et al. (2003) (see also Autor (2013) for an overview of the literature) make the hypothesis of the *routinization-biased technological change* (RBTC). It is also referred to as a *task-based approach*, as it assumes that information and computer technologies (ICT) both substitute for routine tasks and enhance the non-routine tasks. As "routine does not map simply into a one-dimensional definition of skill" ( Goos and Manning 2007), it implies that the polarization of the job market is due to the relatively high degree of the routinization of middle-skill occupations compared to others. According to Autor et al. (2003), the routinization may explain up to 40% of the observed relative demand increase that favors high-skill jobs between the early 1970s and the late 1990s. Following this work, Feng and Graetz (2015) show that before the emerge of ICT, the introduction of the steam engine and the electric motor has also lead to job polarization. Michaels et al. (2014) have successfully tested the RBTC hypothesis among eleven OECD countries and over 25 years. Overall, the RBTC hypothesis performs better than the SBTC hypothesis at explaining more recent empirical observations.

In the following section, we present how technological change has led to labor market polarization.

## 4.2 The hollowing-out of the employment distribution

The polarization of the job market refers to the relative growth in the number of individuals at the tails of the employment distribution, compared to the number of individuals in the middle. It is characterized by an "hollowing out" pattern on the employment distribution, as seen in Figure 5 that is extracted from Autor (2013). This phenomenon is widely documented in economics, with evidence found on the polarization regarding the distribution of individuals both in terms of skill – as in Figure 5 – and also in terms of wages. As the literature shows, this is not a recent phenomenon. Indeed, Siegel and Barany (2017) document the job market polarization since the 1950s. Also, Goldin and Katz (2008) show that different dynamics governed wages one after another during the past century. They observe a narrowing of the wages from 1910 to 1950. Wages were then stable in the 1950s and 1960s, increasing rapidly during the 1980s and polarizing afterward.

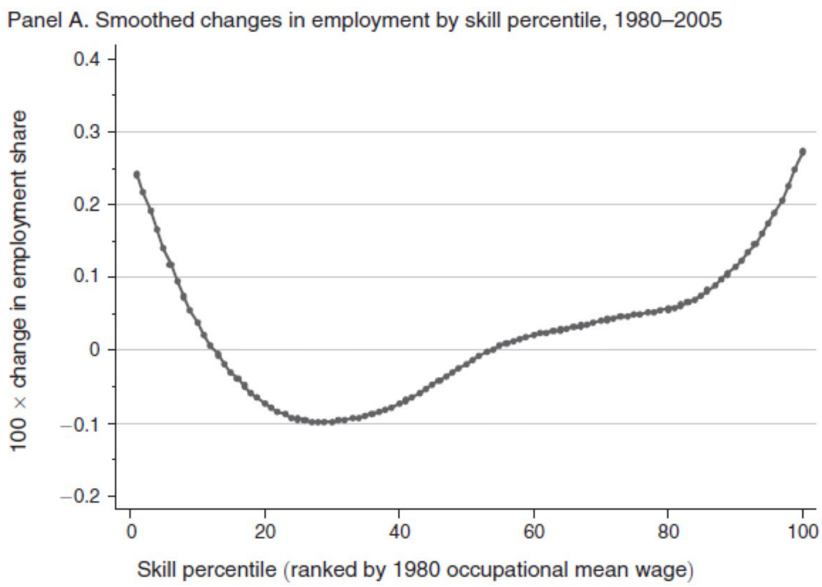



Figure 5: **Polarization of the labor market based on skill – Extracted from Autor and Dorn (2013)** This figure depicts the polarization of U.S. employment between 1980 and 2005. It shows that during this period, the relative growth in demand of both low-skill and high-skill occupations compared to medium-skill occupations.

## 4.3 The automation of high-skill workers

However, these hypotheses fail at providing theoretical predictions in line with recent empirical observations, and it remains puzzling why different agents homogeneously skilled are impacted differently by the advent of robots. Furthermore, there is little work investigating the impact of the advent of automation technologies on high-skill jobs, while it is "about to become a potent force in the U.S. labor market" (Acemoglu and Restrepo (2018)). According to a recent study by McKinsey[4], the current state of the technology enables the automation of a large part of activity exerted by "even those in the highest-paid occupations (for example, financial planners, physicians, and senior executives)". Several striking illustrations of this phenomenon have been offered recently. One of them concerned BlackRock, currently the world's largest

[4] *The transformative power of automation in banking*, McKinsey 2017

asset manager, that decided in 2017 to "change its ecosystem"[5] according to its CEO Laurence D. Fink. As a result, 13 % of the portfolio managers were dismissed and replaced by stock picking algorithms.

Acemoglu and Restrepo (2018b) analyze why modeling automation as a substitution device is "both descriptively realistic and leads to distinct and empirically plausible predictions". They argue that the standard approaches used in the literature to model technological change and employed to study automation (namely, factor augmenting automation or capital-augmenting automation) cannot embed the essential feature of such class of technology: the displacement effect generated by automation over jobs previously performed by humans (Acemoglu and Restrepo, 2019). Indeed, they show that modeling automation (1) as a capital-augmenting technology may rather increase human-labor demand and wages, and (2) as a labor-augmenting technology only decreases the labor share for unrealistic parameter values. They offer to model automation at an extensive margin with a task-based approach à la Autor and Dorn (2013). Here, the set of tasks that can be automated expands over time. It contrasts with the study of automation at the intensive margin, where the machine's efficiency at performing the task improves over time. Under such a setting, automation reduces the demand for human workers, and they can offer novel insights on the impact of the automation technologies' advent. First, the technologies that reduce the most the demand for labor are those "just productive enough to be adopted but not much more productive or cost-saving than the production techniques that they are replacing". Second, they stress the importance of the emergence of tasks to counterbalance the effect of automation on demand for human labor.

The literature also includes Thuemmel (2018), who study the taxation of robots that substitute for routine labor and complement non-routine labor. He shows that it is optimal to distort robot adoption. However, robots may be either taxed or subsidized. Indeed, taxation of robots decreases wage inequality at the top of the wage distribution but increases inequality at the bottom. Grennan and Michaely (2020) show that security analysts may leave the profession due to the advent of automation technologies.

[5] https://www.nytimes.com/2017/03/28/business/dealbook/blackrock-actively-managed-funds-computer-models.html

# 5 Research Question and presentation of the three papers

In principal-agent models, the principal designs an incentive-compatible contract that maximizes the value generated by the project throughout the delegation, and in-depth changes in the contractual environment play a significant role. In this thesis, we focus on two of these changes : (1) the advent of automation technologies able to substitute or enhance the agent, (2) new regulations that limit the agent's ability to benefit from the cash-flow diversion. These have in common that they can be modeled as a persistent shock out of the scope of both the agent and the principal and that their presence is verifiable. Indeed, while automation technologies are developed and launched by third parties, new regulations are implemented by the authorities.

Thus, this thesis poses the following research question :

**To what extent exogenous and persistent shocks in the contractual environment affect the provision of incentives?**

This question has multiple dimensions, namely :

1. technical dimension: how can such shocks be incorporated into a principal-agent model?
2. cognitive dimensions: How does the information available to agents evolve? How do decision-making processes change?
3. policy aspect: How does a policy targeting the executive's misbehavior affect the incentive provision?

We address this question through three original and complementary papers. The first two studies are theoretical and build upon the seminal model of DeMarzo and Sannikov (2006), where we embed a persistent shock out of the scope of both the agent and the principal. The third study is empirical and aims at investigating the effect of the regulation on compensation packages on the agent's dismissal decision. While our two theoretical papers are related to the first two dimensions, the third empirical study discusses the third aspect.

In the first paper, we study how an agent's incentives evolve at the emergence of A.I. and robots. The usage of automation technologies provokes passionate debates in our society and is expected to replace many workers in a large number of industries (see, e.g., Brynjolfsson and Mcafee, 2014, or Ford, 2016). However, the interaction between the emergence of automation technologies and the provision of incentives remains unclear. We set our analysis in the context of asset management, where automation is already pervasive after an outburst in the adoption of such technologies in 2017. During that year, the advent of automation technologies has led both industry incumbents such as BlackRock to "change of ecosystem"[6], and the emergence of new actors such as EquBot that uses IBM's Watson A.I. for fund management.[7] It is noteworthy that BlackRock foreseen how technology would impact the occupations in the asset management industry in a white paper released in 2014.[8] However, we note that while they claimed that " technology supports decision-making, [and] investment professionals make the actual investment decisions", the adoption of algorithm in 2017 actually led to the dismissal of seven of the firm's 53 stock pickers. In this context, we study a principal-agent model where the delegation of asset management to an agent is subject to moral hazard and will become automatable at an uncertain time. We analyze how incentives adjust to the availability of such technology and show that automation impacts the agent since the contracting date.

The second paper aims to understand how changes in the firm's regulatory environment impact the provision of incentives. We focus on regulations such as mandatory compensation disclosures that arguably alleviate the agent's misbehavior. While Hermalin and Weisbach (2012) say about disclosure that "if management has any bargaining power, then it will capture some of the increased benefits via greater compensation", the adaptation of an optimal contract to changes in the mandatory compensation disclosure remains unclear. We explore a continuous-time principal-agent model where the agent can divert cash flow out of the owner's sight and where a new disclosure impacts the benefit of cash-flow diversion. We analyze how the provision of incentives adapt to such shocks, exogenous from the firm performance.

In the third paper, we continue the previous investigation with an empirical study. We analyze the Compensation Discussion and Analysis introduction, which is the largest reform to pay disclosures since 1992 (Yeaton (2007)). We focus on how this reform has impacted the dismissal decision in S&P 500 non-financial firms. This study complements the prior literature, as there exists already empirical evidence that exogenous shocks at the industry level impact the dismissal decision. However,

[6] https://www.nytimes.com/2017/03/28/business/dealbook/blackrock-actively-managed-funds-computer-models.html

[7] https://www.sec.gov/Archives/edgar/data/0001467831/000089418917005486/etfmg-aipowered_497k.htm

[8] https://www.blackrock.com/corporate/literature/whitepaper/viewpoint-asset-management-technology-aug-2014.pdf

none have documented that changes in the regulatory environment that affect CEO pay are also considered when making the dismissal decision.

## 5.1 First study: will asset managers survive the advent of robots? An optimal contracting approach

The first study investigates the adoption of automation technology in asset management. We build a principal-agent model in continuous time à la DeMarzo and Sannikov (2006) in which delegation of asset management to an agent is subject to moral hazard. The novelty is that the delegation will become automatable at an uncertain time. While the characteristics and the advent of automation technology are exogenous and publicly observable, automation may not be as efficient as the agent. Hence, it raises several questions: How to integrate the foreseen advent of automation technology into the agent's and the principal's objective functions? When is it optimal to substitute the agent for the robot? To address these questions, we derive an optimal long-term contract and show that the provision of incentives adjust to the availability of such technology so that automation impacts the agent since the contracting date. Our model suggests that the empirically observed layoffs that accompany the emergence of automation technology may have a contractual foundation. We provide several testable implications on the impact of the emergence of automation technologies on the bonuses and the contract duration.

## 5.2 Second study: mandatory compensation disclosure and CEOs dismissal decision

In the second paper, we explore how changes in the agent's ability to divert cash flow impact an optimal contract design. It illustrates the expansion of mandatory disclosure of CEO compensation. We build a continuous-time principal-agent model where the agent can divert cash flow out of the owner's sight. While it is straightforward that mitigating the agency friction is valuable for the firm's owner, its effect on the provision of incentives throughout the contractual relationship is unclear. First, our result suggests that the compression of the bonuses at the advent of the shock: the reduction (respectively, increase) of the expected bonus of good (respectively, poor) performers. Second, our analysis also predicts the regulation-induced retention of a poor performer, defined as maintaining an agent in place while his poor performance would have induced his dismissal in the absence of the shock on the benefit of cash-flow diversion.

### 5.3 Third study: The effect of incremental mandatory compensation disclosure on the dismissal decision

In the third paper, we investigate the impact of the expansion of mandatory compensation disclosure on the agent's dismissal decision. We analyze the Compensation Discussion and Analysis (CD&A), introduced in 2006 for the 2007 proxy season, and that is the largest reform to pay disclosures since 1992. We find that the introduction of the CD&A act has significantly reduced the probability of forced CEO dismissal in S&P 500 non-financial firms. While prior literature has shown that exogenous shocks at the industry level impact the dismissal decision, we document that changes in the regulatory environment also matter.

## 6 Conclusion of the introductory chapter

In the presence of agency friction, the principal only observes the firm's output to infer the agent's quality or strategy. In this context, standard contracting theory suggests that incentives should filter all exogenous shocks before assessing the agent's performance at managing the firm. However, empirical evidence rejects this result and instead suggests that factors out of the agent's scope also impact the provision of incentives.

Following a review of the theoretical literature that explores optimal contracts in the presence of agency friction, we have presented the evolution over time of the two typical contractual characteristics, namely the agent's compensation and dismissal. We have discussed the main determinants of the changes in these characteristics and how these characteristics are impacted by new regulations and exogenous factors beyond the agent's scope. Third, we have broadened our exploration and presented the main determinants of changes in the labor market. We have investigated how technological change is conceptualized, which is considered an essential factor that impacts labor. Then, we have presented models that assess the impact of automation technologies on substituting for human labor.

This exploration raises the question of how exogenous and persistent shocks affect the provision of incentives. We address this question in three original and complementary papers. Our first two papers build upon dynamic contracting that offers a comprehensive theoretical framework to address this concern. Our last paper presents empirical evidence that new regulations that aim to mitigate the agent's benefit of cash-flow diversion impact the CEO dismissal decision.

In the first paper, we study how an agent's incentives evolve at the emergence of automation technologies that can replace asset managers. Indeed, the interaction between the emergence of such technologies and the provision of incentives is unclear. We analyze how incentives adjust to the availability of such technology and show that automation impacts the agent since the contracting date.

The second paper aims at understanding how a negative shock on the agent's ability to divert cash flow affects the provision of incentives. We provide novel insights on how regulation that alleviates the agent's misbehavior may benefit poor performers.

In the third paper, we continue the previous investigation in an empirical study on adopting new regulations on mandatory compensation disclosure. Specifically, we analyze the Compensation Discussion and Analysis introduction, which is the largest reform to pay disclosures since 1992 (Yeaton, 2007). We focus on how this reform has impacted the dismissal decision in S&P 500 non-financial firms. We provide empirical evidence that fewer dismissals occur after the introduction of the regulatory act.

The remainder of this thesis is composed of four chapters. Chapters 2, 3, and 4 correspond to the three studies. Chapter 5 is devoted to the thesis's conclusion, contains a summary of the main results, highlights its main contributions and limitations, and presents avenues for further research.

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# 7 Summary of Chapter I

Modigliani and Miller's capital structure irrelevance principle states that financing decisions do not affect firm value in an idealized world without financial frictions. However, if we consider the real world, things are different. In particular, the separation of ownership and control may generate agency friction because the manager's objectives are not aligned with those of the owner. In standard principal-agent models over an infinite horizon, the provision of incentives is twofold: a performance-based compensation that divides cash flows between the principal and the agent, and the threat of dismissal. However, it is noteworthy that these elements have evolved over time. While factors withing the relation (the nature of the relation, firm-specific factors, manager-specific factors) may explain such changes, there exists empirical evidence that other factors in the contractual environment induce them. The literature have found that factors at the industry level, at the market level, and at the regulatory level may affect the contractual relationship. In particular, empirical studies suggest that incentive contracts adapt to exogenous and persistent changes. Lately, a new source of changes has emerged and has raised many concerns about the future of labor: the technologies of automation. In the light of these observations, we explore in this thesis three complementary and original papers that study how exogenous and persistent shocks affect the provision of incentives. After an overview of the literature, we have stated the main research question that guides this thesis, and we have presented our three articles.

# Chapter II

# Will Asset Managers Survive the Advent of Robots? An Optimal Contracting Approach

**Abstract**

In this paper, we study the adoption of automation technology in asset management. We build a principal-agent model in continuous time in which delegation of asset management to an agent is subject to moral hazard and will become automatable at an uncertain time. While the characteristics and the advent of the automation technology are exogenous and publicly observable, automation may not be as efficient as the agent. We derive an optimal long-term contract that adjusts the provision of incentives to the availability of such a technology so that automation impacts the agent since the contracting date. Our model suggests that the empirically observed layoffs that accompany the emergence of an automation technology may have a contractual foundation. We provide several testable implications on the impact of the emergence of automation technologies on the bonuses and on the contract duration.

# I. Introduction

It is widely recognized that automation technologies are about to replace many high-skill workers in the years to come (see, e.g., Brynjolfsson and Mcafee, 2014, or Ford, 2016). However, there is currently "no clear consensus on how automation should be conceptualized and modeled" according to Acemoglu and Restrepo (2018b). We claim that contract theory can offer a comprehensive theoretical framework to address this concern, especially when the presence of agency friction and the opportunity to automate interact.

In this paper, we focus on the asset management industry, where automation's benefit is apparent. Indeed, both economists and practitioners acknowledge that strong incentives are necessary to motivate asset managers because this industry suffers from severe agency frictions (Ben-David, Birru, and Rossi (2020)). In this context, we examine the following fundamental economic questions: How to design an optimal contract that embeds the advent of the automation technology? How does such a contract incentivize the agent? When does the investor decide to automate?

To answer these questions, we build a principal-agent model in continuous time. We consider that a representative investor (hereafter, a principal) delegates the long-term management of an asset to an agent (hereafter, also referred to as an asset manager), and that such a task will become automatable by a technology (hereafter, a robot) at an uncertain time. A moral-hazard problem arises due to the unobservability of the agent's effort at managing the asset. To align the objectives of both parties, the principal offers to the agent a long-term contract under full commitment.

As it is standard in dynamic contracting models, the principal provides incentives to the agent both (i) by deferring compensation, so lump-sum payments are given only when the agent has performed sufficiently well, and (ii) by the threat of terminating the contract after the observation of too many bad outcomes. The novelty of our model is that at the contracting date, the advent of an automation technology (hereafter a robot) capable to replace the asset manager is foreseen. We assume that both parties take as given the characteristics and the arrival time of the robot, so the development of such a technology is not internalized.

Using this model, we show that the principal adjusts the provision of incentives according to the availability of automation, so that the contract is impacted by this opportunity even before it emerges. It entails leniency for bad performance prior to the emergence of the technology, so it alleviates the risk of contract termination at this stage when no valuable alternative to the agent exists. The principal then reassesses delegation to the agent when the automation technology becomes available, which puts the agent at greater risk of termination in this new contractual environment. This leads to the agent's instantaneous automation if he has not performed sufficiently well until the technology emergence. It is noteworthy that such an adjustment of the provision of incentives increases the contract's overall efficiency but does not alter its incentive compatibility to induce effort. The foreseeable nature of the automation technology in our model lets us then generate multiple implications.

Our main prediction is the "performance-biased automation" of asset managers, i.e., the impact of the advent of technology on the contract depends on the agent's history of performance of managing the asset. This prediction offers a potential explanation of BlackRock's decision to substitute A.I. algorithms for 7 out of their 53 stock pickers in 2017.[1] According to its CEO Laurence D. Fink, BlackRock automated stock pickers because it had to undertake a necessary "change [of] ecosystem", yet (i) it seems puzzling why a significant part of the team was replaced by technology at once, and (ii) the criterion used to make the decision remain unknown. Our model suggests that Blackrock has lessen the risk of contract termination of the stock pickers prior the emergence of the technology, only to substitute technology in place of the agents who did not perform sufficiently well up until the technology advent. We also predict that the bonuses of the remaining stock pickers should decline afterward and that BlackRock did not substitute technology for 100% of stock pickers because technology was not yet as efficient as the agent at managing the asset. Furthermore, the 2018 *asset management compensation study* by Greenwich Associates documents a drop in the annual bonuses in the industry. Its authors claim that the large cost of investment in automation technologies is "eating out" of the compensation pool of asset managers. Our optimal contracting approach offers an alternative explanation. We show that even in absence of cash constraints, the adjustment of the provision of incentives that puts the agent more at threat of termination following the emergence of the technology lets the principal reduce the payments

[1] https://www.nytimes.com/2017/03/28/business/dealbook/blackrock-actively-managed-funds-computer-models.html

to the agent. Consistent with Philippon (2018), the emergence of *fintech* innovations (such as automation technologies) may then decrease the cost of financial intermediation, even when agents are remaining active.

We also derive several cross-sectional implications. If the automation technology is more profitable to the principal, then the agent must be more sensitive to its emergence. This worsens the decline in bonus following the advent of robots and accelerates the automation of asset management. Hence, the better adaptation of a firm in the asset management industry to the forthcoming automation technology – that makes automation more valuable – is associated with (1) a larger decline in compensation following its emergence and (2) a shorter implementation lag (the time interval between the emergence of the technology and its adoption). According to Brynjolfsson, Rock, and Syverson (2017) the implementation lag is the main reason we do not observe a more significant contribution of A.I. in the economy. Our testable predictions may help understand the difference in firms' responses to the emergence of automation technology in the asset management industry. We also derive a testable prediction on how the time elapsed since the contracting date impacts the agent's propensity to be automated. We show that the probability of being automated is hump shaped (increasing over the first years of the contract, and then decreasing ) when the value of automation is low, and decreases over time otherwise. This is consistent with the observation made by Acemoglu and Restrepo (2018) as they show that middle-aged workers are the most automated.

When no automation technology is foreseen, the baseline model is à la DeMarzo and Sannikov (2006) with effort[2]. Indeed, our optimal contract after the advent of robots is similar to that derived in the cited paper. To solve our problem at the contracting date, we adopt the method introduced by Sannikov (2008) in the context of principal-agent models and based on the martingale optimality principle. Both (i) the asset manager's continuation value (the total value the manager expects to obtain from a contractual relationship) and (ii) the process that accounts for the advent of the automation technology are relevant state processes. The principal controls the sensitivity

[2]Although DeMarzo and Sannikov (2006) build a cash-flow diversion model, they extend the setting to a hidden binary effort choice in Section 3. The authors show that both models lead to the same optimal contract.

of the agent to these processes to achieve optimality. As the technology emergence changes the profitability of terminating the contract, it is optimal to make the agent sensitive to the advent of a robot.

Unlike the case of standard dynamic contracting models without a persistent shock such as that of DeMarzo and Sannikov (2006), the implementation of an optimal contract cannot be achieved through standard securities, but rather through a point-based incentive programme that features the expiration of a number of points at the advent of technology. This number of points traces the agent's continuation value that (1) fluctuates with the asset's performance and (2) is sensitive to the advent of the automation technology. After sufficiently good performance, some points can be redeemed and thus converted into lump-sum payments. In accordance with the contract signed at date 0, a fraction of the points owned by the asset manager expires at the advent of the automation technology, and the contract is terminated as soon as the manager holds no more points in the programme. We note that compared to a scenario where the agent cannot be made sensitive to the advent of robots, such a programme makes more payments in the state of the world where there is no valuable alternative, i.e. before the advent of robots.

We acknowledge that it may be difficult to enforce a contract contingent on a forthcoming automation technology. On the one hand, its advent can be considered industry-wide and thus observable, and for instance Frey and Osborne (2017) rank occupations by their propensity to be automated. On the other hand, the value of implementing a robot-driven process is harder to assess because it is probably firm-specific[3], as suggested by Brynjolfsson et al. (2017). Consequently, it may not be verifiable by a third-party, e.g., a judge. Hence, we also discuss the situation where it is impossible to make the agent sensitive to the advent of technology, while such an exogenous event still occurs.

Finally, we extend our model to examine richer settings. First, we let the principal invest prior to the contracting date to increase the value of the forthcoming automation technology. This may be interpreted as a complementary investment and structural changes that are a prerequisite to an efficient usage of artificial intelligence according to Brynjolfsson et al. (2017). There also

[3]We assume that the principal takes the value of automation as given in our main model.

exists evidence that the asset management industry participates directly in the innovation process – that may lead to the advent of the automation technology – through investments in fintech[4]. We show that, if the automation technology is more efficient than the agent at managing the asset, then we can separate the investment problem and the contracting problem. Consequently, (1) the contracting problem does not distort the level of investment compared to the first-best investment scenario, and (2) both the investment decision and the contract do not interact.

Second, we extend our model and assume that after the technology emergence, the principal can either replace the agent as in the main model, or enhance the agent's productivity, both alternatives being mutually exclusive. This extension suggests the *hollowing out* of asset managers given their performance. Indeed, the continuation value of poor performers decreases to put them at a greater risk of termination and the one of the good performers increases to put them at a greater chance of enhancement at the technology advent. Consequently, the propensity of the advent of automation technology to polarize jobs may have a contractual foundation. In the literature, Autor and Dorn (2013) studies the skill-related polarization due to technological change, while Goos and Manning (2007) and Goos, Manning, and Salomons (2014) investigate the task-based approach, so routine jobs are more at risk of automation. Our theoretical framework would suggest to test for the performance-biased polarization of high-skill workers.

Our study is closely related to those of Hoffmann and Pfeil (2010), Demarzo, Fishman, He, and Wang (2012) and Li (2017) who theoretically investigate how an exogenous shock to the agent's profitability impacts the optimal compensation. They show that the agent's continuation value reacts instantaneously to lucky events and that *rewards for luck* are part of the optimal compensation scheme. This is consistent with the findings of Garvey and Milbourn (2006), Bertrand and Mullainathan (2001), and Francis, Hasan, John, and Sharma (2013) who show that exogenous events significantly impact the compensation of CEOs and VPs. In contrast, we study an exogenous shock to the contract's termination value, where the automation technology can be regarded as a real option held by the principal. Consequently, we also look for the optimal time to implement the technology. It turns out that it is optimal to wait for the manager's continuation value to reach

[4]See Boston Consulting Group's study "Fintech in Capital Markets: A Land of Opportunity", 2016

the fixed termination boundary before implementing the robot. However, the principal may design the contract so that poor performers would see their continuation value drop to zero instantly with the advent of the automation technology.

He (2009) also builds on DeMarzo and Sannikov (2006) but specifies that the cash-flow process follows a geometrical Brownian motion, so changes in firm size generate incentives. Gryglewicz, Hartman-Glaser, and Zheng (2019) present a model where a firm is managed by a risk-averse agent and where the principal holds a growth option. The agent's risk aversion implies compensation for bearing risk. The study of a growth option is relevant in the author's framework as the cash flow process follows a geometric Brownian motion, so the firm size matters. Grenadier and Wang (2005) study a model with an investment option that encompasses both a moral hazard and adverse selection. They show that the agency problem leads to a postponement of the investment decision made by the agent.

Finally, our study tries to bridge the gap between the literature on the contracting theory and that on labour economics, where the impact of automation on jobs is broadly investigated (see Acemoglu and Autor (2011) for an overview of this literature). Consistently with the model of Acemoglu and Restrepo (2018b), we capture the impact of automation "at the extensive margin" as a single task – namely, asset management in our model – becomes at risk of automation. While it is well known in agency theory that contracts are contingent on their environment, there is a consensus in labour economics on the prominent role of technological change in the shape of wages and in polarization of the job market. To the best of our knowledge, no study examines however the interaction between the presence of financial frictions (such as the firm's cash constraint or agency friction) and automation. A body of the literature investigates the propensity of different kinds of jobs to be automated (see, e.g., Frey and Osborne (2017), Arntz, Gregory, and Zierahn (2016)). Another stream of paper (e.g., Autor and Dorn (2013), Goos and Manning (2007), Goos et al. (2014)) adopts the task-based approach introduced by Autor, Levy, and Murnane (2003), and assumes the current substitutability of robots for routine tasks while in our paper we investigate the foreseen "computerisation in a non-routine task" (Frey and Osborne (2017))[5]. Among several

[5]Others approaches to model automation include a factor-augmenting technological change (e.g.,human-augmenting change as in Bessen (2017)) or capital-augmenting technologies in Graetz and Michaels (2018)).

studies, Acemoglu and Restrepo (2020) follow this approach and develop a general equilibrium model to estimate the impact of robots on wages and employment in the U.S. labour market.

This paper is divided into five sections. Section 2 provides an overview of the model and solves for the first-best benchmark. We solve for an optimal contract in Section 3. Section 4 presents an implementation of the optimal contract and empirical implications. In Section 5, we offer two extensions of our main model.

# II. Model

We build upon a principal-agent model in continuous time *à la* DeMarzo and Sannikov (2006) with effort. We investigate the problem of a representative investor (hereafter, the principal) who delegates the management of an asset to an agent (hereafter, also referred to as the asset manager) who may face the risk of automation with a forthcoming technology. While the relationship is subject to moral hazard, the implementation of automation technology (hereafter, the robot) irreversibly substitutes technology for the agent and thus terminates the agency friction. The principal has unlimited wealth, and the agent is protected by limited liability. Both parties fully commit to a long-term contract that characterizes the terms of the relationship. First, we present the agency problem where the agent's effort impacts the dynamics of the asset value. Second, we describe the technology that can replace the agent. Then, we formulate the principal's problem and solve for the first-best scenario. Finally, we describe the set of incentive-compatible contracts that satisfies the limited liability condition.

## *A. Agency Problem*

If the principal delegates the management of the asset to the agent, a moral hazard problem arises due to the unobservability of the agent's effort $a_t \in \{0; \bar{a}\}$ applied to control the performance of the asset.[6] Specifically, the value of the asset under the agent's management, and which is

[6] At each instant, the agent either exerts effort ($a_t = \bar{a}$) or shirks ($a_t = 0$).

observable by the principal, evolves according to the dynamics

$$dX_t = a_t \mu dt + dZ_t^a \tag{1}$$

where $\mu$ is a positive constant that accounts for the asset's specific parameter of profitability, and $(Z_t^a)_t$ is a Brownian motion. Details on the probabilistic background of the model are provided in the appendix B. Shirking by the agent obviously has a negative impact on the value of the asset under management, and lets the agent receive a private benefit $Bdt$, where $B$ is a positive constant. In our setting, the principal is risk-neutral, and we denote by $r > 0$ the principal's discount rate.

## *B. Automation Problem*

While we do not initially consider any competitor to the agent, both parties foresee prior to the contracting date the advent of the automation technology that can manage the asset and thus replace the agent. Such a technological change impacts the contractual environment,[7] and we anticipate based on the existing results in contracting theory[8] that the characteristics of the optimal contract are contingent on this shock.

Let us assume that the robot becomes available at a random time denoted by $\tilde{T}$, and the principal can then decide to automate the management of the asset at any time. The termination of the agent's contract is a prerequisite, and the substitution is assumed to be irreversible. Thus, the automation technology can be regarded as a real option. According to Acemoglu and Restrepo (2018b), modelling automation as an irreversible substitution device is "both descriptively realistic and leads to distinct and empirically plausible predictions".

We study automation at "the extensive margin"[9], so the single task in this model – asset

[7]There is a consensus in labour economics that technological change is a prominent cause of changes on the job market (see,e.g.,Acemoglu and Autor (2011)).

[8]see, e.g., the papers on reward for luck such as Hoffmann and Pfeil (2010) and the extension of Demarzo et al. (2012).

[9]Alternatively, we could model automation "at the intensive margin", where the ability of the robot to manage assets would improve over time. In this setting, a Poisson process could model the dates of technological change. While it makes the model more complex, we claim that our main results are robust to such a change.

management – will become automatable. We assume that the advent of technology able to replace the agent follows a single-jump process $N = \{N_t\}_{t\geq 0}$ with intensity $\lambda$.[10] Specifically, $\lambda dt$ is the probability of the automation technology arising during any time interval $(t, t+dt]$ $\forall t < \tilde{T}$, and such an event will make the process $N$ jump from 0 to 1.[11] We denote by $\mathcal{H} = \{\mathcal{H}_t\}_{t\geq 0}$ the filtration generated by the single-jump process.

Once the principal automates asset management, the asset has a net perpetual profitability of $m\mu dt$ per unit of time.[12] While $\mu$ is the asset's specific parameter of profitability, $m$ denotes the technology-specific parameter that accounts for the automation efficiency. By construction, the principal's expected value associated with a robot-driven asset and observed as of $s \geq \tilde{T}$ satisfies

$$M = \mathbb{E}_{s\geq\tilde{T}}\left[\int_{s}^{+\infty} e^{-r(t-s)}(m\mu dt + dZ_t)\right],$$

where we set $M = \frac{m\mu}{r}$. If the automation technology is available once the principal terminates the contract, it is implemented with no delay. At any date prior to $\tilde{T}$, the principal must wait for the technology's advent, and the principal obtains the following from an expected automation at $\tilde{T}$

$$\frac{\lambda}{\lambda + r}M = \mathbb{E}_{s<\tilde{T}}\left[\int_{\tilde{T}}^{+\infty} e^{-r(t-\tilde{T})}(rMdt + dZ_t)\right].$$

Consequently, the advent of the automation technology at $\tilde{T}$ makes the value of contract termination jump from $M_0 = \frac{\lambda}{\lambda+r}M$ to $M > M_0$.

In our setting, both parties take as given the characteristics and the arrival time of the robot. This describes a situation where the principal does not internalize the development of robots.

[10] We claim that while routine tasks are already automatable (see,e.g.,Autor, Dorn, and Hanson (2013)), non-routine tasks such as asset management will be automatable in the future.

[11] If the agent was instead competing with other high-skill individuals on a scarce job market, then a birth-death process could model the presence of competitors(for a reference in Queuing Theory, see Brémaud (1981)).

[12] Note that switching to a robot-driven asset management may encompass a positive sunk cost, but the principal has unlimited wealth and such a cost can be seen as deterring the perpetual profitability without loss of generality. Furthermore, switching to a robot-driven management does not impact the exposition to the Brownian component.

Hence, the presence of the automation technology does not create a new source of information asymmetry, and thus contrasts with the unobservability of the agent's effort that leads to moral hazard.

## *C. Formulation of the Principal's Problem*

On date 0, the principal offers a long-term contract under full commitment to the agent who may be replaced with a robot in the future. Such a contract $\Pi = \{U;\tau\}$ consists of payments $U = (U_t)_{t\leq\tau}$ and a date of termination $\tau$, which are based on the observed performance of the asset and depend on the advent of the automation technology. Formally, we regard it is as contingent on the total information set that is thus represented by the joint filtration $\mathcal{G}_t = \mathcal{F}_t \vee \mathcal{H}_t$ available to the principal on any date t. Process $U$ is $\mathcal{G}$-adapted, finite, non-decreasing (due to limited liability), and is measured in the same unit as the agent's private benefit. The termination date $\tau$ is a measurable $\mathcal{G}$-stopping time that can be infinite.[13] We assume that the agent is risk-neutral and that the agent discounts at $\gamma > r$, thus being more impatient than the principal. Consequently, the payments to the agent cannot be perpetually postponed in an optimal contract.

Next, we present the agent's value and the principal's value for a given contractual relationship. We fix an arbitrary contract $\Pi$ and the agent's effort strategy $a = (a_t)_t$. We assume that at each instant $t$, the agent's decision on $a_t$ is made prior to the observation of $N_t$ and the realization of $Z_t$, so $(a_t)_t$ is $\mathcal{G}$-predictable. Then, the agent expects to extract from the contractual relationship a total expected payoff[14]

$$\mathbb{E}^a\left[\int_0^{\tau^-} e^{-\gamma t}(dU_t + \frac{B}{\bar{a}}(\bar{a} - a_t)dt) + e^{-\gamma\tau}\Delta U_\tau\right] \tag{2}$$

where $\frac{B}{\bar{a}}$ represents the severity of the agency problem in our model. An effort process $a =$

[13]For instance, Section A3.3 in Daley and Vere-Jones (1989) defines the concepts of adaptability and measurability as well as that of predictability used hereafter for the effort process.

[14]For any two real numbers s and t, we denote by $\int_s^t$ an integral over $[s,t]$ and by $\int_s^{t^-}$ an integral over $[s,t)$.

$(a_t)_t$ generates a unique probability distribution, and we denote by $\mathbb{E}^a$ the associated expectation operator. The long-term contract embeds a terminal payment $\Delta U_\tau = U_\tau - U_{\tau^-} \geq 0$ to let the principal fulfil any remaining contractual promise to terminate the contract. Indeed, there is nothing that prevents the principal from terminating the contractual relationship on any date as long as the principal pays any amount owed to the agent. Afterwards, the agent benefits from an outside option, the value of which we normalize to 0.

The principal's expected value is

$$\mathbb{E}^a \left[ \int_0^{\tau^-} e^{-rt}(a_t \mu dt - dU_t) + e^{-r\tau}(\tilde{M}_\tau - \Delta U_\tau) \right] \tag{3}$$

where $\tilde{M}_\tau = M_0 1_{N_\tau = 0} + M 1_{N_\tau = 1}$ is the value of either waiting for the advent of the automation technology if $N_\tau = 0$ or implementing the robot-driven asset management if $N_\tau = 1$.

An *incentive-compatible* effort process is the agent's best response to a given contract $\Pi$, so it satisfies

$$a^*(\Pi) = \arg\max_a \mathbb{E}^a \left[ \int_0^{\tau^-} e^{-\gamma t}(dU_t + \frac{B}{\bar{a}}(\bar{a} - a_t)dt) + e^{-\gamma\tau} \Delta U_\tau \right] \tag{4}$$

Following the literature's standard approach, we extend this notion and we call $\Pi$ an incentive-compatible contract if it induces the agent to exert effort according to an incentive-compatible effort process $a = (a_t^*(\Pi))_t$.

Hence, the principal's problem is to determine an optimal contract (if it exists), i.e., an incentive-compatible contract that maximizes the principal's value on date 0 and that delivers to the agent the agent's reservation value noted $w_0 > 0$. Formally, this can be formulated as

$$\sup_{\Pi \text{ I.C.}} \mathbb{E}^{a^*(\Pi)} \left[ \int_0^{\tau^-} e^{-rt}(a_t^*(\Pi) \mu dt - dU_t) + e^{-r\tau}(\tilde{M}_\tau - \Delta U_\tau) \right] \tag{5}$$

such that

$$\mathbb{E}^{a^*(\Pi)}\left[\int_0^{\tau^-} e^{-\gamma t}(dU_t + \frac{B}{\bar{a}}(\bar{a} - a_t^*(\Pi))dt) + e^{-\gamma\tau}\Delta U_\tau\right] \geq w_0. \tag{6}$$

Inequality (6) is called the agent's participation constraint.

## *D. First-Best Case : Optimal Contract without Information Asymmetry*

In this section, we focus on the so-called first-best framework, where we relax the information asymmetry. Here, the principal chooses directly the effort process $a^{FB} = (a_t^{FB})_t$ exerted by the agent, and designs a first-best contract $\Pi^{FB} = ((U_t)_t, \tau)$[15] that maximizes the principal's value while providing to the agent at least the agent's reservation value. Hence, this problem can be formulated as

$$\sup_{\Pi^{FB}, a^{FB}} \mathbb{E}\left[\int_0^{\tau^-} e^{-rt}(a_t^{FB}\mu dt - dU_t) + e^{-r\tau}(\tilde{M}_\tau - \Delta U_\tau)\right] \tag{7}$$

such that

$$\mathbb{E}\left[\int_0^{\tau^-} e^{-\gamma t}(dU_t + \frac{B}{\bar{a}}(\bar{a} - a_t^{FB})dt) + e^{-\gamma\tau}\Delta U_\tau\right] \geq w_0. \tag{8}$$

As postponing payments is costly and there is no need to generate incentives in the first-best framework, all payments are front-loaded. We have $U_0 = w_0$ together with $(U_t)_{t>0} = 0$, so the participation constraint is binding.

In the baseline model of DeMarzo and Sannikov (2006) that does not embed the advent of the automation technology, the first-best contract always terminates at $\tau = +\infty$. Here, the principal may be better off terminating the agent's contract if the agent does not perform as well as the robot at managing the asset, which is the case if $m > \bar{a}$, or equivalently $M > \frac{\bar{a}\mu}{r}$. Therefore, we derive a

[15] A first-best contract consists of a stream of payment $(U_t)_t$ and a stopping-time $\tau$ that satisfy the usual conditions provided in section II.C.

first-best contract that stochastically terminates at the advent of the automation technology at $\tilde{T}$ if $M > \frac{\bar{a}\mu}{r}$. The following proposition summarizes our results.

**Proposition** 1: *In absence of agency conflict, the principal's value is*

$$\begin{cases} \frac{\bar{a}\mu}{r} - w_0 & \text{if } M < \frac{\bar{a}\mu}{r} \\ \frac{1}{\lambda+r}\bar{a}\mu + \frac{\lambda}{\lambda+r}M - w_0 & \text{otherwise} \end{cases} \tag{9}$$

*We note that the principal only offers a contract to the agent if it generates a positive pledgeable income, i.e., only if $\frac{\bar{a}\mu}{r} > w_0$ provided that $M < \frac{\bar{a}\mu}{r}$, and if $\frac{1}{\lambda+r}\bar{a}\mu > w_0$ otherwise.*

## *E. Incentive-Compatible Contract with Limited Liability*

In this section, we follow the techniques introduced by Sannikov (2008) in the context of principal-agent models and apply those techniques to characterize the incentive-compatibility effort strategies in the presence of information asymmetry. For now, let us consider an incentive-compatible contract $\Pi$, so the effort strategy $a = (a_t)_t$ satisfies equation (4). Then, we define the agent's continuation value $W^\Pi = (W_t^\Pi)_t$ associated with contract $\Pi$ as

$$W_t^\Pi = \mathbb{E}\left[\int_t^{\tau^-} e^{-\gamma(s-t)}(dU_s + \frac{B}{\bar{a}}(\bar{a} - a_s)ds) + e^{-\gamma(\tau-t)}\Delta U_\tau \mid \mathcal{G}_t\right] \quad \forall t \leq \tau. \tag{10}$$

The agent's continuation value represents the agent's expected earnings on any date. As the stream of payments $(dU_t)_t$ is non-negative and the private benefit is a positive constant, it also holds by construction that $W_t^\Pi \geq 0$ for all $t \leq \tau$. Additionally, we assume that the agent is protected by limited liability, so the contractual relationship has to stop the first time $W_t^\Pi = 0$. In the following lemma, we apply the martingale representation theorem to find a stochastic representation of the agent's continuation value.[16]

**Lemma** 1: ***Representation of the agent's continuation value as a jump-diffusion process*** *There exists a $\mathcal{G}$-predictable pair of processes $(\beta^\Pi, \delta^\Pi) = ((\beta_t^\Pi)_{t\leq\tau}, (\delta_t^\Pi)_{t\leq\tau})$ such that the agent's*

[16]All proofs are provided in the Appendix

*continuation value* $W^\Pi$ *associated with an incentive-compatible contract* $\Pi$ *evolves up to the* $\mathcal{G}$*-stopping time* $\tau$ *with the dynamics*

$$dW_t^\Pi = (\gamma W_t^\Pi - \frac{B}{\bar{a}}(\bar{a} - a_t))dt + \beta_t^\Pi dZ_t^a + \delta_t^\Pi (dN_t - \lambda dt) 1_{t \leq \tilde{T}} - dU_t \qquad \text{for } t \leq \tau \tag{11}$$

*Hereafter,* $\beta^\Pi$ *is called the process of sensitivity to the asset realization, and* $\delta^\Pi$*is called the process of sensitivity to the advent of the automation technology for an incentive-compatible contract* $\Pi$*.*

We interpret the agent's continuation value as a measure of the agent's historical performance at managing the asset for a given contract $\Pi$ and contingent on the availability of a robot capable of replacing the agent. Indeed, Lemma 1 states that while the agent's continuation value grows steadily at the discount rate $\gamma$ up to contract termination, it also depends on the asset realization and the robot's availability. This is a standard feature of dynamic agency models with a Brownian motion and persistent shocks[17]. Specifically, every change in the asset realization due to the Brownian motion $dZ_t^a$ is amplified in the agent's continuation value by a factor of $\beta_t^\Pi$. Additionally, the drift of the continuation value increases by $-\delta_t^\Pi \lambda$ during any time interval $(t, t + dt]$ prior to the advent of the automation technology, while it jumps instantaneously by $\delta_{\tilde{T}}^\Pi$ at such advent. We note that whenever $-\delta_t^\Pi \lambda > 0$, making the agent sensitive to the advent of the automation technology means *boosting* the agent's continuation value and that the term $\delta_t^\Pi (dN_t - \lambda dt)$ disappears from the continuation value's dynamics after the said advent. Furthermore, every time the agent enjoys a private benefit because the contract lets the agent shirk and every time the agent receives a payment, the dynamics of the continuation value decreases. We also remark that if the incentive-compatible contract induces the full-effort strategy $a = (\bar{a})_{t \leq \tau}$, the term $\frac{B}{\bar{a}}(\bar{a} - a_t)dt$ disappears.

Next, we characterize the set of contracts that are incentive compatible. To this end, we apply the martingale optimality principle as introduced by Sannikov (2008) in the context of principal-agent models. It enhances the principal able to enforce implicitly any effort strategy by controlling the pair of sensitivity processes $(\beta^\Pi, \delta^\Pi)$. First, we consider a pair of $\mathcal{G}$-predictable processes $(\beta, \delta)$ , and consider a $\mathcal{G}$-adapted, finite and non-decreasing process $U = (U_t)_t$. This lets us define the

[17]See Hoffmann and Pfeil (2010) and the extension of Demarzo et al. (2012) for models where the agent's profitability experiences a persistent shock.

process $W^\alpha = (W_t^\alpha)_t$, where $\alpha = (\beta, \delta, U)$, with the following controlled stochastic differential equation under $\mathbb{P}^{\bar{a}}$

$$\begin{cases} dW_t^\alpha = (\gamma W_t^\alpha + f(\beta_t))dt + \beta_t dZ_t^{\bar{a}} + \delta_t(dN_t - \lambda dt)1_{t\leq\tilde{T}} - dU_t \\ W_0^\alpha \geq w_0 \end{cases} \tag{12}$$

The following lemma characterizes incentive-compatible contracts as a function of the process of sensitivity to the asset realization $\beta$ that is controlled by the principal.

**Lemma** 2: ***Incentive compatible contract***

*For a given pair of $\mathcal{G}$-predictable processes $(\beta, \delta)$ and for a given $\mathcal{G}$-adapted, finite and non-decreasing process $U = (U_t)_t$, a contract that induces effort on date $t$ $(a_t = \bar{a})$ if $\beta_t \geq \frac{B}{\bar{a}}$ and lets the agent shirk $(a_t = 0)$ otherwise is incentive-compatible. Hereafter, we denote by $\underline{\beta} := \frac{B}{\bar{a}}$ the lowest sensitivity to the asset realization that induces effort, so the incentive-compatible effort strategy is $a_t^*(\beta) = \bar{a}1_{\beta_t\geq\underline{\beta}}$.*

It follows from Lemma 2 that setting $\beta_t \geq \underline{\beta} = \frac{B}{\bar{a}}$ induces the agent to exert effort (so $a_t = \bar{a}$) because it ensures that the agent obtains a greater expected value from exerting the effort than instantaneously from shirking. Thus, making the agent sensitive to the advent of a robot does not alter an incentive-compatible effort strategy because it does not depend on the controlled processes of sensitivity $(\delta_t)_{t\leq\tilde{T}}$.

For the process $W^\alpha$ associated with such an incentive-compatible contract to be the agent's continuation value, it must satisfy the limited liability constraint, so $W_t^\alpha \geq 0$ for all $t \leq \tau$. To this end, we first introduce

$$\tau_0^\alpha = inf\{t \geq 0 \mid W_t^\alpha = 0\} \tag{13}$$

and require the contract termination to occur whenever $\tau_0^\alpha$ is reached, so $\tau \leq \tau_0^\alpha$. Second, as the agent's continuation value jumps instantaneously by $\delta_{\tilde{T}}$ at the stochastic advent of the automation technology while it must remain nonnegative, the limited liability condition also leads to a lower boundary on the feasible control $(\delta_t)_{t\leq\tilde{T}}$.[18] To ensure that $W^\alpha_{\tilde{T}} \geq 0$, we require that for all $t$ up to $\tau \wedge \tilde{T}$, $\delta_t \geq -W^\alpha_{t^-}$, where a $\mathcal{G}$-predictable process. $W^\alpha_{\cdot^-} = (W^\alpha_{t^-})_t$ is the left-hand limit of the continuation value process $(W^\alpha_t)_t$[19]

Hence, any contract such that (1) $\beta_t \geq \underline{\beta}$ up to $\tau$ (incentive compatibility) and (2) $\delta_t \geq -W^\alpha_{t^-}$ for all t up to $\tau \wedge \tilde{T}$ (limited liability) that implements $W^\alpha_0 \geq w_0$ (participation constraint) and that terminates before $\tau^\alpha_0$ is a candidate for solving (5)-(6). We derive an optimal contract in the following section[20].

# III. Optimal Solution to the Principal's Problem

In this section, we heuristically derive the optimal contract and the associated principal's value function to establish some intuition. Our results are summarized in propositions, and the verification is provided in the appendix. We focus on the characterization of an optimal contract that induces the agent to follow the full effort strategy, so $a_t = \bar{a}$ up to contract termination. Such a restriction is standard in the literature (see, among others, the baseline model of DeMarzo and Sannikov (2006), its extension by Hoffmann and Pfeil (2010) with persistent shock, or Biais et al. (2010) in the case of the agent preventing the occurrence of a large risk), and necessary and sufficient conditions for the optimality of the full-effort strategy are provided in Appendix A.

The optimal contract we derive can be described with two state variables prior to the advent of the automation technology: the single-jump process that accounts on any date for the availability of such technology, and the agent's continuation value. Once such technology has emerged, the continuation value remains the only relevant state variable. As value functions are forward-looking processes, we use backward induction to solve the principal's problem. We will start by characterizing the optimal contract after the advent of the automation technology, and then the optimal contract prior to such advent.

[18] Such a restriction by limited liability is standard in models with Poisson shocks, whether they are controlled by the agent as in Biais, Mariotti, Rochet, and Villeneuve (2010)) or independent as in Hoffmann and Pfeil (2010).

[19] The left-hand limit of any process $(Y_t)_t$ is defined as $Y_{t^-} = \lim_{s\uparrow t} Y_s$ together with $Y_{0^-} = Y_0$.

[20] In the rest of the paper, we get rid of the superscript $\alpha$

## A. *Heuristic Derivation*

Let us denote by $V_n(w)$ the principal's value function, which refers to the highest value the principal can obtain from delegating to an agent with a current continuation value $w$ and where $n = \{0; 1\}$ specifies whether the automation technology is available ($n = 1$) or not ($n = 0$). As the principal can provide at any moment a lump-sum payment $\Delta U$ and then proceed with the optimal contract and a remaining continuation value $w - \Delta U$, the following inequality holds

$$V_n(w) \geq V_n(w - \Delta U) - \Delta U, \qquad \text{with } n = \{0; 1\}. \tag{14}$$

It implies that $V_n'(w) \geq -1, \forall\, w$ and for $n = \{0; 1\}$, so the marginal benefit of providing incentives must remain greater than the marginal value of making a lump-sum payment to the agent. As equation (11) shows, making a payment reflects downwards the agent's continuation value, and deferring a payment mitigates the risk of termination that exists when the continuation value hits zero for the limited liability reason. The agent is more impatient than the principal, so deferring payments is costly and cannot be done in perpetuity. Consequently, we conjecture that the principal's value function is concave. We denote by $\bar{W^0} = \inf\{w \mid V_0'(w) = -1\}$ and $\bar{W^1} = \inf\{w \mid V_1'(W) = -1\}$ the lowest continuation values where equation (14) holds with an equality. These thresholds will play the role of the payment barrier in the optimal contract. Unlike the payment barrier in the baseline model of DeMarzo and Sannikov (2006), the payment barrier here is contingent on the state of variable $(N_t)_t$ that accounts for the availability of a robot. Then, the agent is employed in the interval $[0, \bar{W^0}]$ prior to the advent of the automation technology and $[0, \bar{W^1}]$ afterwards. Finally, the principal can terminate the relationship at any instant $t$ only if he is better off paying any amount owed to the agent (the agent's current continuation value $w$) and obtaining the value $\tilde{M} = M_0 1_{N_t=0} + M 1_{N_t=1}$. Hence, $\forall w$, $V_n(w) \geq \tilde{M} - w$.

Therefore, one expects that the principal's value when delegating to the agent is given by the following Hamilton-Jacobi-Bellman (HJB) equation:

$$max\left(\tilde{M} - . - v_n, \mathcal{L}_n v_n - r v_n, 1 + v_n'\right) = 0, \text{for } n = \{0; 1\} \tag{15}$$

and where $\mathcal{L}_n V_n(w) =$

$$\bar{a}\mu + (\gamma w - \lambda\delta 1_{n=0})\, V_n'(w) + \frac{1}{2}\beta^2 V_n''(w) + \lambda(V_1\,(w+\delta) - V_0\,(w))1_{n=0}, \tag{16}$$

where the first term in equation (15) represents the value associated with the opportunity of terminating the contract to automate, the second refers to the value associated with delegating to the agent, and the third states that the slope of the principal's value is always greater than $-1$. We note that $\tilde{M} - .$ has a slope of $-1$, while $V_n' > -1\ \forall w$ below the payment boundary. Then, the marginal benefit of delegating to the agent is equal to or greater than that of automation for any strictly positive continuation value. Therefore, whenever the principal is in a contractual relationship with an agent, the principal always prefers to incentivize the agent rather than to pay any amount owed at once in order to automate. We infer that the principal always waits until reaching the stopping time $\tau = \tau_0$ to automate.

Note that whenever the principal offers a contract to the agent, $\beta^2$ appears as a multiplier of $V_0''(w)$ in the principal's value function, and $V_0''(w) \leq 0$ since the value function is concave. Hence, the principal sets the lowest sensitivity to the asset realization that induces the agent to exert effort, i.e. $\beta_t = \underline{\beta}$ up to $t = \tau$. The first-order condition with respect to the sensitivity to the advent of the automation technology leads to $V_1'\,(w+\delta) = V_0'\,(w)$ as long as it satisfies the limited liability condition that requires that $\delta \geq -w$.

The following propositions characterize the optimal contract prior to and after the advent of a robot; such a contract is discussed in Section III.B.

**Proposition** 2: ***Optimal contracting after the advent of the automation technology***
*Suppose that an automation technology is already available and can replace the agent at any moment. The agent's continuation value is the only relevant state variable in the contracting problem, and*

*its dynamics under an incentive-compatible contract that implements the full-effort strategy satisfy*

$$dW_t = \gamma W_t dt + \underline{\beta} dZ_t^{\bar{a}} - dU_t, \quad \forall \quad t \leq \tau_0 \tag{17}$$

*until contract termination that occurs at $\tau_0$ – the first time $w$ hits 0.*

*The principal's value function is that derived in section III, Proposition 7 of the baseline model of DeMarzo and Sannikov (2006). It is concave and solves the following second-order differential equation*

$$rV_1(w) = \bar{a}\mu + \gamma w V_1'(w) + \frac{\underline{\beta}^2}{2} V_1''(w) \qquad \text{if } w \in [0; \bar{W}^1]; \tag{18}$$

*together with $V_1(0) = M$ (the value matching condition); $V_1'(\bar{W}^1) = -1$ (the smooth pasting condition) ; and $V_1''(\bar{W}^1) = 0$ (the super contact condition). The value function extends linearly afterwards with slope -1.*

*Consequently, whenever the robot is more efficient than the agent at managing the asset, $\bar{W}^1 = 0$ and the principal's value function satisfies*

$$V_1(w) = M - w \quad \forall w \geq 0. \tag{19}$$

If the technology is already available, the agent's continuation value $(W_t)_t$ is the only relevant state variable, and Proposition 2 characterizes the optimal contract. $(W_t)_t$ evolves within an interval $[0, \bar{W}^1]$ and is subject to uncertainty arising through the Brownian component $(Z_t)_t$ that ties its dynamics with the asset's performance. On the one hand, if the robot is less efficient than the agent at managing the asset, the agent is paid if good performance leads $W$ to reach $\bar{W}^1 > 0$, and the contract only stops when poor performance makes $W$ hit zero for the first time. On the other hand, if the robot is at least as good as the agent, the principal would not continue the delegation to an agent subject to a costly agency friction while the principal can automate. Then, $\bar{W}^1 = 0$, so the agent is paid the agent's current continuation value at once, and the principal automates. Consequently, the principal who already delegates to an agent prefers to postpone automation if and only if the available technology is less efficient.

Nevertheless, when the principal has to decide prior the contracting date to either automate from the outset or delegate to an agent, the principal may prefer automation even if the robot is less efficient. As illustrated in Figure 1, this occurs if (1) providing incentives is too costly or (2) the agent's reservation value is too large. First, the presence of agency friction lets the agent extract rent, so the principal cannot internalize the total surplus. Consequently, there exists a threshold $\underline{M} = inf\{M \geq 0 \mid \sup_w V_1(w) = V_1(0)\}$ such that $\forall M \geq \underline{M}$, the principal prefers to automate from the outset. This case is depicted in the left panel of Figure 1. Such threshold depends on how profitable automation is compared with the contract. It is noteworthy that the advantage of automating is greater if the asset intrinsic profitability $\mu$ is lower. Indeed, the severity of agency friction captured by $\frac{B}{\bar{a}}$ is independent of $\mu$, so it is less profitable to delegate to an agent if $\mu$ is lower. Second, the principal may prefer to automate from the outset because the agent's reservation value is too large. we denote by $\tilde{w_0} = \{w \geq 0 \mid V_1(\tilde{w_0}) = M \quad \& \quad V_1'(\tilde{w_0}) \leq 0\}$, so $\forall w_0 \geq \tilde{w_0}$,[21] the agent is too *expensive* and the principal automates from the outset. The right panel of Figure 1 illustrates this scenario.

**Proposition** 3: ***Optimal contracting prior to the advent of the automation technology*** *Assume that both parties foresee the advent of the automation technology that occurs at an uncertain date. The dynamics of the agent's continuation value under an incentive-compatible contract that implements the full-effort strategy satisfy*

$$dW_t = \gamma W_t dt + \underline{\beta} dZ_t^{\bar{a}} + \delta(dN_t - \lambda dt) - dU_t, \quad \forall \quad t \leq \tau_0 \wedge \tilde{T}. \tag{20}$$

*The principal's value function is concave and is given by the solution to the following second-order differential equation*

$$\begin{aligned}\forall w \in [0; \bar{W^0}], \quad (\lambda + r)V_0(w) = &\\ &\bar{a}\mu + (\gamma w - \lambda\delta)V_0'(w) + \frac{1}{2}\underline{\beta}^2 V_0''(w) + \lambda V_1(w + \delta)\end{aligned} \tag{21}$$

[21] $\forall M \geq \underline{M}, \tilde{w_0} = 0$.

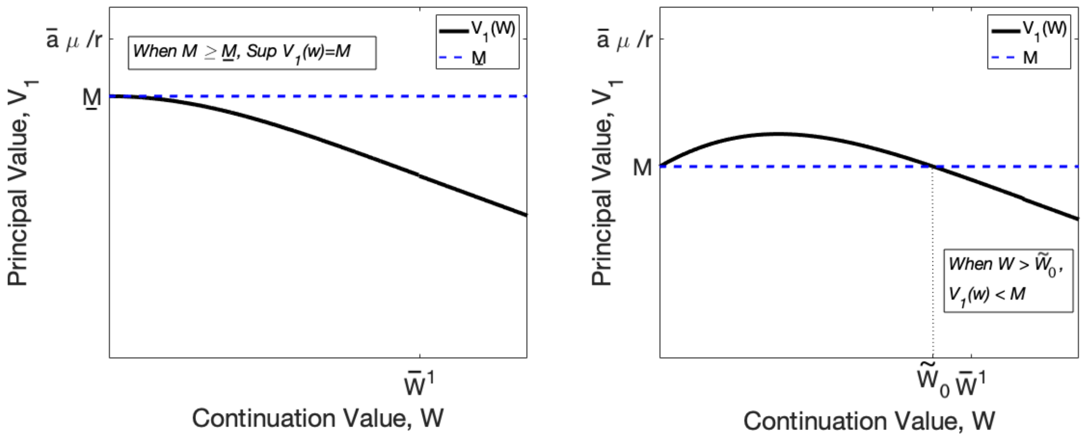


**Figure 1. Principal's value function $V_1$ after the advent of the technology.** Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, \underline{M} = 91$ (left panel), $M = 80$ (right panel). $\bar{W}^1$ is the payment barrier and $\tilde{W}_0$ is the largest reservation value such that the principal is better off automating from the outset rather than delegating first to the agent.

*together with $V_0(0) = M_0$ (the value-matching condition), $V_0'(\bar{W}^0) = -1$ (the smooth-pasting condition), $V_0''(\bar{W}^0) = 0$ (the super-contact condition), and where the value function $V_1$ is given in Proposition 2. The value function extends linearly afterwards with slope -1. Process $\delta$ is given by the first-order condition on $V_0(w)$ if it satisfies the limited liability condition. Therefore, it is determined by $V_1'(W_{t^-} + \delta(W_{t^-})) = V_0'(W_{t^-})$ for all $W_{t^-}$ such that $V_1'(W_{t^-}) \geq V_1'(0)$ and $\delta(W_{t^-}) = -(W_{t^-})$ otherwise (the limited liability condition).*

## *B. Analysis of the Optimal Contract*

We illustrate the value functions associated with the optimal contract and the optimal sensitivity to the advent of a robot in Figure 2 for $M < \frac{\bar{a}\mu}{r}$. In this case, the value function jumps from $V_0$ to $V_1 > V_0$ because asset management becomes more valuable in the state of the world where the contract is terminated. As the technology is implemented at the termination boundary $W = 0$, the difference in value decreases with $W$. At the payment barrier, the two value functions $V_0$ and $V_1$ are close because the probability of substituting the robot for the agent in the near future is

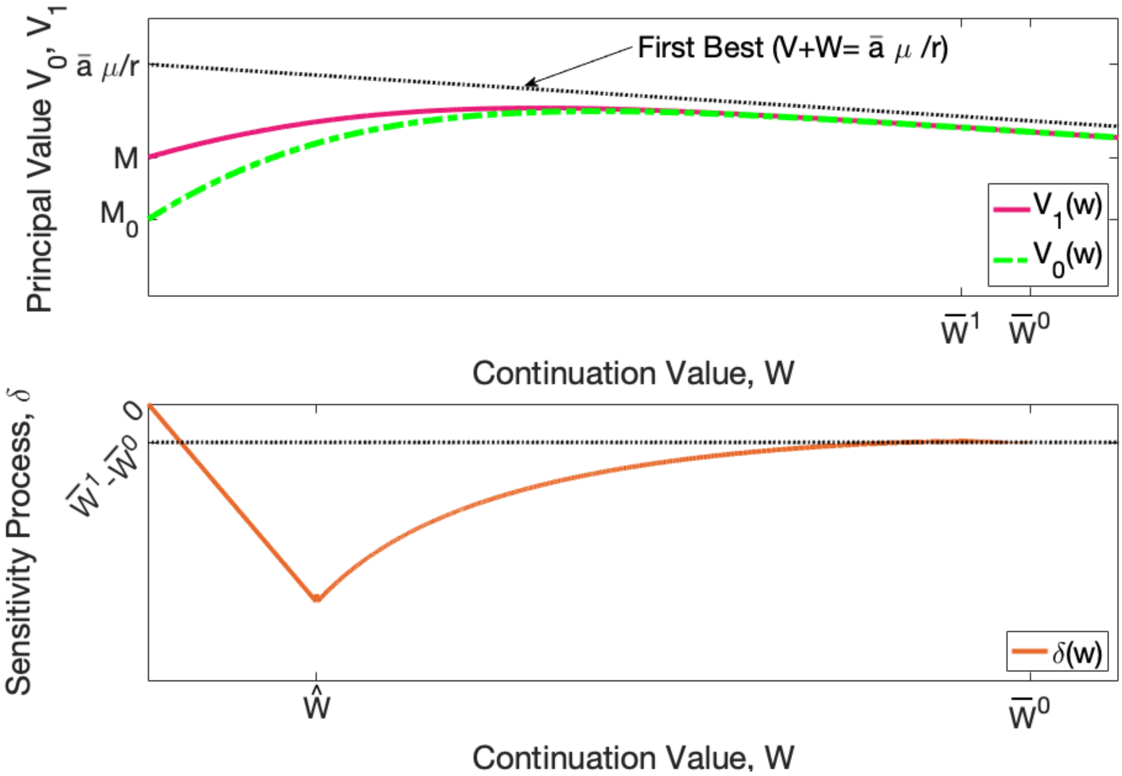


**Figure 2. Principal's value functions $V_0$ and $V_1$ prior to and after the advent of the automation technology, and sensitivity process $\delta$ if $M < \frac{\bar{a}\mu}{r}$.**
Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, M = 60$. $\bar{W}^0$ (resp., $\bar{W}^1$) is the payment barrier – a reflecting boundary – before (resp., after) the advent of the automation technology. The value function attaches the payment frontier with slope -1, and then extends linearly. For sufficiently large $w$, the limited liability constraint over $\delta(w)$ is not binding and the optimal controlled sensitivity keeps the marginal value of delegating to the manager constant before and after the advent of technology. Otherwise, such an advent triggers an instantaneous termination of the asset manager's contract and automation of asset management. We denote by $\hat{W}$ the largest value on $w$ such that the limited liability constraint binds. We provide in Appendix Section D a description of our algorithm to simulate $(V_0, V_1, \bar{W}^0, \bar{W}^1, \delta)$.

small. Furthermore, we note that the first-best value of asset management that would be reached in the absence of agency friction is higher than $V_0$ and $V_1$, because the robot is less efficient than the agent at managing the asset. Thus, automation would never occur in the first-best framework if $M < \frac{\bar{a}\mu}{r}$.

Next, the question raised is how the agent's continuation value reacts to the advent of the automation technology, i.e., how the jump from $V_0$ to $V_1$ occurs. Since $W_{\tilde{T}} = W_{\tilde{T}^-} + \delta(W_{\tilde{T}^-})$, it is the value of the sensitivity to the advent of the automation technology at $\tilde{T}$ that provides this information. The following proposition states that the jump is always negative according to the optimal contract, so the agent's continuation value decreases at the advent of the technology.

**Proposition** 4: *The optimal contract prior to the advent of the automation technology, as presented in the Proposition 3, implements a negative sensitivity to such an advent, so* $\forall t \leq \tilde{T}$, $\delta_t =\leq 0$, *where* $\delta_t = \delta(W_{t^-})$. *As the limited liability constraint imposed on the processes of sensitivity* $\delta$ *binds over the interval* $[0, \hat{W}]$, *the principal instantaneously substitutes the robot for the agent if* $W_{\tilde{T}^-} \leq \hat{W}$. *Furthermore, the payment boundary is sensitive to the advent of the automation technology and decreases from* $\bar{W}^0$ *to* $\bar{W}^1 < \bar{W}^0$ *after the advent of technology.*

Consequently, it is optimal to continuously *boost* the drift of the agent's continuation value by $-\lambda\delta(W) > 0$ prior to the advent of the technology, and then let the agent's continuation value decline instantly by $\delta(W_{\tilde{T}})$. Such a mechanism may substitute the robot for the agent instantaneously if the agent's continuation value at $\tilde{T}$ is below the threshold $\hat{W}$, defined by $V_0'(\hat{W}) = V_1'(0)$.

We note that because the advent of automation technology changes the future profitability of terminating the contract, it is optimal to make the agent sensitive to the advent of a robot. This contrasts with standard results in contracting theory, where the optimal contract does not rely on exogenous changes in the contractual environment, as in the seminal paper of Holmstrom (1979). Such a jump could also be interpreted as a *punishment for luck* to emphasize on the worsening of the agent's efficiency relative to the contract's environment. Indeed, an analogue mechanism is at play in Hoffmann and Pfeil (2010) or Demarzo et al. (2012), where a *lucky event* changes the intrinsic profitability of the asset, captured here by parameter $\mu$.

Next, we consider the case of $M \geq \frac{\bar{a}\mu}{r}$. Figure 3 shows the typical form of value functions in this case. The principal's value jumps instantaneously from $V_0$ to $V_1(0) = M$ at the advent of the technology because it is optimal to substitute the robot for the agent as soon as the robot becomes

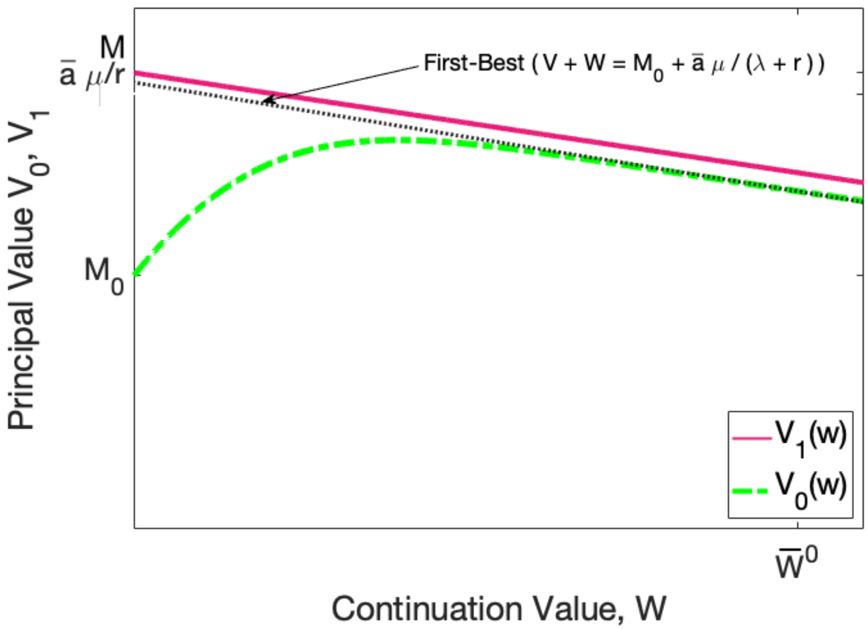


**Figure 3. Principal's value functions prior to and after the advent of the automation technology if $M \geq \frac{\bar{a}\mu}{r}$.**
Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, M = 105$. In this case, the limited liability constraint on the processes of sensitivity $\delta$ is always binding. Consequently, the principal instantaneously substitutes the robot for the agent at $\tilde{T}$.

available. Indeed, $V_1'(0) = V_0'(\bar{W}^0) = -1$, so we obtain following the Proposition 4 that $\hat{W} = \bar{W}^0$. Furthermore, the first-best scenario that would consist here of delegating to an agent up to $\tilde{T}$ and switch to automation provides a lower value than $V_1$, where the robot is always in charge.

**Contracting Upon the Forthcoming Automation Technology and Firm Value.** We acknowledge that contracting upon the forthcoming automation technology may be difficult. It means that it is verifiable by a third-party, e.g., a judge. Following Frey and Osborne (2017) who rank occupations by their propensity to be automated, the availability of the robot may be assumed industry-wide, so would be $\lambda$ observable. However, the value of implementing a robot-driven process is harder to assess because it is probably firm-specific, as suggested by Brynjolfsson et al. (2017). $M$ would be then firm-specific and may even depend on the asset under management.

To examine formally the benefit of contracting upon the robot, we next compare the optimal contract derived in Propositions (2)-(3) with the suboptimal contract where the principal cannot make the agent sensitive to the advent of a robot, so we impose $\delta_t = 0$, $\forall t$. In this case, the dynamics of the continuation value if the agent who exerts full-effort satisfy

$$dW_t = \gamma W_t dt + \underline{\beta} dZ_t^{\bar{a}} - dU_t, \quad \forall \quad t \leq \tau_0. \tag{22}$$

The principal terminates the contract if and only if $\tau_0 = inf\{t \geq 0 \mid W_t = 0\}$ is reached. The principal's value $V_0^s$ associated with the suboptimal contract satisfies :

$$\forall w \in [0; \bar{W_s^0}], \quad (\lambda + r)V_0^s(w) = \bar{a}\mu + \gamma w V_0^{s\prime}(w) + \frac{1}{2}\underline{\beta}^2 V_0^{s\prime\prime}(w) + \lambda V_1(w) \tag{23}$$

together with $V_0^s(0) = M_0$ (the value-matching condition), $V_0^{s\prime}(\bar{W^0}) = -1$ (the smooth-pasting condition), $V_0^{s\prime\prime}(\bar{W^0}) = 0$ (the super-contact condition), and where the value function $V_1$ is still that given in Proposition 2. Indeed, value functions are forward-looking processes, so imposing $\delta_t = 0$, $\forall t$ does not alter the value function $V_1$ once a robot is available.

Next, we compare $V_0(W)$ with $V_0^s(W)$. On the one hand, if we assume that the agent's reservation value is sufficiently low, then the agent is offered to start the contract with an initial continuation value $W_0^s = \arg\max_W V_0^s(W)$ in the suboptimal contract and $W_0 = \arg\max_W V_0(W)$. As illustrated in Figure 4, the suboptimal contract provides a lower (respectively, larger) value to the principal (respectively, the agent). On the other hand, if the reservation value $w_0$ is such that $w_0 > max\left(\arg\max_W V_0^s(W), \arg\max_W V_0(W)\right)$, then the inefficiency of the suboptimal contract is lower because the difference between $V_0^s$ and $V_0$ decreases with W.

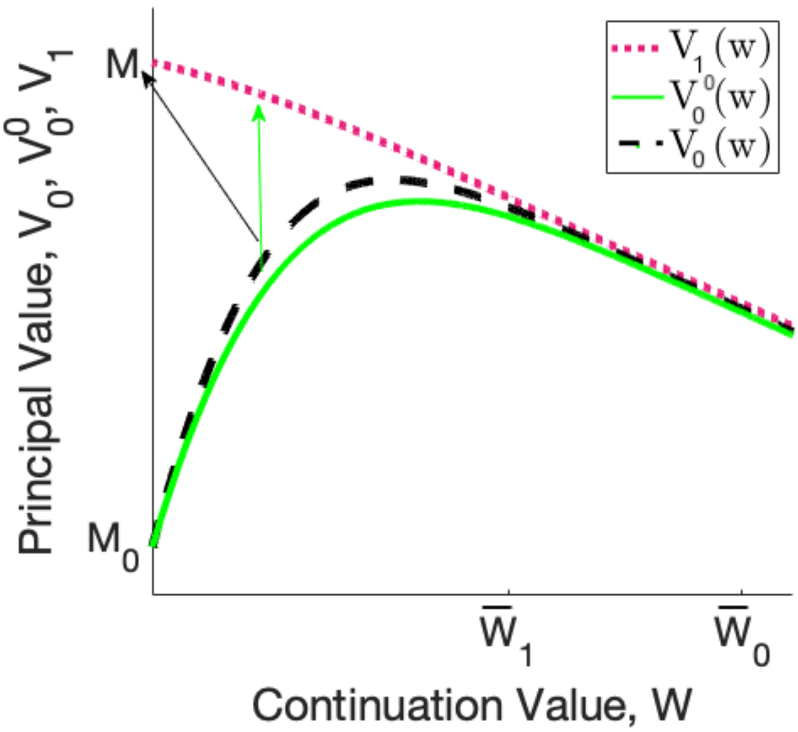


**Figure 4. Value functions $V_0$ and $V_1$ derived from the optimal contract, and $V_0^s$ derived from a suboptimal contract where we impose $\delta = 0$.** Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, M = 95$.

# IV. Implementation and Empirical Implications

## *A. Implementation*

To implement the optimal contract presented in the Propositions (2)-(3), we design a *point-based incentive programme* where the number of points coincides with the asset manager's continuation value. On the one hand, whenever the point balance hits an upper payment boundary, the excess is converted into a lump sum of cash paid to the asset manager. On the other hand, the contract is terminated as soon as the agent has no more points, because the agent is then "too poor to be punished effectively" (Spear and Wang (2005)). At the advent of the automation technology, $\delta_{\tilde{T}}$ points expire and are removed from the programme. This mechanism may trigger termination due to the limited-liability condition if the number of points at $\tilde{T}$ was too low. Then and as long as the agent manages the asset, the points accumulate at a slower rate.

As in He (2009), the implementation of an optimal contract cannot solely use a cash balance à la DeMarzo and Sannikov (2006) that would mimic the dynamics of cash flows to trace the asset manager's continuation value. Otherwise it would be impossible to make it jump at the technological advent $\tilde{T}$.

## *B. Performance-Biased Automation of Asset Managers*

We offer a theoretically grounded novel prediction of *performance-biased automation* of asset managers. Indeed, under an optimal contract and for a given automation technology, observing the agent's continuation value below a given threshold at the technology's advent is sufficient for deciding to instantaneously automate. This threshold is agent-specific and is determined by solving for the optimal contract (see Proposition 4). We interpret the agent's continuation value as a measure of the agent's performance because it traces the agent's history of success at managing the asset within a given contractual environment. Hence, only an agent who has performed poorly up to the advent of the automation technology is instantaneously replaced with technology.

Furthermore, we claim that a striking illustration of performance-biased automation has been offered when BlackRock substituted algorithms for 7 of its 53 stock pickers in 2017. BlackRock's CEO Laurence D. Fink has justified such a decision by a "change [of] the ecosystem"[22], and we interpret this change as the advent of technology that can replace stock pickers. This justifies our approach of studying automation at the extensive margin, i.e., the extension of the set of automatable tasks (the task here being stock picking).

Finally, we infer that BlackRock's stock-picking algorithm is not yet as efficient as an agent would be in the absence of agency friction. Indeed, only a fraction of stock pickers have been replaced with technology. Our model predicts that otherwise every stock picker would have been replaced instantaneously, irrespective of the individual's performance history. Consequently, we

[22]https://www.nytimes.com/2017/03/28/business/dealbook/blackrock-actively-managed-funds-computer-models.html

predict that BlackRock has implemented a technology that is less efficient than the agent at picking stocks mainly because it is costly to provide incentives to stock pickers.

## *C. Other Testable Implications*

Following the implementation of the optimal contract discussed in Section IV.A, the principal controls the dynamics of the points in the incentive programme – that mimics the dynamics of the agent's continuation value – to achieve optimality. While the number of points may not be observable by a third party at each instant, it then maps onto a stream of payments and a termination date that can be empirically observed. Consequently, we examine how the advent of the automation technology impacts (1) the payments made to the agent and (2) the duration of the contract. Furthermore, we also analyze (3) how the elapsed time since the contractual date ($t = 0$) impacts the propensity for agents to be automated at the advent of robots. Indeed, Acemoglu and Restrepo (2018) shows that agents' aging is an important determinants of the automation technology's adoption. These analyses let us make several testable predictions.

First, we solve numerically for the optimal contract by the shooting method, and then perform Monte Carlo simulations[23]. Following the baseline model of DeMarzo and Sannikov (2006), we set the principal's discount rate to $r = 10\%$, and the instantaneous performance of the asset under full effort to $\bar{a}\mu = 10$. We fix the agent's discount rate to $\gamma = 12\%$, and assume that $B = 8$, so $\frac{B}{\bar{a}} = 0.8$, where $\frac{B}{\bar{a}} \in [0, 1]$ to simulate the presence of a severe agency friction observed in the finance industry. As to the automation technology, there is no consensus on what figure to use. According to Frey and Osborne (2017) who categorize jobs according to the probability of automation, "securities, commodities, and financial services sale agents" (SOC code 41-3031) such as asset managers are at slight risk of automation (probability of 1.6%, ranked the $74^{th}$ less likely occupation to be automated over 702 occupations). Nevertheless, BlackRock has already in 2017 substitutes stock pickers for algorithms. Thus, we fix the intensity of its advent to $\lambda = 0.125$, so the technology should become available on average in $\frac{1}{0.125} = 8$ years, and the probability of the technology arising

[23]For the initial continuation value, we take $W_0 \in [\hat{W}, \bar{W}^0]$, where $\hat{W}$ is the smallest value such that $V_1'(w + \delta(w)) = V_0'(w)$. For $W_0 < \hat{W}$, the contract would be instantaneously terminated if $N_0 = 1$, so the analysis of the bonus and the contract duration is irrelevant below that threshold.

in less than a year is $1 - e^{-0.125} = 11.75\%$. We consider the value of automating $M \in [60; 99]$, so the robot-managed asset reaches between 60% and 99% of the performance of agent-managed asset in the absence of agency friction, and the latter is given by $\frac{\bar{a}\mu}{r} = 100$ (see Proposition 1). Table I presents the parameter values used in the numerical analysis.

| Variable | Symbol | Parameter | Symbol | Value |
|---|---|---|---|---|
| Value of the robot | M | Principal's discount rate | r | 0.10 |
| Cumulative cash flows | X | Agent's discount rate | $\gamma$ | 0.12 |
| Contract termination date | $\tau$ | Full effort | $\bar{a}$ | 10 |
| Date of advent of technology | $\tilde{T}$ | Asset's intrinsic performance | $\mu$ | 1 |
| Firm value prior to the advent of the automation technology | $V_0$ | Private benefit | B | 8 |
| Firm value after the advent of the automation technology | $V_1$ | Intensity of the advent of the automation technology | $\lambda$ | 0.125 |
| Payment boundary prior to the advent of the automation technology | $\bar{W}^0$ | Agent's reservation value | $w_0$ | 0 |
| Payment boundary after the advent of the automation technology | $\bar{W}^1$ | | | |
| Sensitivity to the asset performance | $\beta$ | | | |
| Sensitivity to the advent of the automation technology | $\delta$ | | | |

**Table I**
**Parameter Values and Variables**

**Expected Bonus Following the Advent of a Robot.** Bonuses are easy to observe empirically. Thus, we consider here the sum of payments that have been received by the agent over a year, as it can be regarded as a proxy for an annual bonus. To examine whether the expiration of points at the advent of a robot leads to a decline in bonus, we then compare this to the counterfactual scenario of this event not occurring.

We fix the starting number of points in the incentive programme to $W_0 = w$, and consider the discounted sum of payments received over $[0, t \wedge \tau]$ just after the advent of the automation technology ($N_0 = 1$), and that we denote by $\phi_1^t$. We have

$$\phi_1^t(w) = \mathbb{E}_w \left[ \int_0^{t\wedge\tau} e^{-\gamma s} dU_s \mid N_0 = 1 \right], \tag{24}$$

where, according to Proposition (3), the agent's number of points jumps instantly from $W_{0^-} = w$ to $W_0 = w + \delta(w)$. In the counterfactual scenario, the discounted sum of payments received over $[0, t \wedge \tau]$ if the automation technology does not emerge ($N_0 = 0$) is given by

$$\phi_0^t(w) = \mathbb{E}_w \left[ \int_0^{t\wedge\tau} e^{-\gamma s} dU_s \mid N_0 = 0 \right]. \tag{25}$$

In this case, the automation technology can still emerge during the interval $]0; t \wedge \tau]$. We remind the reader that the contract characteristics $(U_t)_t$ and $\tau$ are adapted to the entirety of information available to the principal, so they differ in equations (24) and (25). We compare the cross-sectional estimates $\phi_1^t(w)$ and $\phi_0^t(w)$, and consider $t = 1$; our results are provided in Table II for $M = \{60, 75, 95, 99\}$.

We estimate that $\phi_0^t$ dominates $\phi_1^t$. This is illustrated in Figure 5 for $M = 90$, and the values reported in Table II for other values of $M$. Thus, we conclude that the annual bonus declines after the advent of the automation technology. This is consistent with the empirical observation made by the 2018 *Asset Management Compensation Study* by Greenwich Associates. Nevertheless, The authors claim that the large cost of investing in automation technologies reduces the incentive compensation pool of asset managers, while our optimal contracting approach offers a potential alternative channel based on the decline in the agency rent.

Furthermore, we also note that the annual bonus increases with the number of points in the incentive programme. This is intuitive because the latter can be interpreted as a measure of the agent's performance history. Figure 6 shows the severity of the decline in the annual bonus at the advent of a robot, which is given by $\frac{\phi_1^t - \phi_0^t}{\phi_0^t}$. As expected, the decline in the bonus is larger if $M$ is higher.

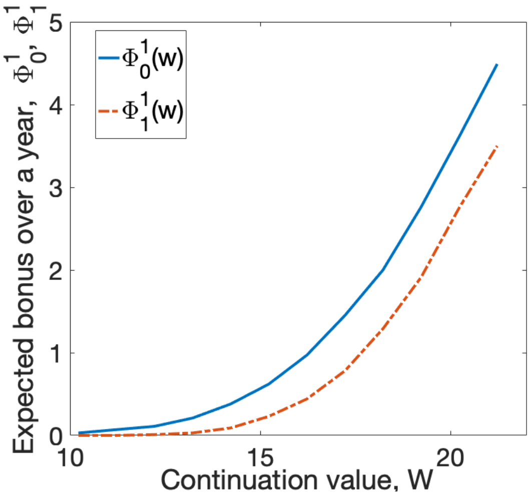


**Figure 5.** Expected Annual Bonus following the advent of technology $\Phi_1^1$ and in the counterfactual scenario $\Phi_0^1$ (M=95).

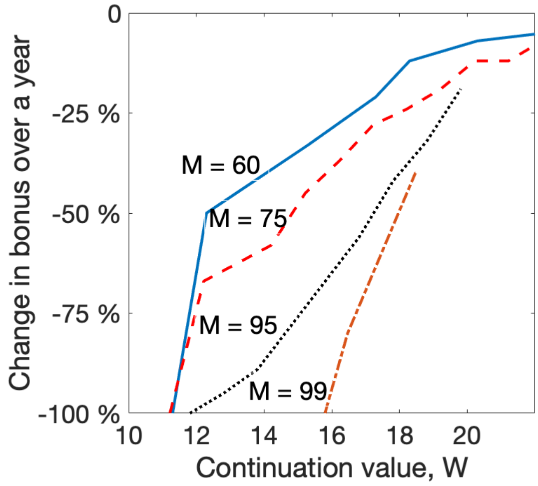


**Figure 6.** Change in Expected Annual Bonus following the advent of technology.

The value of $M$ may be firm-specific if it is interpreted as the efficiency of the firm in adopting the forthcoming robot. While it is in practice difficult to observe directly, Brynjolfsson et al. (2017) assert that firms adapt to technology, and that complementary investments and structural changes are important factors for efficient usage of innovations. Hence, we could for instance infer the value of $M$ from the size of the firm's I.T. department or the firm's investment in fintechs. This leads to the following cross-sectional implication :

**Implication** 1: *The average decline in the annual bonus following the advent of technology is higher in firms that are better adapted to the usage of automation technology.*

**Threat of Termination, Implementation Lag, and the Advent of a Robot.** Does the advent of a robot always put an agent at a greater risk of termination ? Are robots adopted faster in firms better adapted to their usage ?

To answer these questions, let us first investigate the expected contract duration denoted by

M = 99

| | | | |
|---|---|---|---|
| w | 15.80 ($\hat{W}$) | 17.47 | 18.47 ($\bar{W}^0$) |
| $\Phi_0^1$(w) | 3.19 | 4.17 | 5.11 |
| $\Phi_1^1$(w) | 0 | 1.73 | 3.12 |

M = 95

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| w | 11.44 ($\hat{W}$) | 12.81 | 13.81 | 14.81 | 15.81 | 16.81 | 17.81 | 18.81 | 19.81 ($\bar{W}^0$) |
| $\Phi_0^1$(w) | 0.24 | 0.38 | 0.65 | 1.00 | 1.44 | 2.09 | 2.83 | 3.66 | 4.57 |
| $\Phi_1^1$(w) | 0 | 0.02 | 0.07 | 0.22 | 0.47 | 0.92 | 1.63 | 2.5 | 3.7 |

M = 75

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| w | 6.41 ($\hat{W}$) | 8.22 | 9.22 | 10.22 | 11.22 | 12.22 | 13.22 | 14.22 | 15.22 | 16.22 |
| $\Phi_0^1$(w) | 0 | 0 | 0 | 0,01 | 0.01 | 0.03 | 0.06 | 0.12 | 0.22 | 0.38 |
| $\Phi_1^1$(w) | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.02 | 0.05 | 0.12 | 0.24 |
| w | 17.22 | 18.22 | 19.22 | 20.22 | 21.22 | 22.22 | 23.22 ($\bar{W}^0$) | | | |
| $\Phi_0^1$(w) | 0.61 | 0.97 | 1.44 | 1.98 | 2.76 | 3.58 | 4.5 | | | |
| $\Phi_1^1$(w) | 0.44 | 0.74 | 1.17 | 1.74 | 2.43 | 3.32 | 4.12 | | | |

M = 60

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| w | 4.64 ($\hat{W}$) | 6.3 | 7.3 | 8.3 | 9.3 | 10.3 | 11.3 | 12.3 | 13.3 | 14.3 |
| $\Phi_0^1$(w) | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.02 | 0.03 | 0.06 |
| $\Phi_1^1$(w) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.01 | 0.03 |
| w | 15.3 | 16.3 | 17.3 | 18.3 | 19.3 | 20.3 | 21.3 | 22.3 | 23.3 | 24.3 ($\bar{W}^0$) |
| $\Phi_0^1$(w) | 0.12 | 0.24 | 0.39 | 0.59 | 0.98 | 1.46 | 2.01 | 2.8 | 3.64 | 4.59 |
| $\Phi_1^1$(w) | 0.08 | 0.16 | 0.31 | 0.52 | 0.82 | 1.36 | 1.85 | 2.65 | 3.48 | 4.26 |

**Table II**
**Estimates of the average bonuses paid over the year following the advent of the automation technology ($\Phi_1^1$) and in the counterfactual scenario of the automation technology not emerging ($\Phi_0^1$). Estimates are provided for the set $M = (60; 75; 95; 99)$ of value of the automation technology.**

$\tau_1^t$. It satisfies

$$\tau^1(w) = \mathbb{E}_w \left[ \inf\{t > 0 \mid W_t = 0 \text{ such that } \quad W_0 = w \quad \& \quad N_0 = 1\} \right], \tag{26}$$

where, according to Proposition (3), $W_{0^-} = w$ jumps instantaneously to $W_0 = w + \delta(w)$ because a robot has appeared ($N_0 = 1$). In the counterfactual scenario, the expected contract duration is denoted by $\tau^0(w)$ and satisfies

$$\tau^0(w) = \mathbb{E}_w \left[ \inf\{t > 0 \text{ such that } W_t = 0, \text{ given } \quad W_0 = w \quad \& \quad N_0 = 0\} \right]. \tag{27}$$

Estimating the change in contract duration due to the advent of the automation technology means comparing the cross-sectional estimates $\tau^1(w)$ and $\tau^0(w)$. Our estimates are provided in Table III for $M = \{60, 75, 95, 99\}$.

As illustrated in Figure 7 for the case of $M = 95$, $\tau^0$ dominates $\tau^1$ so the advent of a robot makes contract termination occurs sooner. This is particularly true if the number of points in the incentive programme is small. The decline in the expected annual bonus following the advent of a robot and the greater risk of contract termination once the robot has becomes available, considered together, mean that the optimal contract effectively adjusts the provision of incentives to the availability of the robot. Thus, we posit that the early-stage period – the period prior to the advent of the automation technology – is a *golden age* of asset managers. While many authors argue that the costs of asset management, and in particular the delegation of active investment are too high (see French (2008), etc.), our paper shows that a golden-age at an early stage may not be abnormal and rather serves the purpose of increasing the efficiency of the contractual relationship in the long term when an automation technology capable of replacing the agent is foreseen to emerge.

Finally, we offer a prediction for the expected time necessary to adopt the robot after its advent. Brynjolfsson et al. (2017) refer to this as the *implementation lag* and argue that it is the main reason we have not yet observed a more significant contribution of A.I. in the economy. This lag is defined in our setting by $(\tau(w) \vee \tilde{T}) - \tilde{T}$, where $\tau(w)$ is the contract termination time, and $\tilde{T}$ represents the advent of a robot. As illustrated in 8, the implementation lag decreases with $M$. We note that

M = 99

| w | 15.80 ($\hat{W}$) | 17.47 | 18.47 ($\bar{W}^0$) |
|---|---|---|---|
| $\tau^0$(w) | 3173 | 3175 | 3131 |
| $\tau_1$(w) | 282 | 504 | 584 |

M = 95

| w | 11.44 ($\hat{W}$) | 12.81 | 13.81 | 14.81 | 15.81 | 16.81 | 17.81 | 18.81 | 19.81 ($\bar{W}^0$) |
|---|---|---|---|---|---|---|---|---|---|
| $\tau^0$(w) | 6898 | 6808 | 6961 | 7238 | 7465 | 7646 | 7721 | 7759 | 7768 |
| $\tau_1$(w) | 977 | 3233 | 4294 | 5162 | 5783 | 5918 | 6225 | 6341 | 6399 |

M = 75

| w | 6.41 ($\hat{W}$) | 8.22 | 9.22 | 10.22 | 11.22 | 12.22 | 13.22 | 14.22 | 15.22 | 16.22 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\tau^0$(w) | 6725 | 7500 | 7966 | 8323 | 8855 | 9307 | 9625 | 9765 | 9830 | 10153 |
| $\tau_1$(w) | 2074 | 4082 | 5728 | 6849 | 7615 | 8439 | 8832 | 9299 | 9532 | 9748 |
| w | 17.22 | 18.22 | 19.22 | 20.22 | 21.22 | 22.22 | 23.22 ($\bar{W}^0$) | | | |
| $\tau^0$(w) | 10095 | 10248 | 10435 | 10321 | 10371 | 10430 | 10333 | | | |
| $\tau_1$(w) | 10020 | 10010 | 10133 | 10212 | 10178 | 10268 | 10237 | | | |

M = 60

| w | 4.64 ($\hat{W}$) | 6.3 | 7.3 | 8.3 | 9.3 | 10.3 | 11.3 | 12.3 | 13.3 | 14.3 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\tau^0$(w) | 5506 | 6495 | 7129 | 7788 | 8275 | 8893 | 9229 | 9454 | 9713 | 10165 |
| $\tau_1$(w) | 1744 | 3542 | 4843 | 5899 | 6827 | 7829 | 8634 | 9123 | 9455 | 9755 |
| w | 15.3 | 16.3 | 17.3 | 18.3 | 19.3 | 20.3 | 21.3 | 22.3 | 23.3 | 24.3 ($\bar{W}^0$) |
| $\tau^0$(w) | 10259 | 10317 | 10337 | 10433 | 10563 | 10611 | 10577 | 10594 | 10602 | 10628 |
| $\tau_1$(w) | 9999 | 10141 | 10393 | 10407 | 10525 | 10598 | 10622 | 10650 | 10614 | 10651 |

**Table III**
**Estimates of the average contract duration following the advent of the automation technology ($\tau_1^1$) and in the counterfactual scenario of the automation technology not emerging ($\tau_0^1$). Estimates are provided for the set $M = (60; 75; 95; 99)$ of value of the automation technology.**

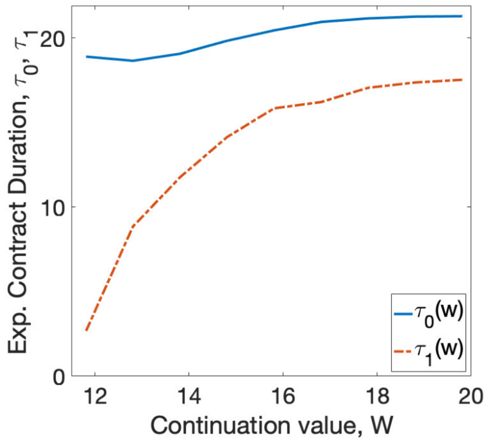


**Figure 7.** Expected contract duration following the advent of technology $\tau_1$ and in the counterfactual scenario $\tau_0$ (M=95).

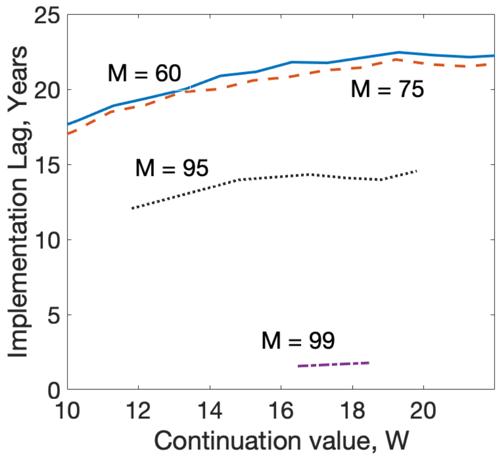


**Figure 8.** Implementation Lag for different values of $M$.

it is not significantly sensitive to a change in the initial continuation value $W$, because $W$ does not measure the future performance of the agent involved in the criteria for automating. Again, $M$ can be interpreted as the firm-specific efficiency of using the robot, and we have the following implication:

**Implication** 2: *Firms that are better adapted to the usage of a forthcoming technology will implement it faster.*

**Elapsed Time Since Contracting date, Aging, and the Threat of Automation.** Acemoglu and Restrepo (2018) have shown that a demographic change such as aging is an important determinant of the adoption of automation technologies. As aging can be proxied by the elapsed time $t$ since the contracting date ($t = 0$), we investigate here the following questions: How does the agent's propensity to be automated depend on $t$? Is it affected by the value of automation $M$? Following proposition (4), this is equivalent to study the probability for the agent's continuation value to be below the threshold $\hat{W}$ at time $t$, and how such a probability is impacted by a change in $M$. As $\hat{W}$, $W_0$ and the payment boundary are impacted by a change on $M$, the effect of a change in $M$ on the agent's propensity to be automated is not clear.

At first, we remark that the dynamics of the agent's continuation value that is given by equation (22) embeds a positive feedback component $\gamma W_t$. Thus, the agent's continuation tends to grow with $t$.

However, we must also consider how the agent's continuation value is initialised at the contracting date, namely how is set $W_0$. If we assume that $W_0$ is such that it maximizes the principal's value at $t = 0$,[24] then $W_0$ decreases with $M$, and $W_0$ and $\hat{W}$ are moved away when M decreases. Consequently, the probability for the agent's continuation value to reach $\hat{W}$ soon after the contracting date decreases with $M$. Thus, we anticipate that (1) the agent's propensity to be automated may be hump shaped if M is low enough, and decreases in time otherwise, and (2) that the agent's propensity to be automated increases with the value of automation. To see if this intuition is correct, we investigate the probability for the agent's continuation value to be below $\hat{W}$ for a discrete set of time and for a set of automation value $M$. This probability is defined as

$$P_t(W_0) = \mathbb{P}\left[W_t \leq \hat{W} \mid W_0 = Sup_w[V_0(w)]\right] \tag{28}$$

We estimate this probability the set of dates $t = \{1, 2, 5, 8, 10, 15\}$ (in years) and for the values of $M = \{60, 75, 95\}$. Our estimates are provided in Table IV.

As illustrated in Figure 9, our intuition is correct. First, we note that the agent's propensity to be automated increases with $M$. For instance, if the advent of robots would occur 1 year after the contracting date, the probability for an agent to be instantaneously automated would be 44% if $M = 95$, but only 1.2% if $M = 60$. However, while such a probability decreases over time when M is large ($M = 95$ illustrating this case on the figure), this is not always true when M is sufficiently low (for $M = 75$ and $M = 60$). Indeed, we observe that in both these cases the propensity to be automated is hump-shaped : it increases over a short period following the contracting date (on about the first 2 years of the contract), and then decreases over time. This reflects the small likelihood for the agent's continuation value to drop below $\hat{W}$ quickly after being initiated at $W_0$ for small values of $M$.

[24] Such an assumption is correct if the principal has the full bargaining power at the contracting stage.

Acemoglu and Restrepo (2018) study a model where middle-aged workers have a comparative advantage in production tasks compared to older workers. They suggest that when middle-aged workers are a scarce resource, firms automate. Their model provides a comprehensive framework where differences in demographic trends as aging may explain to some extent cross-country differences in automation, so that Germany, Japan and South Korea where the population is rapidly aging are adopting automation faster than the United States or the United Kingdom. Our analysis shows that, without providing to agents comparative advantage according to their age (here age being approximated by the elapsed time since the contracting date, i.e. t), the positive drift of the agent's continuation value makes automation less likely for "older" agents (when $t$ is large). When $M$ is low (for $M = \{60; 75\}$ in our illustration), the propensity of automation is hump shaped and reaches its maximum around two years after the contracting date. This is in line with the observation of Acemoglu and Restrepo (2018) concerning the automation on the US market, where middle-aged workers are the more at threat of being automated. We summarize this analysis with the following implication:

**Implication** 3: *The agent's propensity to be automated over time is hump shaped when the value of automation is low, and is decreasing when the value of automation is high.*

# V. Extensions

## A. *Optimal investment in automation technology*

Thus far, both parties have been presumed to take as given the characteristics and the arrival time of the robot. However, varied empirical evidence suggests that the principal may actually take action to improve the efficiency of the technology. First, Brynjolfsson et al. (2017) show that a complementary investment and structural changes are a prerequisite to an efficient usage of artificial intelligence. Second, a study by Boston Consulting Group[25] (2016) suggests that firms in the capital markets and asset management industry may also participate directly in the innovation

[25] *Fintech in Capital Markets: A Land of Opportunity*, 2016.

M = 95

| t | 1 | 2 | 5 | 8 | 10 | 15 |
|---|---|---|---|---|---|---|
| $P_t(w_0)$ | 0.436 | 0.280 | 0.097 | 0.052 | 0.045 | 0.039 |

M = 75

| t | 1 | 2 | 5 | 8 | 10 | 15 |
|---|---|---|---|---|---|---|
| $P_t(w_0)$ | 0.052 | 0.064 | 0.034 | 0.016 | 0.011 | 0.008 |

M = 60

| t | 1 | 2 | 5 | 8 | 10 | 15 |
|---|---|---|---|---|---|---|
| $P_t(w_0)$ | 0.012 | 0.025 | 0.020 | 0.009 | 0.006 | 0.004 |

**Table IV**
**Estimates of the agent's propensity to be automated for the dates $t = \{1, 2, 5, 8, 10, 15\}$ (years) and different values of automation $M = \{60, 75, 95\}$.**

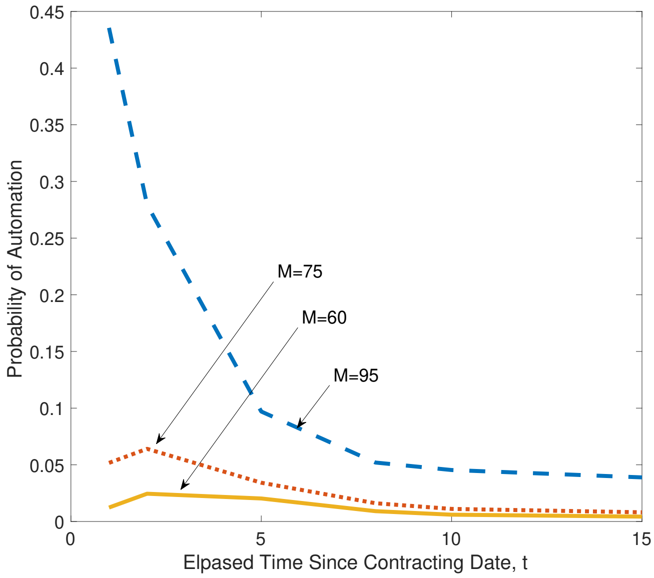


**Figure 9.** Expected contract duration following the advent of technology $\tau_1$ and in the counterfactual scenario $\tau_0$ (M=95).

process through investments in fintechs. It shows that external innovation tends to be preferred over internal R&D, and that fintechs are mainly engaged through M&A and VC funding by such firms. In both of these examples, large investments are made prior to the advent of the automation technology to increase its profitability. However, the delegation to an asset manager that is subject to a financial friction before the adoption of the automation technology may impact this investment decision.

In this section, we extend the model to allow for the case of the principal making an investment at $t = 0^-$ – prior to the contracting date – to increase the profitability of the forthcoming automation technology from $M$ to $(1 + \kappa)M$ at a sunk cost $c(\kappa)M$, with $\kappa > 0$. We assume a quadratic investment cost, and $c(\kappa) = \frac{\kappa^2}{2}$, and the firm has to bear the cost of investment at $t = 0^-$ and wait up until $t = \tilde{T}$ to benefit from the implementation of the automation technology. As in the main model, the automation technology emerges following a single jump process of intensity $\lambda$ and the principal offers a contract to delegate the management of the asset to an agent at $t = 0$. Our goal is to explore how the presence of the agency conflict impacts the optimal investment compared to the first-best benchmark. The necessary condition for such an investment not to be worthless is that

$$\frac{\lambda}{\lambda+r}\kappa > c(\kappa), \tag{29}$$

so it follows that the principal investment is within $[0; 2\frac{\lambda}{\lambda+r}]$.

Next, let us consider the first-best benchmark. If the value of automation after the investment – net of the cost of investment at $t = 0^-$ – remains lower than the value of continuing to delegate to the asset manager, then the principal never invests. The investment is made in the first-best benchmark if and only if[26] :

$$\Pi(\kappa)M > \frac{\lambda}{\lambda+r}\frac{\bar{a}\mu}{r}, \tag{30}$$

where $\Pi(\kappa) = \frac{\lambda}{\lambda+r}(1+\kappa) - c(\kappa)$ is the scaled (by $M$) profit of investing at level $\kappa$. Thus, the first-order condition with respect to $\kappa$ shows us that the optimal level of investment in the first-best framework satisfies $c'(\kappa^{FB}) = \frac{\lambda}{\lambda+r}$. The first-best level of investment is

$$\kappa^{FB*} = \begin{cases} \frac{\lambda}{\lambda+r} \quad \text{if} \quad (1+\frac{1}{2}\frac{\lambda}{\lambda+r})M > \frac{\bar{a}\mu}{r}; \\ 0 \quad \text{otherwise.} \end{cases} \tag{31}$$

Next, let us examine the optimal level of investment in the presence of agency friction. The principal's problem is to determine

$$\sup_{\kappa} V_0^{\kappa}(w) - c(\kappa)M \tag{32}$$

where $V_0^{\kappa}(w)$ denotes the principal's value function when investment $\kappa$ is made and when the agent manages the asset under an optimal contract. It satisfies the following second-order differential

[26] We note that if inequality (31) holds, then the inequality (30) holds as well.

equation

$$\forall w \in [0; \overline{W}_0^\kappa], \quad (\lambda + r)V_0^\kappa(w) = \\ \bar{a}\mu + (\gamma w - \lambda\delta)V_0^{\kappa\prime}(w) + \frac{1}{2}\underline{\beta}^2 V_0^{\kappa\prime\prime}(w) + \lambda V_1^\kappa(w+\delta) \tag{33}$$

together with $V_0^\kappa(0) = \frac{\lambda}{\lambda+r}(1+\kappa)M$, $V_0^{\kappa\prime}(\bar{W}_0^\kappa) = -1$ and $V_0^{\kappa\prime\prime}(\bar{W}_0^\kappa) = 0$ for some $\bar{W}_0^\kappa \geq 0$ that is the payment boundary prior to the availability of the technology. It depends on $V_1^\kappa(w)$, the principal's value function after the advent of the automation technology that is the solution of equation (18) together with the boundary conditions $V_1^\kappa(0) = (1+\kappa)M$, $V_1^{\kappa\prime}(\bar{W}_1^\kappa) = -1$ and $V_1^{\kappa\prime\prime}(\bar{W}_1^\kappa) = 0$ for some $\bar{W}_1^\kappa \geq 0$ that plays the role of the payment boundary once the technology is available. Applying Lemma 2, we obtain that the sensitivity to the asset realization remains at $\beta = \underline{\beta}$, and the sensitivity $\delta$ to the advent of automation technology is the solution of $V_1'(W_{t^-} + \delta(W_{t^-})) = V_0'(W_{t^-})$ for all $W_{t^-}$ such that $V_1'(W_{t^-}) \geq V_1'(0)$ and $\delta(W_{t^-}) = -(W_{t^-})$ otherwise (the limited liability condition).

For now, let us focus on the case of the automation technology being more efficient than the agent, so inequality (30) holds. We show that in this case, the contracting problem and the investment problem can be separated. The following Proposition summarizes this result:

**Proposition** 5: *If condition (30) is satisfied, the principal's problem becomes*

$$V_0(w) + \sup_\kappa \Pi(\kappa)M, \tag{34}$$

*where $V_0$ is the value function prior to the advent of technology; this function was characterized in Proposition 3. Thus, the contracting problem and the investment problem can be separated, and the principal always optimally invests as in the first-best benchmark.*

In turns out that the first-best level of investment in the automation technology is reached if inequality (30) holds. Consequently, investing at a level $\kappa$ shifts the principal's value function upward by $\Pi(\kappa)M$, as illustrated in Figure 10. In particular, it means that the investment problem does not impact the contractual characteristics.

If the automation technology is not as efficient as the agent, then the principal does not necessarily substitute the robot for the agent at the technology's advent $\tilde{T}$, but does so only at the contract termination $\tau$[27]. Consequently, while at first-best the principal never invests in the automation technology if the inequality (30) does not hold, this is not the case in the presence of agency friction. We draw in Figure 11 a typical form of the optimal investment strategy. We can interpret this result as long-termism, as the principal over-invests in the quality of the *future* automation technology (with respect to the first-best case) to mitigate the *current* agency concern.

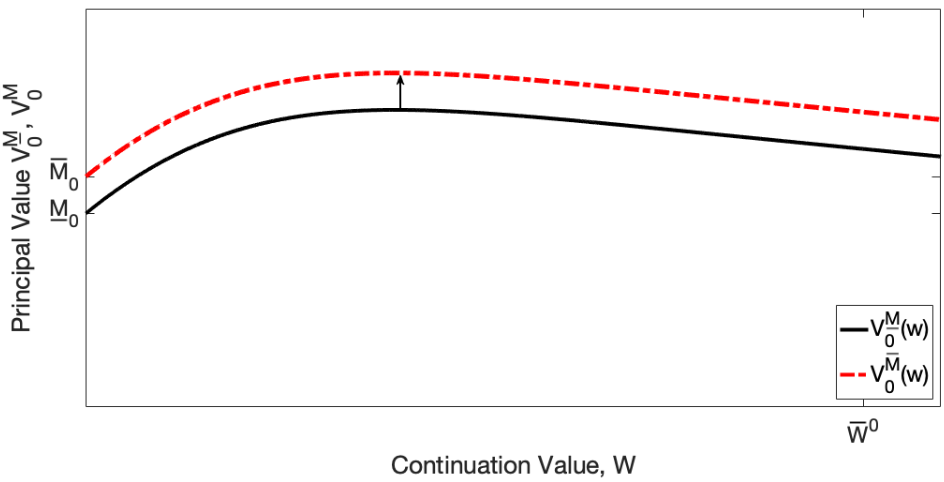


**Figure 10. Change in the value function associated with an increase in $\underline{M}$ to $\bar{M}$, where $\frac{\bar{a}\mu}{r} < \underline{M} < \bar{M}$.**
When the technology is more efficient than the agent, the investment problem and the contracting problem can be separated. Consequently, investing moves upward the value function, and does not impact the payment barrier $\bar{W}^0$.
Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, \underline{M} = 105,\ \bar{M} = 125$.

[27] $\tau = \tilde{T}$ if the agent has not performed sufficiently well at managing the asset.

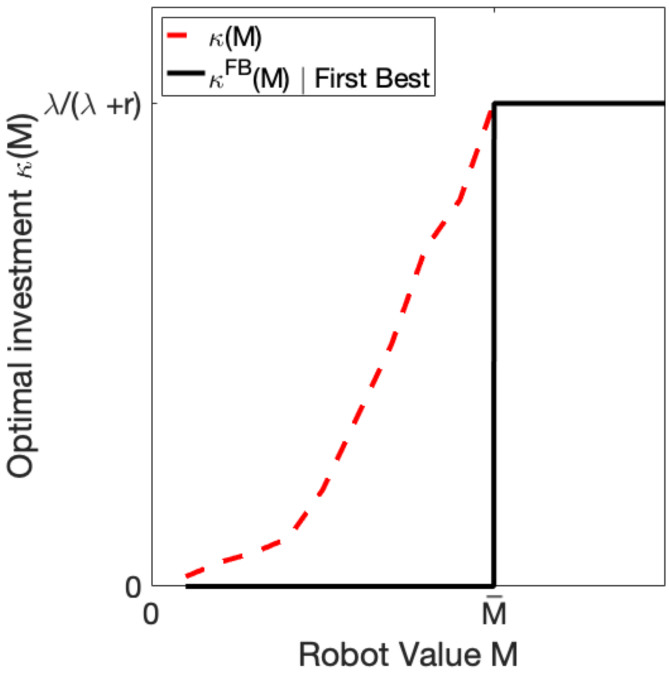


**Figure 11. Optimal investment in the automation technology at first best and in presence of agency friction.**
Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, M = 90$. $\bar{M}$ is such that $\Pi(\kappa)\bar{M} = \frac{\lambda}{\lambda+r}\frac{\bar{a}\mu}{r}$. For values of $M$ over $\bar{M}$, the optimal investment is not distorted by the presence of agency friction. Under $\bar{M}$, the presence of the agency friction makes the principal over-invest in the automation technology.

## B. *Technology Enhancing or Replacing the Agent*

So far, our model has solely considered substituability between robots and high-skill jobs, as advocated by Acemoglu and Restrepo (2018b). Next, we depart from such a setting and assume that the robot can also work in synergy with the agent, so contract termination is no longer a prerequisite for the implementation of the robot. At the advent of the automation technology that follows a single jump process with intensity $\lambda$, suppose that the principal faces two mutually exclusive opportunities: either (1) terminate the agent's contract and replace the agent with the robot (this is the case that has been covered thus far in this paper) or (2) continue the contractual relationship and instead of replaced the agent, enhance the agent with the same technology at a sunk cost $I > 0$. Enhancing the agent permanently augments the agent's productivity,[28] so it increases from $a\mu$ to $(1+\theta)a\mu$, where $\theta > 0$ is the parameter of *synergy* between the agent and the robot. As the changes in production are at the firm level and not agent-specific, we assume that it does not impact the agent's outside option that is normalized to 0. Then, it leads us to the following questions : What are the optimal incentives to provide to an agent when both parties foresee the advent of the automation technology that can either replace or enhance the agent? When is it optimal to enhance the agent or to replace an agent with a robot?

To answer these questions, we derive heuristically an optimal contract under the assumption that the full-effort strategy is optimal. Using backward induction, we first characterize the value function after the advent of the automation technology, which is associated with the principal's decision on the optimal time to enhance or replace the agent. Following the growth option model of Décamps and Villeneuve (2007), such a value function is the solution of the stopping problem

$$V_1(W_t) = \sup_{\tau \geq t} \mathbb{E}\left[ e^{-r(\{\tau\wedge\tau_0\}-t)} \left( V_s(W_{\tau\wedge\tau_0}), V_e(W_{\tau\wedge\tau_0)} \right) \right], \tag{35}$$

where $\tau_0 = \inf\{s \geq 0 \mid W_s = 0\}$ as defined in Proposition (2), and $V_s$ (respectively $V_e$) is the value function associated with the opportunity to replace the agent with a robot (respectively, to enhance the agent). In the rest of the section, $V_1$ is assumed to be concave. While $V_s$ has been characterized already and satisfies equation (18) in Proposition 2, we still have to characterize $V_e$. It is the largest solution of

$$rV_e(w) = \sup_{\beta \geq \underline{\beta}} \left( (1+\theta)\bar{a}\mu + \gamma w V_e'(w) + \frac{1}{2}\beta^2 V_e''(w) \right) \tag{36}$$

with boundary conditions $V_e(0) = 0$, $V_e'(\bar{W}_e) = -1$, and $V_e''(\bar{W}_e) = 0$ for some $\bar{W}_e \geq 0$ that plays the role of the payment boundary once the human-enhancing technology has been implemented. As it is optimal to lay off the agent when the agent's continuation value drops to 0, we set $V_e(0) = 0$

[28]Factor-augmenting technological change is one of the approaches to the study of automation in labour economics (See Bessen (2017), etc.).

because the implementation of an agent-enhancing robot does not produce any benefit if no agent is managing the asset. Then, $V_1$ is the largest solution to

$$rV_1(w) = \sup_{\beta \geq \underline{\beta}} \left( \bar{a}\mu + \gamma w V_1'(w) + \frac{1}{2}\beta^2 V_1''(w) \right) \tag{37}$$

with boundary conditions $V_1(0) = V_s(0) = M$ $V_1(b) = V_e(b) - I$ (the value matching condition) and $V_1'(b) = V_e'(b)$ (the smooth pasting condition) for some threshold $b \geq 0$ where it is optimal to implement the agent-enhancing robot, and where we assume $M < \frac{\bar{a}\mu}{r}$. Figure 12 shows a typical construction of the value function $V_1$, where the sensitivity to the asset realization is set to $\beta_t = \underline{\beta}, \quad \forall t$ as stated in Lemma 2. As before, the principal waits for $\tau_0 = \inf\{t \geq 0 \mid W_t = 0\}$ to replace the agent with the robot, and thus the equality between $V_1$ and $V_s$ holds for $W = 0$. Moreover, the agent-enhancing robot is not implemented when the agent is at too great a risk of termination, and the principal defers its implementation up to a positive threshold far enough to the termination boundary. Then, the principal waits for the agent's continuation value to hit $\bar{W}^1 = \bar{W}_e$ to compensate the agent. We note that the presence of a robot able to either replace or enhance the agent leads to complex non-monetary incentives.

Next, let us consider the value function $V_0$ prior to the advent of the automation technology. Under an optimal contract that implements the full-effort strategy, the dynamics of the agent's continuation value satisfy equation (22) in Proposition 3, and $V_0$ is the largest solution of

$$rV_0(w) = \sup_{\beta \geq \underline{\beta}; \delta \geq -w} \left( \bar{a}\mu + (\gamma w - \lambda\delta) V_0'(w) + \frac{1}{2}\beta^2 V_0''(w) + \lambda(V_1(w+\delta) - V_0(w)) \right) \tag{38}$$

with boundary conditions $V_0(0) = \frac{\lambda}{\lambda + r} M$ $V_0'(\bar{W}^0) = -1$ and $V_0''(\bar{W}^0) = 0$. $V_1$ is the value function after the advent of the automation technology and is characterized by the equation (37). Then, the sensitivity to the asset realization remains as before to $\beta = \underline{\beta}$, and the sensitivity $\delta$ to the advent of the automation technology is the solution of $V_1'(W_{t^-} + \delta(W_{t^-})) = V_0'(W_{t^-})$ for all $W_{t^-}$ such that $V_1'(W_{t^-}) \geq V_1'(0)$ and $\delta(W_{t^-}) = -(W_{t^-})$ otherwise (the limited liability condition).

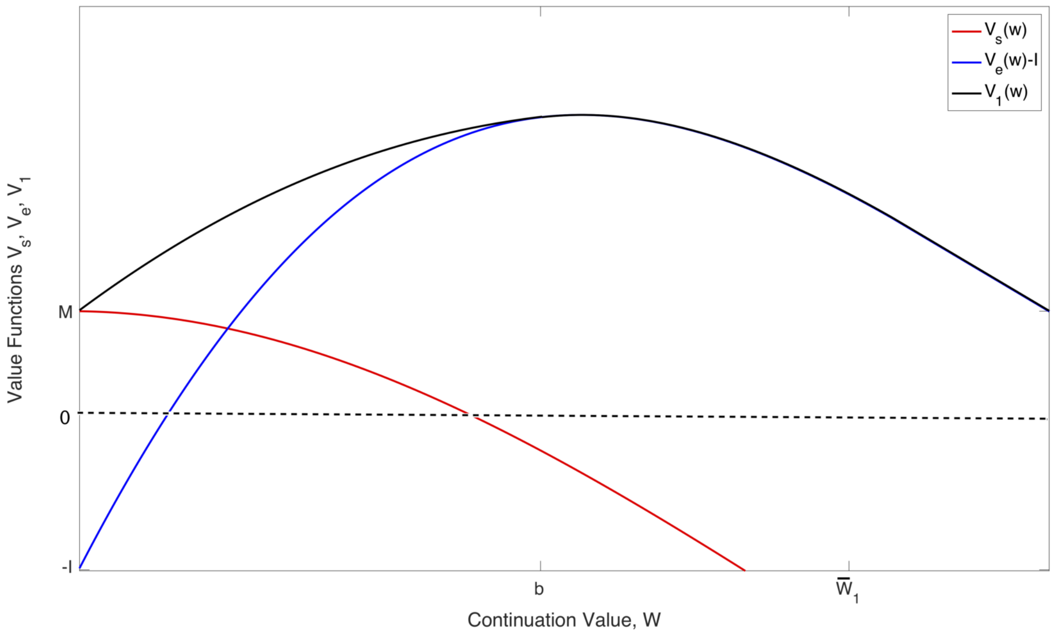


**Figure 12. Principal value after the advent of the automation technology when robot can either replace or enhance the agent.**
Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, M = 90, I = 10$. The principal substitutes the robot for the agent when his continuation value hits 0 for the first time, and the robot enhances the agent when his continuation value is above the threshold $b$ for the first time. b is by $V_1(b) = V_e(b) - I$. Then, payments are provided at the threshold $\bar{W^1}$ to an agent who has been enhanced.

By construction, $V_0'(\bar{W^0}) = V_1'(\bar{W^1})$, and thus $\delta(\bar{W^0}) = \bar{W^1} - \bar{W^0}$. The next proposition states that here $\bar{W^1} > \bar{W^0}$, and thus $\delta(w)$ is always positive on the upper part of the employment interval $[0, \bar{W^0}]$.

**Proposition** 6: *When the robot enhances the agent, the payment boundary moves upwards at the advent of the automation technology, i.e.* $\bar{W^1} > \bar{W^0}$. *Furthermore,* $V_1'(0)$ *increases with* $\theta$.

Consequently, two cases that depend on the value of the synergy parameter $\theta$ may arise. If $\theta$ is sufficiently low, the agent is pushed towards the tails of the employment interval $[0; \bar{W^1}]$, and the sensitivity $\delta$ exhibits a “hollowing-out” pattern for a middle-performing agent, as shown in Figure13.a. Indeed, $\delta$ is negative (positive) for small (respectively, large) values of $w$ because $V_0'(0) > V_1'(0)$, so the principal prefers to put at risk of automation an agent that has not performed sufficiently well (and, respectively, to push an agent that has performed well towards the region where the agent-enhancing robot is implemented). As in the main model of this paper, the contract instantaneously automates a bad performer. If $\theta$ is sufficiently large, the Figure13.b indicates that the enhancement effect may also dominate the "displacement" effect. Indeed, if $\theta$ is large enough then $V_0'(w) \leq V_1'(w) \quad \forall \quad w$, so $\delta \geq 0$ for all $w$. Consequently, the agent's continuation value is always *boosted* by the advent of technology in this case. We note that due to the full-commitment assumption, the threshold $b$ still has to be reached for implementation of the agent-enhancing robot and the agent is still replaced at $\tau_0 = \inf\{t \geq 0 \mid W_t = 0\}$, so the contract can still be terminated after the advent of technology and before enhancing the agent. To conclude, this extension suggests that the propensity of the advent of the automation technology to polarize asset managers and more generally high-skill jobs may have a contractual foundation and be due to the ability of robots to either enhance or replace agents.

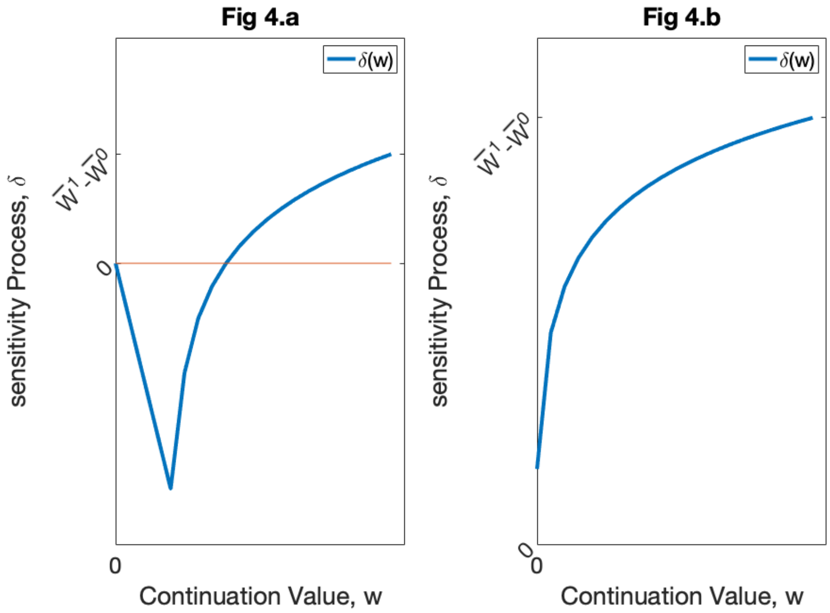


**Figure 13. Process $\delta$ of sensitivity to the advent of the automation technology when the technology can either replace or enhance the agent. $\theta = \theta_{low}$ on the left panel, and $\theta = \theta_{high}$ on the right panel, with $\theta_{low} < \theta_{high}$.**
Parameters are $r = 10\%, \gamma = 12\%, \lambda = 12.5\%, \bar{a} = 10, \mu = 1, B = 0.8, M = 90, \theta_{low} = 20\%, \theta_{high} = 150\%$. The payment boundary jumps from $\bar{W}^0$ before the advent of technology to $\bar{W}^1 > \bar{W}^0$. For low values of synergy which is the case on the left panel, the advent of the automation technology has a "hollowing-out" pattern for middle-performers : continuation value of poor-performers decreases and continuation value of good-performers increases. If the synergy parameter is sufficiently large as in the right panel, the enhancing effect dominates the displacement effect, and the agent's continuation value always increases instantly at the advent of the automation technology.

# VI. Concluding Remarks

In this paper, we study a continuous-time principal-agent model à la DeMarzo and Sannikov (2006) with effort. We embed the advent of a robot that can compete with the agent at managing the asset. It is regarded as an irreversible substitution device that arises stochastically.

We derive an optimal long-term contract that adjusts the provision of incentives to the availability of the robot. Indeed, the principal foresees from the contracting date that a valuable alternative to the agent will become available in the future, and thus designs an incentive-compatible contract to take advantage of this forthcoming and valuable alternative.

We show that it is optimal to automate at the advent of technology if the agent has performed poorly at managing the asset, or if the robot is more efficient than the agent. Hence, we predict a *performance-biased automation* of asset managers, as the impact of the advent of technology on the contract depends on the agent's history of performance of managing the asset.

Finally, we acknowledge that many important factors that impact the decision to automate in the presence of moral hazard are left unaccounted for. Further studies may intend to, e.g., embed ambiguity on the inherent black-box nature of the automation technology, internalize the technology's development within the firm, and include the presence of a sunk cost to automate when the principal has cash constraints.

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# Appendix A. Optimality of the Full-Effort Strategy

In this section, we provide necessary and sufficient conditions for the optimality of the high-effort strategy. It is derived directly from the Proposition 8, section III of DeMarzo and Sannikov (2006) which is our baseline model.

Assume that an optimal contract lets the asset manager shirk on a small period $[t; t + dt)$ without terminating the contract. Then, the agent enjoys a private benefit $Bdt$ while the asset is expected to earn no value during this period. The dynamics of the asset manager's continuation value on $[t, t + dt)$ satisfies

$$dW_t^{\Pi} = \gamma W_t^{\Pi} dt - Bdt + \delta_t (dN_t - \lambda dt) 1_{n_t=0} \tag{A1}$$

Therefore, allowing the agent to shirk is never profitable if and only if

$$V_i(W_t) > e^{-rdt} V_i(W_t + dW_t) \quad \text{where } i = \{0; 1\} \tag{A2}$$

A necessary and sufficient condition for the optimality of the full-effort strategy is

$$\begin{cases} \min\limits_{w \in [0, \bar{W}^0]} \left\{ V_0(w) + \frac{\gamma}{r}\left(\frac{B}{\gamma \bar{a}} - w\right) V_0'(w) \right\} & \geq 0; \\ \min\limits_{w \in [0, \bar{W}^1]} \left\{ V_1(w) + \frac{\gamma}{r}\left(\frac{B}{\gamma \bar{a}} - w\right) V_1'(w) \right\} & \geq 0 \end{cases} \tag{A3}$$

Given $\bar{a}$, this conditions impose an upper boundary on $B$, so the private benefit of shirking has to be not too large.

# Appendix B. Probabilistic background of the model

Here, we define formally the probability measure induced by any effort process $(a_t)_t$, coming from both the observation of the asset value process and from the observation of the availability of the automation technology up to date $t$. We show its equivalence to the standard Weiner measure $\mathbb{P}^0$ on the classical Weiner Space $\Omega = C([0, +\infty), \mathbb{R})$, the set of all continuous real functions that takes their values in $[0, +\infty)$. Let $(Z_t^0)$ be a $\mathcal{F}_t$-Brownian motion under $\mathbb{P}^0$, where $(\mathcal{F}_t)_t$ is the completion of the natural filtration generated by $(Z_t^0)$. Under $\mathbb{P}^0$, we assume that the dynamics of the cash-flow process evolves as

$$dX_t = dZ_t^0$$

Thus, $\mathbb{P}^0$ corresponds to the probability distribution of the cash flows when no active management or effort is exerted. It can be the case when either the agent shirks or when he is laid off. Besides, one may consider $(\mathcal{H}_t)_t$, the completion of the natural filtration generated by the advent of the automation technology, such that

$$\mathcal{H}_t = \begin{cases} 0 \text{ if } t < T; \\ 1 \text{ otherwise.} \end{cases}$$

We call $(\mathcal{G}_t)_t = (\mathcal{F}_t \vee \mathcal{H}_t)_t$ the information set at date $t$. For any effort strategy $a = (a_t)_{t \geq 0}$, which is assumed to be $\mathcal{G}$-adapted and that takes its values in $\{0, \bar{a}\}$, we define a $G$-predictable process

$$\eta_t(a) = exp(-\int_0^t (a_s\mu) dZ_s^0 - \frac{1}{2}\int_0^t (a_s\mu)^2 ds)$$

$(\eta_t(a))_{t\geq 0}$ is a $G_t$-martingale as the effort process takes its values in a bounded interval. Its expectation equals 1 when no effort is exerted. A probability measure $\mathbb{P}^a$ on $\Omega$ can then be defined as

$$\frac{d\mathbb{P}^a}{d\mathbb{P}^0} \mid G_t = \eta_t(a) \tag{B1}$$

Assuming enough integrability conditions, the process $(Z_t^a)$ defined as

$$Z_t^a = Z_t^0 + \int_0^t a_s\mu ds \tag{B2}$$

is a Brownian motion under $\mathbb{P}^a$. Then, any effort strategy $a = (a_t)_{t \leq \tau}$ induces a probability measure $\mathbb{P}^a$ on $\Omega$ for which the dynamics of the cash flows is given by (1).

Consequently, we have that

- The asset manager's expected value of shirking forever from date t with respect to the filtration $G_t$ is given by:

$$\mathbb{E}^0 \left[ \int_t^{+\infty} e^{-\gamma(s-t)} \frac{B}{\bar{a}} ds \mid G_t \right] = \frac{B}{\bar{a}\gamma} \tag{B3}$$

- The expected value of the asset if $\bar{a}$ is enforced forever from date t is given with respect to the filtration $G_t$ by:

$$\mathbb{E}^{\bar{a}} \left[ \int_t^{+\infty} e^{-r(s-t)} (\bar{a}\mu ds + dZ_s^{\bar{a}}) \mid G_t \right] = \frac{\bar{a}\mu}{r}, \tag{B4}$$

- The expected asset value from automating irreversibly at date t is given with respect to the filtration $G_t$ by:

$$M := \mathbb{E}^0 \left[ \int_t^{+\infty} e^{-r(s-t)} (m\mu ds + dZ_s^0) \mid G_t \right] = \frac{m\mu}{r}, \tag{B5}$$

- The expected value of the forthcoming automation, seen from t before the technological advent is given with respect to the filtration $G_t$ by

$$\mathbb{E} \left[ e^{-r(T-t)} M \mid G_t \right] = \frac{\lambda}{\lambda + r} M. \tag{B6}$$

# Appendix C. Omitted Proofs

*Proof.* of Proposition 1

Assume that $M \leq \frac{\bar{a}\mu}{r}$, then the optimal contract in the first-best benchmark (7)-(8) is given by $\Pi^{FB} = (\tau = +\infty, U_0 = w_0)$. Hence, the principal is better off delegating to the agent forever, and he never automates. If the principal cannot get a pledgeable income larger then the value to wait for the technology to arise (i.e. if $\frac{\bar{a}\mu}{r} - w_0 < \frac{\lambda}{\lambda+r}M_0$), he does not delegate to the asset manager.

Now, assume that $M > \frac{\bar{a}\mu}{r}$, then the principal is better off automating at $\tilde{T}$ and the optimal contract in the first-best benchmark is $\Pi^{\tilde{FB}} = (\tau = \tilde{T}, U_0 = w_0)$, and so exhibits a stochastic termination at $\tilde{T}$. The delegation to the agent on $[0, \tilde{T})$ followed by the robot-driven asset generates a the total benefit that is given by

$$\left[\int_0^{+\infty} e^{-rs}\bar{a}\mu ds + e^{-r(s-\tau)}rMds\right] = \frac{1}{\lambda+r}\bar{a}\mu + \frac{\lambda}{\lambda+r}M \tag{C1}$$

Again, the principal offers such a contract to the agent if and only if it generates a positive pledgeable income over $[0, \tilde{T})$, i.e. if and only if $\frac{1}{\lambda+r}\bar{a}\mu \geq w_0$. Otherwise, the principal waits for the advent of the automation technology and automates from $\tilde{T}$.

□

*Proof.* of Lemma 1

At any time t, the agent's total expected value from the incentive-compatible contract Π and an agent's continuation value $W_t^{\Pi}$ – the sum of the prior earnings on $[0, t]$ and the expected future earnings over the time interval $[t, \tau]$– is given by

$$\Upsilon_t^a = \int_0^t e^{-\gamma s}(dU_s + \frac{B}{\bar{a}}(\bar{a} - a_s)ds) + e^{-\gamma t}W_t^{\Pi} \qquad \text{for } t \leq \tau \tag{C2}$$

$$= \mathbb{E}^a\left[\int_0^{\tau^-} e^{-\gamma s}(dU_s + \frac{B}{\bar{a}}(\bar{a} - a_s)ds) + e^{-\gamma\tau}\Delta U_\tau\right] \qquad \text{for } t \leq \tau \tag{C3}$$

It is an uniformly-integrable $\mathcal{G}$-martingale under the probability measure $\mathbb{P}^a$.

Now, let us consider the process

$$(N_t - \int_0^{t\wedge\tilde{T}} \lambda ds)_t, \quad \forall t \leq \tilde{T}. \tag{C4}$$

It is a $\mathcal{H}$-martingale following the theory of point processes, where $\mathcal{H}_t$ is the information set available at date $t$ as it has been introduced in section B of the appendix that concerns the probabilistic background of the model. Thus, we can apply the martingale representation theorem and there exists a unique $\mathcal{G}$-predictable and square-integrable pair of processes $(\beta^{\Pi}, \delta^{\Pi})$ associated with the incentive-compatible contract $\Pi$ such that, for all $t \leq \tau$

$$\Upsilon_t^a = \Upsilon_0^a + \int_0^t e^{-\gamma s} \beta_s^{\Pi} dZ_s^a + \int_0^{t \wedge \tilde{T}} e^{-\gamma s} \delta_s^{\Pi} (dN_s - \lambda ds) \tag{C5}$$

Applying the Itô's formula yields to (11). □

*Proof.* of Lemma 2

Again, let us consider the agent's total expected value at a date t for an incentive-compatible contract $\Pi$ and given an agent's continuation value $W_t^{\alpha}$ that satisfies the dynamics given by (12). This former is defined as a stochastic process $R_t^a$ that follows the dynamics

$$R_t^a = \int_0^t e^{-\gamma s} (dU_s + \frac{B}{\bar{a}}(\bar{a} - a_s) ds) + e^{-\gamma t} W_t^{\alpha} \tag{C6}$$

we must determine the function $f$ for $(R_t^a)_t$ to be a $\mathbb{P}^a$-supermartingale $\forall$ $a$.

$$\begin{aligned}
dR_t^a &= e^{-\gamma t} \left( dU_t + \frac{B}{\bar{a}}(\bar{a} - a_t) dt + dW_t^{\alpha} - \gamma W_t^{\alpha} dt \right) && \text{(C7)} \\
&= e^{-\gamma t} \left( \frac{B}{\bar{a}}(\bar{a} - a_t) dt + f(\beta_t) dt + \beta_t dZ_t^{\bar{a}} + \delta_t (dN_t - \lambda dt) 1_{t \leq \tilde{T}} \right) && \text{(C8)} \\
&= e^{-\gamma t} \left( \frac{B}{\bar{a}}(\bar{a} - a_t) dt + f(\beta_t) dt + \beta_t (dZ_t^a - (a_t - \bar{a}) dt) + \delta_t (dN_t - \lambda dt) 1_{t \leq \tilde{T}} \right) && \text{(C9)} \\
&= e^{-\gamma t} \left( \left( (\frac{B}{\bar{a}} - \beta_t)(\bar{a} - a_t) + f(\beta_t) \right) dt + \beta_t dZ_t^a + \delta_t (dN_t - \lambda dt) 1_{t \leq \tilde{T}} \right) && \text{(C10)}
\end{aligned}$$

Thus, $(R_t^a)_t$ is a supermartingale under $\mathbb{P}^a$ if and only if

$$f(\beta) := \underset{a\in\{0,\bar{a}\}}{inf}\left((\bar{a}-a)(\beta-\frac{B}{\bar{a}})\right) \tag{C11}$$

$$= \begin{cases} \bar{a} & \text{if } \beta \geq \frac{B}{\bar{a}} \\ 0 & \text{otherwise} \end{cases} \tag{C12}$$

Then, $R_t^a$ is a supermartingale under $\mathbb{P}^a$ and $R_t^{a^*}$ is a martingale under $\mathbb{P}^{a^*}$. The contract $((U_t)_t, (\beta_t)_t, (\delta_t)_t)$ is incentive compatible with $a_t^*(\beta) = \bar{a}1_{\beta_t \geq \underline{\beta}}$, where $\underline{\beta} = \frac{B}{\bar{a}}$. Therefore,

$$\mathbb{E}^a\left[\int_0^{\tau^-\wedge\tau_0} e^{-\gamma s}(dU_s + \frac{B}{\bar{a}}(\bar{a}-a_s)ds) + e^{-\gamma(\tau\wedge\tau_0)}\Delta U_{\tau\wedge\tau_0}\right] \leq R_0^a \tag{C13}$$

$$= W_0^\alpha \tag{C14}$$

$$= R_0^{a^*} \tag{C15}$$

And as it is a $R_t^{a^*}$ is a martingale under $\mathbb{P}^{a^*}$,

$$R_0^{a^*} = \mathbb{E}^{a^*}\left[\int_0^{\tau^-\wedge\tau_0} e^{-\gamma s}(dU_s + \frac{B}{\bar{a}}(\bar{a}-a_s^*)ds) + e^{-\gamma(\tau\wedge\tau_0)}\Delta U_{\tau\wedge\tau_0}\right]. \tag{C16}$$

Therefore, if in addition $W_0^\alpha \geq w_0$, the contract $((U_t)_t, (\beta_t)_t, (\delta_t)_t)$ is a candidate solution to the principal's problem (5)-(6). □

*Proof.* of Proposition 2

For now, we consider that the automation technology is always available. For simplicity and without loss of generality, we set $\tilde{T} = 0$. The dynamics of the agent's continuation value follows:

$$dW_t^\beta = (\gamma W_t^\beta - -\frac{B}{\bar{a}}(\bar{a}-a_t))dt + \beta dZ_t^a - dU_t, \quad \forall \quad t \leq \tau\wedge\tau_0.$$

We start by proving that the value function $V_1$ satisfies the dynamic programming principle.

**Lemma** 3: *The value function $V_1$ satisfies the dynamic programming principle :*

$$V_1(w) = \sup_{\beta,\tau} \mathbb{E}_w \left[ \int_0^{(\tau\wedge\tau_0)^-} e^{-rs} \left( \bar{a} 1_{\beta \geq \underline{\beta}} \mu ds - dU_S \right) + e^{-r(\tau\wedge\tau_0)} \left( M - W^{\beta}_{\tau\wedge\tau_0} \right) \right] \tag{C17}$$

We now derive the value function $V_1$ as a mixed optimal control / stopping problem. Let us consider

$$\Phi(w) = \sup_{\beta,\tau} \mathbb{E}_w \left[ e^{-r(\tau\wedge\tau_0)} \Psi(W_{\tau\wedge\tau_0}) \right]. \tag{C18}$$

where $\Psi$ is given by:

$$\Psi(w) = max \left( M - w, \tilde{F}_{\oslash}(w) \right) \tag{C19}$$

and $\tilde{F}_{\oslash}$ satisfies the Stochastic Differential Equation

$$0 = -r\tilde{F}_{\oslash}(w) + \bar{a} 1_{\beta \geq \underline{\beta}} \mu + \gamma w \tilde{F}'_{\oslash}(w) + \frac{\beta^2}{2} \tilde{F}''_{\oslash}(w) \tag{C20}$$

together with the conditions at the boundaries $\tilde{F}_{\oslash}(0) = 0$, $\tilde{F}'_{\oslash}(\bar{W}_{\oslash}) = -1$, and $\tilde{F}''_{\oslash}(\bar{W}_{\oslash}) = 0$. We show that the following holds

**Lemma** 4: *For all $w$, $V_1(w) = \Phi(w)$*

This implies that the principal only considers two strategies: (i) ignore the automation technology and design a contract in a setting à la DeMarzo and Sannikov (2006); (ii) pays what is owed to the agent – his current continuation value– and implements the automation technology with value $M$.

*Proof.* Fix $\beta = \underline{\beta}$, then the problem reduces to an optimal stopping problem and the equality holds following the theorem 3.1 in Décamps and Villeneuve (2007). We still have to show that it is true for any value of the process $\beta$. It is done by proving that $\left(e^{-r(t\wedge\tau_0)} V_1(W_{t\wedge\tau_0})\right)_{t\geq 0}$ is the Snell envelope of $\Psi(.) = max \left( M - ., \tilde{F}_{\oslash}(.) \right)$.

First, we consider the solution to the baseline model of DeMarzo and Sannikov (2006) provided in section III Proposition 7, and noted $F_M$. It is concave and solves

$$0 = -rF_M(w) + \bar{a}\mu + \gamma w F_M'(w) + \frac{\beta^2}{2} F_M''(w)$$

together with $F_M(0) = M$, $F_M'(\bar{W}_M) = -1$, $F_M''(\bar{W}_M) = 0$, and it extends linearly with slope -1 after $\bar{W}_M$. Now, we show that $F_M = V_1$.

**Lemma** 5: *The following holds:* $V_1(w) = \begin{cases} F_M(w) & \textit{if } M \leq \frac{\bar{a}\mu}{r} \\ M - w & \textit{otherwise} \end{cases}$

*Proof.* The proof relies on the property of the Snell envelope. Fix $\beta = \underline{\beta}$ and consider a subsolution to our problem noted $\tilde{V}_1$ and given by

$$\tilde{V}_1(w) = \sup_{\tau} \mathbb{E}_w \left[ \int_0^{(\tau\wedge\tau_0)^-} e^{-rs} \left(\bar{a}\mu ds - dU_S\right) + e^{-r(\tau\wedge\tau_0)} \left( M - W^{\beta}_{\tau\wedge\tau_0} \right) \right] \tag{C21}$$

It is straightforward to see that whenever $M \geq \frac{\bar{a}\mu}{r}$, then it optimal to set $\tau = 0$. Consequently, there is no contract offered to the agent and the terminal payment is $W^{\beta}_{0^-} = 0$. Furthermore, we have by definition and for any given $\tau$

$$\begin{aligned} \tilde{V}_1(w) &\geq \mathbb{E}_w \left[ \int_0^{(\tau\wedge\tau_0)^-} e^{-rs} \left(\bar{a}\mu ds - dU_S\right) + e^{-r(\tau\wedge\tau_0)} \left( M - W^{\beta}_{\tau\wedge\tau_0} \right) \right] &\text{(C22)} \\ &= \mathbb{E}_w \left[ \int_0^{(\tau\wedge\tau_0)^-} e^{-rs} \left(\bar{a}\mu ds - dU_S\right) + e^{-r(\tau\wedge\tau_0)} \tilde{V}_1(W^{\beta}_{\tau\wedge\tau_0}) \right] &\text{(C23)} \end{aligned}$$

The strategy with $U_s = 0$ for all $s$ up to $t$ and $\tau = t$ gives that

$$\tilde{V}_1(w) \geq \mathbb{E}\left( e^{-r(t\wedge\tau_0)} \tilde{V}_1(W^{\beta}_{t\wedge\tau_0}) \right) \tag{C24}$$

According to the Markov property, $(e^{-r(t\wedge\tau_0)}\tilde{V}_1(W^{\beta}_{t\wedge\tau_0}))_{t\geq 0}$ is a supermartingale which dominates $\Psi$. From Lemma (4), we have $\tilde{V}_1(w) = ess\sup_{\tau} \mathbb{E}_w \left[ e^{-r(\tau\wedge\tau_0)} \Psi(W^{\beta}_{\tau\wedge\tau_0}) \right]$ for all $w$, so $\tilde{V}_1$ is the Snell envelope of $\Psi$ when $\beta = \underline{\beta}$.

Moreover, we have from DeMarzo and Sannikov (2006) :

- $(e^{-r(t\wedge\tau_0)}F_M(W^{\beta}_{t\wedge\tau_0}))_{t\geq 0}$ is a supermartingale,
- $F_M$ is concave,
- and $F_M$ dominates $\Psi$, as $F_M(0) = \Psi(0)$, $F'_M(w) \geq -1$ and $F_M \geq F_{\oslash}$.

By definition of the Snell envelope, $\tilde{V_1} = F_M$.

As according to DeMarzo and Sannikov (2006) $(e^{-r(t\wedge\tau_0)}F_M(W^{\beta}_{t\wedge\tau_0}))_{t\geq 0}$ is a supermartingale for any $\beta$, we have that $F_M = \sup_{\beta,\tau} \mathbb{E}_w \left[e^{-r(\tau\wedge\tau_0)}\Psi(W^{\beta}_{\tau\wedge\tau_0})\right]$, which leads to the desired result. □

Hence, $F_M$ is the Snell envelope of $\Psi$. So it extends the result of Décamps and Villeneuve (2007) for any value of the control process $\beta$. □

□

*Proof.* of Proposition 3

When $M_0 \leq \frac{\bar{a}\mu}{r}$, we have derived an optimal contract where the optimal sensitivity parameter $\delta(W_{t^-})$ is not differentiable, as it is shown in Figure 2. Therefore, we cannot apply directly the proof provided in Hoffmann and Pfeil (2010) or Demarzo et al. (2012) to our Proposition, and we provide here an alternative proof that the value function $V_0(w)$ is concave. Then, we verify that it corresponds indeed to the principal's value function before the advent of the automation technology.

- **Step 1 – Concavity :**

  From the boundary condition, there exists $\epsilon > 0$ such that:

$$V_0''(\bar{W}^0 - \epsilon) > V_0''(\bar{W}^0) \tag{C25}$$

  If we assume that $V_0$ is concave close to the boundary $\bar{W}^0$, then in addition

$$0 > V_0''(\bar{W}^0 - \epsilon) \tag{C26}$$

Now, let us show that it implies that the function is concave over the whole interval $[\frac{B}{\gamma}; \bar{W}^0]$. In order to do so, let us assume that there exists $\tilde{W} := \sup_{w \in [\frac{B}{\gamma}; \bar{W}^0]} \{V_0''(W) \geq 0\}$. We have by continuity that $V_0''(\tilde{W}) = 0$ while $V_0''(\tilde{W} + h) < 0$, for a small $h > 0$ taken such that $(\tilde{w} + h)V_0'(\tilde{w} + h) = \tilde{w}V_0'(\tilde{w})$. From (21) we have that $V_0'(\tilde{w}) > 0$.

We can also write the following expression for the difference quotient:

$$
\begin{aligned}
(r+\lambda)\left[\frac{V_0(\tilde{w}+h) - V_0(\tilde{w})}{h}\right] = \\
\frac{1}{h}[\gamma(\tilde{w}+h) - \lambda\delta(\tilde{w}+h))V_0'(\tilde{w}+h) - (\gamma\tilde{w} - \lambda\delta(\tilde{w})))V_0'(w) \\
+ \underbrace{\frac{\beta^2}{2}V_0''(\tilde{w}+h)}_{<0} \\
+\lambda \underbrace{(V_1(w+h+\delta(w+h)) - V_1(w+\delta(w)))}_{\text{roughly zero}}]
\end{aligned}
\tag{C27}
$$

So,

$$
\begin{aligned}
(r+\lambda)\left[\frac{V_0(\tilde{w}+h) - V_0(\tilde{w})}{h}\right] < \\
\frac{1}{h}\left[\gamma(\tilde{w}+h) - \lambda\delta(\tilde{w}+h)\right)V_0'(\tilde{w}+h) - (\gamma\tilde{w} - \lambda\delta(\tilde{w})))V_0'(w)
\end{aligned}
\tag{C28}
$$

Now, we use that $(\tilde{w} + h)V_0'(\tilde{w} + h) = \tilde{w}V_0'(\tilde{w})$, then

$$
\begin{aligned}
(r+\lambda)\left[\frac{V_0(\tilde{w}+h) - V_0(\tilde{w})}{h}\right] < \\
\frac{1}{h}[-(B + \lambda\delta(\tilde{w}+h))V_0'(\tilde{w}+h) + (B + \lambda\delta(\tilde{w}))V_0'(w)]
\end{aligned}
\tag{C29}
$$

Which translates, if $\lambda\delta(w)$ is sufficiently small, to

$$(r+\lambda)\left[\frac{V_0(\tilde{w}+h)-V_0(\tilde{w})}{h}\right] < -B\left[\frac{V_0'(\tilde{w}+h)-V_0'(\tilde{w})}{h}\right] \tag{C30}$$

$$\text{Therefore, } \left[\frac{V_0(\tilde{w}+h)-V_0(\tilde{w})}{h}\right] < 0 \tag{C31}$$

As it contradicts with the assumption that $V_0'(w) > 0$, therefore we have that $V_0''(W) < 0$ $\forall w \in [\frac{B}{\gamma}; \bar{W^0}]$. We conclude that $V_0$ is concave over the whole employment interval as long as it is concave close to $\bar{W^0}$. The complete proof of the concavity of the value function in this case is not provided yet.

- **Step 2 – Verification :** As usual in dynamic contracting theory, our last step is to verify that we have indeed derived an optimal contract. For any incentive-compatible contract, let us define
$\mathrm{F}_t = \int_0^t e^{-rt}(a^*\mu dt - dU_t) + e^{-rt}V_1(W_t,)1_{\{t\geq T\}} + e^{-rt}V_0(W_t)1_{\{\tilde{T}>t>\tau\}}$
$+ e^{-rt}\left(\frac{\lambda}{\lambda+r}M\right)1_{\{t\leq\tau\}}$

By Itô's Lemma, its drift is

$$e^{-rt}\left(\frac{a^*\mu}{r}-M\right) \tag{C32}$$

which is always negative as here $M \geq \frac{a^*\mu}{r}$. Therefore, $F_t$ is a supermartingale and

$$V_0(W_0) = F_0 \geq \mathbb{E}^{a^*}[F_t \mid \mathcal{G}_t] \tag{C33}$$

with an equality for the contract derived in the Proposition 3. Then, the optimal choice of sensitivity $\delta$ satisfies:

$$V_0'(w) = V_1'(w+\delta) \tag{C34}$$

as long as it remains larger than $-w$ to fulfill the limited-liability condition.

When $M_0 > \frac{\bar{a}\mu}{r}$, then $M_0 - w$ dominates the largest solution of the HJB Equation (15) for $n = 0$. Consequently, the principal is better off solely waiting for the robot without offering a contract to the agent and implements the robot-driven asset management from $\tilde{T}$.

*Proof.* of Proposition 4
First, we show that $\delta(w) < 0$ in the neighbourhood of 0. We call $V_1^M$ the principal's value function associated to the contract à la DeMarzo and Sannikov (2006) together with a value of automation $M$. It is the optimal contract after the advent of technology. Because this contract does not make the agent sensitive to the advent of robots, it is a subsolution to our problem. Consequently, $V_0(0) = V_1^{M_0}(0) = M_0$ together with $V_0'(0) > V_1^{M_0}{}'(0)$. Now, we use that $\frac{dV_1(0)}{dM} \leq 0$ from Table A1 of Explicit Comparative Statics Calculations in DeMarzo and Sannikov (2006). Consequently, $V_1^{M_0}{}'(0) > V_1^{M}{}'(0)$, and we have $V_0'(0) > V_1^{M}{}'(0)$. Thus, $\delta(W) < 0$ in the neighbourhood of 0 because value functions are concave.

Now, we prove the existence of $\hat{W} = \inf\{w \mid V_1^{M}{}'(0) = V_0'(w)\}$. By construction, $V_1^{M}{}'(0) \geq -1$, so we have $V_0^{M_0}{}'(0) \geq V_1^{M}{}'(0) \geq V_0'(\bar{W}^0)$, where $\bar{W}^0$ is such that $V_0^{M_0}{}'(\bar{W}^0) = -1$. Because $V_0$ is concave, we can apply the Intermediate Value Theorem to conclude that $\hat{W}$ exists. By limited-liability, we impose that $\delta(w) = -w$, $\forall w \leq \hat{W}$. Furthermore, there exists by construction $\bar{W}^1$ such that $V_1{}'(0) = -1$. To show that $\delta(w) \leq 0$ , $\forall w$, it remains to show that $\bar{W}^1 < \bar{W}^0$, which is analogous to the proof of Lemma B2 in Hoffmann and Pfeil (2010). $\square$

*Proof.* of Proposition 5
Assume that the value of the technology jumps from $M \geq \frac{\bar{a}\mu}{r}$ to $M + \epsilon$. Then, it leads $V_1(w)$ to increase to $V_1(w) + \epsilon$. As the value function $V_0$ satisfies Equation 21, $V_0$ increases by $\frac{\lambda}{\lambda+r}\epsilon$, and $V_0(0) = \frac{\lambda}{\lambda+r}(M + \epsilon)$. Consequently, $V_0$ moves upwards by $\frac{\lambda}{\lambda+r}\epsilon$ when $M \geq \frac{\bar{a}\mu}{r}$ increases by $\epsilon$, which leads to the desired result. $\square$

*Proof.* of Proposition 6
The proof of $\bar{W}^1 > \bar{W}^0$ relies on analogous arguments than the proof of Lemma B2 in Hoffmann and Pfeil (2010). To show that $V_1'(0)$ increases with $\theta$, we start by showing that $V_e$ increases with $\theta$. Let us examine 2 value functions $V_e^{\underline{\theta}}$ and $V_e^{\bar{\theta}}$ associated to $\underline{\theta}$ and $\bar{\theta} > \underline{\theta}$. We have $V_e^{\bar{\theta}} = V_e^{\underline{\theta}} = 0$

together with $V_e^{\bar{\theta}}(W) > V_e^{\underline{\theta}}$ for $W > 0$. As (1) we have by construction $V_1(b) = V_e^{\underline{\theta}}(b)$, while (2) $V_1(0) = M$, the concavity of $V_1$ leads to the desired result.

□

# Appendix D. Algorithm

Finding an optimal contract is a free-boundary problem as both the principal's value function and the payment boundary are unknown. We solve for $(V_n, \bar{W}_n$ where $n = 0; 1$ using the shooting method.

1. First, we solve for $(V_1, \bar{W}^1)$,
2. Then, we set $\delta(w) = -w$,
3. (a) Given $\delta$, we solve for $(V_0, \bar{W}^0)$,
   (b) For each $w$ such that $V_0'(w) \leq V_1'(0)$ we set $\delta$ such that $V_0'(w + \delta(w)) = V_1'(w)$, and otherwise we let $\delta(w) = -w$.
4. We repeat step 3 until convergence, with the convergence criteria :

$$| V_0^i(w) - V_0^{i-1}(w) |< 10^{-3}, \tag{D1}$$

where i stands for the number of iterations already made.

## Summary of Chapter II

In this paper, we study the adoption of automation technology in asset management. We build a principal-agent model in continuous time in which delegation of asset management to an agent is subject to moral hazard and will become automatable at an uncertain time. We derive an optimal long-term contract, and predict that that the empirically observed layoffs that accompany the emergence of an automation technology may have a contractual foundation. We provide several testable implications on the impact of the emergence of automation technologies on the bonuses and on the contract duration. Then, we extend our model to consider a richer setting. First, we let the principal invest prior to the contracting date to increase the value of the forthcoming automation technology, and show that, if the automation technology is more efficient than the agent at managing the asset, then we can separate the investment problem and the contracting problem. Second, we extend our model and assume that after the technology emergence, the principal can either replace the agent as in the main model, or enhance the agent's productivity, both alternatives being mutually exclusive. We show that for some parameters' value, the advent of robots may lead to the polarization of asset management.

# Chapter III

# Optimal Dynamic Contract with a Shock on the Ability to Divert Cash Flow

**Abstract**

This paper explores a continuous-time principal-agent model where the agent can divert cash flow. The novelty is that the benefit of cash-flow diversion is subject to an exogenous and persistent shock that can be interpreted as a new regulation on the executive pay that limits the usage of fringe benefits or perquisites out of the owner's sight. First, our result suggests that the compression of the bonuses at the advent of the shock: the reduction (respectively, increase) of the expected bonus of good (respectively, poor) performers. Second, our analysis also predicts the regulation-induced retention of a poor performer, defined as maintaining an agent in place while his poor performance would have induced his dismissal in the absence of the shock on the benefit of cash-flow diversion.

# 1 Introduction

The seminal work of Jensen and Meckling (1976) on agency costs has emphasized the necessity of an adequate provision of incentives to align the agent's interests with those of the owner. Otherwise, it may be tempting for the agent to divert cash flow out of the owner's sight. A recent and striking illustration of this phenomenon has led to Carlos Ghosn's dismissal from his CEO position at Renault-Nissan in January 2019. While it was found that Renault paid part of Ghosn's wedding reception at Versailles in 2016,[1] an external audit has also identified about 11 million euros in questionable spendings.[2] Enforcing regulations that limit the agent's ability or benefit to misbehave may be an effective tool to address such a concern.

This paper presents a dynamic contracting model that allows for an exogenous and persistent change in the agent's benefit of cash-flow diversion. We take an optimal contracting approach to investigate how the incentives adapt to the advent of such a shock. Indeed, while reforms on executive pay that address this problem are valuable for the shareholders, it is not clear how they impact the long-term provision of incentives to the executives.

Our analysis starts by the formulation of a dynamic principal-agent model à la DeMarzo and Sannikov (2006) in which an owner (hereafter the principal) hires a manager (hereafter the agent) to operate a firm. An agency problem arises because the principal only observes the cash flow level reported by the manager so that the latter can divert cash flow. Then, the provision of incentives consists of two parts : (i) lump-sum payments given once the principal has observed good performance of the firm (deferred compensation), and (ii) the agent's dismissal once the principal has observed too poor performance (performance-induced dismissal). The novelty of our model is that at the contracting date, both parties foresee that a persistent and exogenous change may occur at an uncertain date and make the agent's benefit of cash-flow diversion drop. We interpret this shock as a new regulation on the executive compensation that limits the usage of fringe benefits or perquisites out of shareholders' sight, hence reducing the agency friction.

We highlight our main findings. Because the agent can divert cash flow, the principal must steadily tie the agent's expected wealth to the reported cash flow, which is costly. Thus, the advent of a shock that drops the agent's benefit of cash-flow diversion is valuable for the principal, reducing the cost of the contractual delegation.

[1] https://fr.media.groupe.renault.com/assets/communication-groupe-renault-21221855-e3532.html

[2] https://www.reuters.com/article/us-renault-nissan-ghosn/renault-nissan-audit-findings-submitted-to-french-prosecutors-idUSKCN1U72BK

At the advent of such a shock, we show that the agent's expected wealth changes in a way such that an agent who has performed well up to date (i.e., with a large expected wealth) is punished while a poor performer (i.e., with a low expected wealth) is rewarded by being moved further away from the termination boundary. While the optimal contract maintains the incentive compatibility throughout the delegation, a negative shock on the agent's benefit of cash-flow diversion benefits a poor performer and disadvantages a good performer. However, adjusting incentives at the advent of such a shock increases the contract efficiency, and thus it is valuable for the principal.

Our paper derives testable implications based on this mechanism of incentives adjustment. First, poor performers are at a lesser risk of dismissal. To that extent, we introduce the concept of regulation-induced retention, defined as maintaining an agent active while he would have been dismissed in the absence of the shock on his benefit of cash-flow diversion. While in the baseline model of DeMarzo and Sannikov (2006), solely poor performance induces the agent's dismissal, we show that in this framework, an exogenous change to firm performance may also affect the dismissal decision. Jenter and Kannan (2015) observe that exogenous industry and market shocks affect CEO retention. Hence, their empirical evidence contrasts with standard results in contracting theory stating that the principal should filter what is beyond the agent's scope in the optimal provision of incentives. We complement the literature by providing novel insights on an additional factor exogenous to the firm performance that also impacts such a decision.

Second, we predict the compression of the expected bonuses at the advent of the shock: a good performer should receive lower bonuses, while a poor performer should receive larger bonuses. This finding is in line with Mas (2019), who shows that the 1934 mandated pay disclosure has induced both an increase in the average CEO compensation and a reduction in the earnings of outperforming CEOs. While the author considers this empirical finding "intriguing", we show that the dynamic contracting perspective provides a comprehensive explanation for such a result. However, our predictions contrast with Hermalin and Weisbach (2012), as the authors argue that managers with bargaining power may be able to obtain a larger compensation from such a reform that increases the firm value.

Our study is closely related to Hoffmann and Pfeil (2010), who build a similar model with a shock to the mean of cash flows. They show that, under the optimal contract, the agent is rewarded (respectively, penalized) when a positive (respectively, negative) shock occurs (see also Demarzo et al. (2012), and Li (2017)). Their model provides a theoretical explanation to the empirical findings of Garvey and Milbourn (2006), Bertrand and Mullainathan (2001), and Francis et al. (2013) who show that exogenous events significantly impact the compensation of CEOs and

VPs. The main difference between a shock on the mean of cash flows and a shock on the agent's benefit of cash-flow diversion is that in the first case, the agent's productivity increases, and in the second case, the cost of the contractual delegation decreases. While the sensitivity of the agent's expected wealth must remain constant for incentive-compatibility when a shock of the mean of cash flow is considered, it decreases in our model with a shock on the agent's benefit of cash-flow diversion. Consequently, we find that the advent of the shock penalizes a good performed in our model.

Our paper is also related to the literature that studies the impact of new regulations on executive pay. Greenstone et al. (2005) find that shareholders positively value reforms on executive pay. They study the introduction of the 1964 Securities Acts Amendments and find abnormal excess returns for firms significantly impacted by such a reform. On the agent's side, the literature shows that reforms expanding the mandatory compensation disclosure of executives have achieved mixed results. First, Morse et al. (2011) advocate that additional disclosures mitigate rent extraction and reduce the average pay. While we may indeed interpret the drop in the agent's benefit at cash-flow diversion as a decline in the agent's ability to extract rent, we show that it does not necessarily reduce the average pay. Empirical investigations of the effect of mandatory compensation disclosure support this idea and an increase in the average CEO pay has been observed following the introduction of the 2006 Compensation Discussion and Analysis act (Gipper, 2021).

# 2 The Model

In this section, we present a model in continuous time where the owner of a firm delegates its management to an agent who can divert cash flow out of the owner's sight and where an exogenous and persistent change can impact the benefit of cash-flow diversion. Both parties fully commit to a long-term contract that characterizes the delegation, and limited liability protects the agent. Let us assume that the cash flow generated by the firm evolves according to the dynamics

$$dX_t = (\mu - a_t)dt + dZt, \tag{1}$$

where $a_t \in \{0; \bar{a}\}$, $\bar{a} > 0$ represents the level of cash flow diversion. We assume that a moral-hazard problem arises, so the principal only observes $X_t$, not $a_t$. At each instant where the agent diverts cash flow, his consumption increases by $\lambda_t \bar{a}$, with $\lambda_t \in (0, 1]$. $\mu$ is the drift parameter of cash flows in the absence of diversion, and Z is a standard Brownian motion on a complete probability space. In addition,

$\lambda_t$ is subject to exogenous and verifiable shock that makes it jump from $\bar{\lambda}$ to $\underline{\lambda} < \bar{\lambda}$ with a probability $pdt$ in any time interval $(t, t+dt]$. Thus, after the advent of the shock, the benefit of diverting cash flow decreases permanently. Besides, we assume that both the agent and the principal are risk-neutral, and the agent is protected by limited liability. While the principal discounts at a rate $r > 0$, the agent is more impatient and discounts at $\gamma > r$.

The delegation starts at date 0 and follows the term of a contract $\Pi = \{U; \tau\}$ that consists of cumulative payments $\{U_t : 0 \leq t \leq \tau\}$ and a date of termination $\tau$. We assume that the agent cannot save, so the level of agent's consumption is given at any time t by $dU_t + \lambda_t a_t dt$. For an arbitrary contract $\Pi$ and a startegy of cash-flow diversion $a = (a_t)_t$, the agent gets in expectation from the contractual relationship a value

$$\mathbf{E}^a \left[ \int_0^\tau e^{-\gamma t} (dU_t + \lambda_t a_t dt) \right]. \tag{2}$$

The cash-flow diversion strategy induces a unique probability measure $\mathbf{Q}^a$, and $\mathbf{E}^a$ is the associated expectation operator. The agent's outside option is normalized to zero without loss of generality. Concerning the principal, he gets in expectation

$$\mathbf{E}^a \left[ \int_0^\tau e^{-rt} ((\mu - a_t)dt - dU_t) + e^{-r\tau} L \right], \tag{3}$$

where L is the scrap value of the firm at the contract termination. We remark that in the absence of shock on the agent's benefit of cash-flow diversion, the model is similar to the model of DeMarzo and Sannikov (2006).

# 3 Optimal Contract

At date 0, both parties fully commit on the long-term to contract $\Pi$ that is contingent on the observed cash flows and the exogenous shock that affects the agent's ability to divert cash flows. Let us define $\mathcal{F}_t$ as the information set available to the principal at any date t. Formally, we say that $U$ is a $\mathcal{F}$-adapted process, and that $\tau$ is a measurable $\mathcal{F}$-stopping time that can be infinite.

The agent chooses a strategy that maximizes his total expected wealth given in equation (2), and we say that the contract $\Pi = \{U; \tau\}$ is incentive-compatible if it induces the agent to exert a strategy $a^* = (a_t^*(\Pi))_t$ that satisfies

$$a^* = \arg\max_a \mathbf{E}^a \left[ \int_0^\tau e^{-\gamma t} (dU_t + \lambda_t a_t dt) \right] \tag{4}$$

Hence, the principal's problem is to find an incentive-compatible contract that maximizes the principal's total expected value. It can be formulated as

$$\sup_{\Pi \text{ I.C.}} \mathbf{E}^a \left[ \int_0^\tau e^{-rt}((\mu - a_t)dt - dU_t) + e^{-r\tau} L \right] \tag{5}$$

As it is standard in the dynamic contracting literature, the agent's continuation value is a state variable in our model. It represents how much the agent expects to earn from any date t onwards. To define the agent's continuation value $W = (W_t)_t$ associated with the contract $\Pi$, take an incentive-compatible contract $\Pi$, so both the principal and the agent have the same set of information. Then, we have

$$W_t = \mathbf{E}^a \left[ \int_t^\tau e^{-\gamma t}(dU_t + \lambda_t a_t dt) \right]. \tag{6}$$

The agent's continuation value represents the agent's future expected earnings from any date t. As the agent is protected by limited liability, we impose that the contractual relationship stops the first time $W_t = 0$. As a consequence, we introduce

$$\tau_0 = inf\{t \geq 0 \mid W_t = 0\} \tag{7}$$

and we have that $\tau \leq \tau_0$.

Besides, our model relies on a second state variable that accounts for the advent of the shock on the agent's benefit of cash-flow diversion. This is the purpose of the variable that we denote $N = \{N_t\}_{t \geq 0}$, a single-jump process that makes the variable $\lambda$ jumps from $\bar{\lambda}$ to $\underline{\lambda} < \bar{\lambda}$ with intensity $p$. Specifically, $pdt$ is the probability that the jump occurs during any time interval $(t, t+dt]$. $N$ takes the value 0 when $\lambda = \bar{\lambda}$ and the value 1 when $\lambda = \underline{\lambda}$.

In the following lemma, we apply the martingale representation theorem to find a stochastic representation for the agent's continuation value.

**Lemma 1.** ***Representation of the agent's continuation value as a jump-diffusion process***
*There exists a pair of $\mathcal{F}$-predictable processes $(\beta, \delta)$ where $\beta = (\beta_t, t \geq 0)$ and $\delta = (\delta_t, t \geq 0)$ such that the agent's continuation value $W$ evolves according to the dynamics*

$$dW_t = \gamma W_t dt + \beta_t(dZ_t - a_t dt) + \delta_t(dN_t - pdt1_{N_t=0}) - dU_t \qquad \text{for } t \leq \tau \tag{8}$$

*We call $\beta$ the agent's sensitivity to the cash-flow process and $\delta$ the agent's sensitivity to the advent of the shock.*

First, we note that the martingale term $\delta_t(dN_t - pdt1_{N_t=0})$ is zero on expectation, so the agent's continuation value grows at the rate $\gamma$. Second, the agent is made sensitive to the realization of the firm's cash flows through the term $\beta_t dZ_t$. Whenever the agent diverts cash-flow and $a_t = \bar{a}$, it impacts the profitability of the firm and thus it reduces his continuation value by $\beta_t\bar{a}$ per unit of time. Also, we note the agent's continuation value instantly jumps at the advent of the shock, and the size of the jump is given by the value of the process $\delta$ when the shock occurs.

Now, we derive the optimal contract using the dynamic programming approach. As value functions are forward-looking processes, we use backward induction to solve the principal's problem. Thus, we will derive the solution after the exogenous shock on the agent's benefit of cash-flow diversion and then before the shock. We call the principal's value the highest value that the principal can extract from the delegation to the agent. It depends on both the agent's continuation value and on whether the shock on the agent's benefit of cash flow diversion has occurred. In the rest of this paper, we denote the principal's value by $V_0$ before the shock and $V_1$ after the shock. Once the shock has occurred, the agent's benefit of cash-flow diversion remains constant forever. Then the optimal contract is the one derived in DeMarzo and Sannikov (2006) and characterized in the following proposition.

**Proposition 1.** [3] ***The optimal contract after the shock on the agent's benefit of cash-flow diversion***

*Suppose that the agent's benefit of cash-flow diversion is equal to $\underline{\lambda}$. Then, under the optimal contract that induces the agent to never divert cash flow, the principal's value function is concave and solves the following Second-Order Differential Equation*

$$rV_1(w) = \mu + \gamma w V_1'(w) + \frac{1}{2}\underline{\lambda}^2 V_1''(w) \quad \text{for any } w \in [0; \bar{W}^1]; \tag{9}$$

*together with $V_1(0) = L$ (value-matching condition); $V_1'(\bar{W}^1) = -1$ (smooth-pasting condition); and $V_1''(\bar{W}^1) = 0$ (super-contact condition). The value function extends linearly afterward with slope -1. In addition, it is optimal to terminate the contract at $\tau_0$.*

As making the agent sensitive to the project's cash flow is costly, $\beta$ is set to the minimum value that induces the agent not to divert cash flow, i.e., $\beta_t = \underline{\lambda}$ up to the contract termination. It is maintained constant as the agent's private benefit is fixed after the advent of the exogenous shock.

[3] The proof is provided in DeMarzo and Sannikov (2006), Section 3, Proposition 7

Moreover, it is valuable for the principal to postpone payment up to a certain threshold denoted $\bar{W}^1$. A lump-sum payment $\Delta U$ provided at any instant would make the principal proceed with the optimal contract and a remaining continuation value of $w - \Delta U$. Hence, the inequality $V(w) \geq V(w - \Delta U) - \Delta U$ must holds at any instant. It implies that $V'(w) \geq -1, \forall\, w$, so the marginal benefit of providing incentives through deferred compensation remains greater than the marginal value of making a lump-sum payment to the agent.

Finally, the contract is terminated as soon as $W$ reaches 0. Indeed, it implies that the agent no longer expects to earn any benefit from exerting effort, so nothing precludes that he diverts cash flow onwards.

We consider now the principal's value before the jump on the agent's benefit of cash-flow diversion. The following proposition characterizes the optimal contract in this situation.[4]

**Proposition 2.** ***The optimal contract before the shock on the agent's benefit of cash-flow diversion***
*Assume that both parties foresee the advent of a shock on the agent's benefit of cash-flow diversion that makes the parameter $\lambda$ drop from $\bar{\lambda}$ to $\underline{\lambda} < \bar{\lambda}$. Then, under the optimal contract that induces the agent to never divert cash flow, the principal's value function is concave and is given by the solution to the following second-order differential equation*

$$\forall w \in [0; \bar{W}^0], \quad (p+r)V_0(w) = \mu + (\gamma w - p\delta(w))V_0'(w) + \frac{1}{2}\bar{\lambda}^2 V_0''(w) + pV_1\left(w + \delta(w)\right) \tag{10}$$

*together with $V_0(0) = L$ (the value-matching condition), $V_0'(\bar{W}^0) = -1$ (the smooth-pasting condition), $V_0''(\bar{W}^0) = 0$ (the super-contact condition), and where the value function $V_1$ is characterized in Proposition 1. The value function extends linearly afterwards with slope -1. $\delta$ is such that $V_1'(W_{t^-} + \delta(W_{t^-})) = V_0'(W_{t^-})$.*

## 3.1 Analysis of the Optimal Contract

Let us now discuss the optimal contract in detail. Figure 1 illustrates the principal's value functions associated with the optimal contract and the optimal sensitivity to the shock on the agent's benefit of cash-flow diversion. At the advent of the shock,

[4] For that purpose, we need to define the left-limit of any continuous-time process $Y_t$ as $Y_{t^-} = \lim_{s \uparrow t} Y_s$ together with $Y_{0^-} = Y_0$.

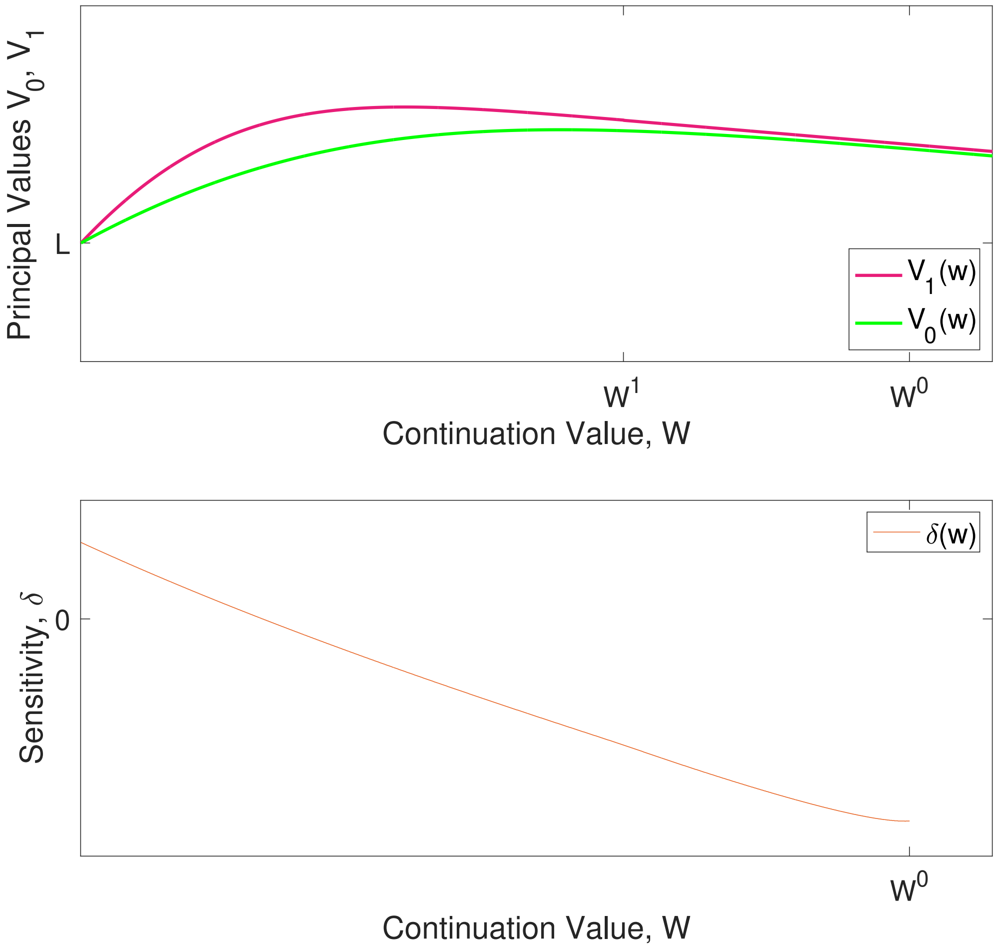


Figure 1: **Principal's value functions $V_0$ and $V_1$ prior to and after the shock on the agent's benefit of cash-flow diversion (upper graph), and a representation of $\delta$ the agent's sensitivity process to the advent of the shock (lower graph).**
The parameters value is provided in Table 1.

the value function jumps from $V_0$ to $V_1 > V_0$. Indeed, the shock alleviates the severity of the agency friction, so providing the incentives to the agent becomes cheaper, and diverting cash flow becomes relatively less efficient for the agent. Hence, the principal can lower the sensitivity of the agent to the cash-flow process. Furthermore, it is no longer necessary to defer compensation as much as before, and thus we conjecture that the payment boundary moves from $\bar{W}^0$ to $\bar{W}^1 < \bar{W}^0$.

Next, we discuss how the agent is made sensitive to the advent of the shock, i.e., how the agent's continuation value changes to the advent of the shock. We show in proposition 2 that the sensitivity to the advent of the shock is such that it maintains the marginal value of delegating to the agent constant $(V_1'(W_{t^-}+\delta(W_{t^-})) = V_0'(W_{t^-}))$. We now proceed to discuss why it leads to the compression of the agent's continuation value at the advent of the shock. First, our preceding conjecture that $\bar{W}^1 < \bar{W}^0$ together with the equality $V_0'(\bar{W}^0) = V_1'(\bar{W}^1) = -1$, leads to $\delta(\bar{W}^0) = \bar{W}^1 - \bar{W}^0 < 0$. Consequently, an agent who has performed well enough up to the advent of the shock experiences a drop in his continuation value. Hence, that would imply that $\delta$ to takes negative values when W is large enough. Second, the drop in the benefit of cash-flow diversion makes the contract termination relatively less efficient for the principal too $(V_1'(0) > V_0'(0))$[5]. Hence, $\delta$ takes positive values when W is low, and poor performers are moved further away from the termination boundary at the advent of the shock. Both these effects lead to the compression of the agent's continuation value when the shock occurs. We summarize this discussion in the following Conjecture.

**Conjecture 1.** *When the benefit of cash-flow diversion drops, the agent's continuation value jumps upward for W low enough and drops for W high enough.*

In the following section, we present several testable implications to investigate how a change in the regulatory environment of the contract impacts the provision of incentives.

# 4 Testable Implication

In this section, we focus on the testable prediction of our model in the context of regulatory changes that affect the agent's benefit of cash-flow diversion. Indeed, it appears that authorities such as the SEC are tailoring regulatory reforms to new practices leading to excessive pay. Murphy (2013) documents several of the U.S. reforms adopted over the last century to maintain aligned the managers' objectives with the shareholders' ones. First, we can mention the Securities Act of 1934 amid the Great

[5]We have that $V_0(0) = V_1(0)$ while $V_0 < V_1$ as $\bar{\lambda} > \underline{\lambda}$. Hence,$V_0'(0) = V_1'(0)$

Depression to disclose executives' benefits of trading shares of their own company. Then, the high usage of perquisites due to tax advantages has been regulated in the 1970s, and new rules on stock options have been passed in the 1990s. More recently, the 2006 Compensation Discussion and Analysis imposes the description of performance metrics and targets for each component of the managers' incentive structure. Finally, the Dodd-Frank act (2010-2011) has regulated the pay package in both financial institutions and other publicly traded companies. We argue that an expansion of mandatory compensation disclosure (MCD) mitigates the executives' ability to divert cash out of shareholders' sights. Consequently, we claim that our theoretical framework can shed light (1) on the empirically observed change in executive bonuses and also (2) on the propensity of executives to be dismissed following the new regulations. While the first impact is already documented in the academic literature (Mas 2019; and Gipper 2020, among others), no study shows that such rules may impact the threat of dismissal to the best of our knowledge.

To provide our testable implications, we use (1) the dynamics of the agent's continuation under the optimal contract and solve numerically for the optimal contract using the shooting method to extract (2) the estimated payment boundaries and (3) the estimated sensitivity to the implementation of MCD. Then, Monte Carlo simulations are performed to analyze how the introduction of MCD changes the contractual characteristics. Murphy (2013) have identified four reforms on the MCD implemented by the SEC in the 1970-2011 period. Consequently, a new reform is expected every 10 years, and we set the intensity of such reforms to $p = 0.1$. The complete list of the parameters and the variables is provided in the following table.

**Expected bonus following an MCD reform.** We consider a discrete set of values to initialize the agent's continuation value and estimate the expected bonuses received over a fixed period that is associated. Formally, the total discounted bonus received over a period $t \wedge \tau$ following the MCD reform is given by

$$\phi_1^t(w) = \mathbf{E}_w^a \left[ \int_0^{t\wedge\tau} e^{-\gamma s} dU_s \mid N_0 = 1 \right], \tag{11}$$

where, the agent's continuation value jumps initially from $W_{0^-} = w$ to $W_0 = w + \delta(w)$. In the counterfactual scenario where no MCD reform occurs at date 0, the total discounted bonus received over the same period $t \wedge \tau$ is given by

$$\phi_0^t(w) = \mathbf{E}_w^a \left[ \int_0^{t\wedge\tau} e^{-\gamma s} e^{-\gamma s} dU_s \mid N_0 = 0 \right]. \tag{12}$$

where $W_0 = w$. While no reform occurs at date 0 in the counterfactual situation, it does not preclude that it may occur during the interval $]0; t \wedge \tau]$. We compare the

| Variable | Symbol | Parameter | Symbol | Value |
|---|---|---|---|---|
| Cumulative cash flows | X | Principal's discount rate | r | 0.10 |
| Contract termination date | $\tau$ | Agent's discount rate | $\gamma$ | 0.12 |
| Principal's value prior to the MCD reform | $V_0$ | Intensity of the advent of the MCD reform | $p$ | 0.1 |
| Principal's value after the MCD reform | $V_1$ | Fraction of the cash-flow diverted consumed by the agent before the MCD reform | $\bar{\lambda}$ | 0.5 |
| Payment boundary prior to the MCD reform | $\bar{W}^0$ | Fraction of the cash-flow diverted consumed by the agent after the MCD reform | $\underline{\lambda}$ | 0.25 |
| Payment boundary prior to the MCD reform | $\bar{W}^1$ | Principal's value at contract termination | L | 40 |
| Sensitivity to the output | $\beta$ | Agent's action | $\bar{a}$ | 10 |
| Sensitivity to the MCD reform | $\delta$ | | | |

Table 1:
**Parameter Values and Variables**

cross-sectional estimates $\phi_1^t(w)$ and $\phi_0^t(w)$, and consider $t = 15$ years. Our results are presented in the figure 2.

Our simulations suggest a compression of the bonuses following the MCD reform: while agents with a low continuation value expect to earn more following the MCD reform, those endowed with a large continuation value just before the MCD reform are expecting a decrease in their bonuses. We formalize this result in the following implication.

**Implication 1.** *Enforcing a regulation that limits the agent's benefit of cash-flow diversion leads to the compression of the bonuses.*

This is consistent with Mas (2019)[6] who studies the impact of the 1934 SEC reform on the CEOs compensation. The author finds that the CEOs' pay above the $97^{th}$ percentile of the earnings distribution has dropped following the reform, while the rest of the CEOs have gained from the reform. Here, the initial agent's continuation value is a good proxy for the CEO earnings distribution because it measures how much the CEO expects to earn in the future from the contractual relationship. While

[6]see figure 9 & 10, pp.43–44 in Mas (2019).

Mas considers "intriguing" the drop in compensation for the CEOs at the right-tail of the distribution, our optimal contracting approach provides a potential theoretical explanation to this phenomenon. Mas finds a decline in compensation (around 78%) for CEOs at the top of the distribution that is of the same amplitude as the one we simulate. Gipper (2020) finds that globally the effect of the 2006 CD&A reform on CEO pay is positive, but he does not distinguish the effect for CEOs at the top of the earnings distribution from the others. In Mas (2017), pay disclosure in the public sector has led to wages cut for managers above the mean of the earning distribution but does not affect the managers below. The author concludes that pay disclosure leads to a compression of wages.

**Manager dismissal following an MCD reform.** We derive now a testable prediction on how the MCD reform impacts the managers' contract termination. First, let us consider the following process :

$$\tau^1(w) = \mathbf{E}_w^a \left[ \inf\{t > 0 \mid W_t = 0 \text{ such that } \quad W_{0^-} = w \quad \& \quad N_0 = 1\} \right]. \tag{13}$$

It represents the expected contract duration following the implementation of the MCD reform where the agent's continuation value jumps from $W_{0^-} = w$ to $W_0 = w + \delta(w)$. In the counterfactual scenario, the expected contract duration is denoted by $\tau^0(w)$ and satisfies

$$\tau^0(w) = \mathbf{E}_w^a \left[ \inf\{t > 0 \text{ such that } W_t = 0, \text{ given } \quad W_0 = w \quad \& \quad N_0 = 0\} \right]. \tag{14}$$

Next, we compute the probability that the contract terminates by 1 year and illustrate our result in Figure 3. We observe that the MCD reform significantly reduces the risk of termination over the first year for the managers on the bottom of the continuation value distribution. Indeed, those agents at great risk of dismissal and are moved away instantly from the termination boundary. For example, we estimate that for an agent endowed with a very low continuation value just before the MCD reform ($W_0 = 0.5$), the probability of termination over the following year drops from 88% to 15%. We also remark that the impact of the MCD reform decreases with the agent's continuation value. The impact is almost insignificant for an agent when the continuation value is large enough because the risk of reaching the termination boundary is close to zero. To that extent, we introduce the concept of regulation-induced retention, defined as maintaining an agent active while he would have been dismissed in the absence of the shock on his benefit of cash-flow diversion. It leads to the following implication :

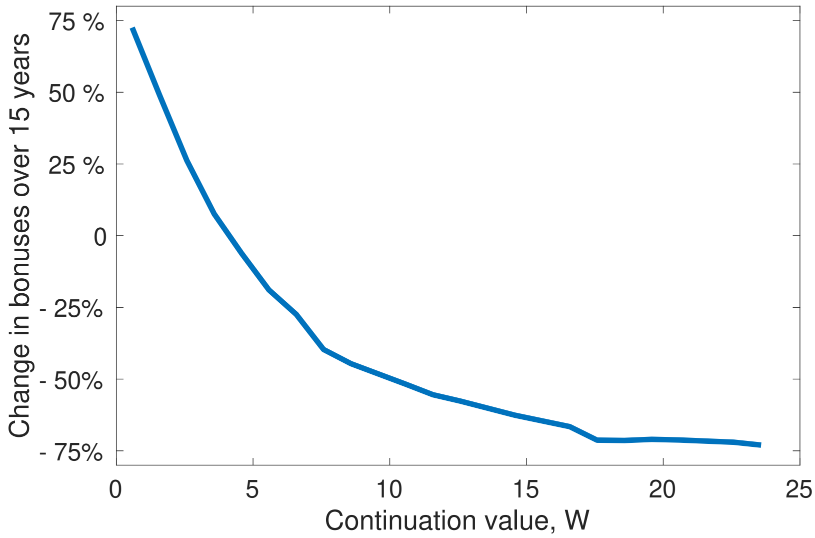


Figure 2: Change in expected bonus over the 15 years following the shock of the agent's benefit of cash-flow diversion.

**Implication 2.** *Enforcing a regulation that limits the agent's benefit of cash-flow diversion leads to the regulation-induced retention of poor performers.*

Considering both our predictions, our paper suggests that enforcing new regulations that reduces the agent's ability to divert cash-flow may benefit poor performers (larger expected bonuses, lower risk of dismissal) and penalize good performers (lower expected bonuses). Hence, we recommend to account for these indirect implications when regulations design new policies on executive compensation.

# 5 Conclusion

In this paper, we show that the regulation of executive pay to limit the benefit of cash-flow diversion may benefit poor performers and penalize good performers. First, we predict that it reduces the bonuses given to good performers and increases the bonuses paid to poor performers. Our article provides theoretical support to the empirical findings of Mas (2019), who considers "intriguing" that the 1934 mandated pay disclosure has induced both an increase in the average CEO compensation and a reduction in the earnings of outperforming CEOs. Second, we show that the advent of such a shock reduces the threat of dismissal for poor performers. We introduce

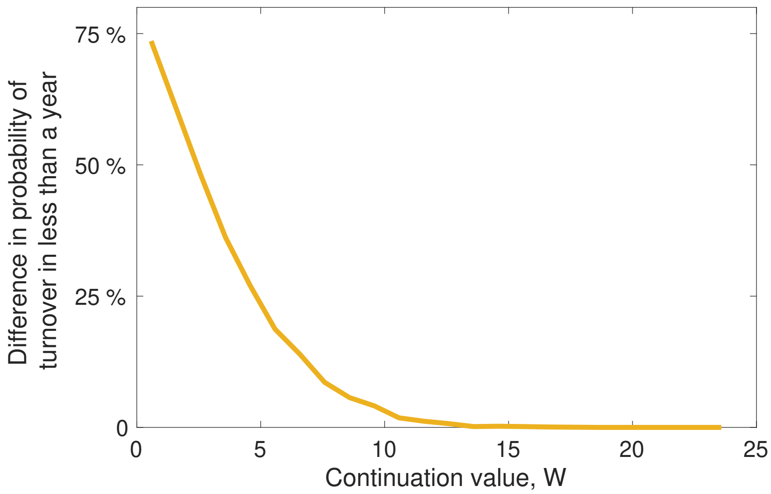


Figure 3: Difference in the probability of dismissal in the year following the shock of the agent's benefit of cash-flow diversion and compared with the counterfactual situation where no shock occurs.

the concept of regulation-induced retention of poor performers. We show that the dismissal decision should account for an exogenous change to firm performance, which contrasts with the findings in standard contracting theory. While Jenter and Kannan (2015) observe that exogenous industry and market shocks affect CEO retention, our paper provides novel insights on an additional factor exogenous to the firm performance that also impacts such a decision.

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# Appendices

*Proof.* of Lemma 1
First, we remind that $N = \{N_t\}_{t\geq 0}$ is a single-jump process that makes the variable $\lambda$ jumps from $\bar{\lambda}$ to $\underline{\lambda}$ with intensity $p$. Specifically, $pdt$ is the probability that the jump occurs during any time interval $(t, t+dt]$. $N$ takes the value 0 when $\lambda = \bar{\lambda}$ and the value 1 when $\lambda = \underline{\lambda}$. We note that $(dN_t - pdt1_{N_t=0})$ is a compensated single-jump process.

Now, let us consider the agent's total expected wealth from the incentive-compatible contract $\Pi$. It is given by

$$\Upsilon_t = \int_0^t e^{-\gamma s}(dU_s + \lambda_s a_s ds) + e^{-\gamma t} W_t \tag{15}$$

$$= \mathbf{E}^a \left[ \int_0^\tau e^{-\gamma s}(dU_s + \lambda_s a_s ds) \right] \tag{16}$$

By construction, it is a martingale with respect to the filtration generated by (Z,N) under the probability measure $\mathbf{Q}^a$ induced by the agent's cash-flow diversion strategy. We assume that the filtration satisfies the usual conditions.

Thus, we can apply the martingale representation theorem, so and there exists a pair of predictable processes $(\beta, \delta)$ such that

$$\Upsilon_t = \Upsilon_0 + \int_0^t e^{-\gamma s}\beta_s dZ_s^a + \int_0^t e^{-\gamma s}\delta_s (dN_s - pds1_{N_s=0}) \tag{17}$$

Differentiating (15) and (18) with respect to t we find that

$$dW_t = \gamma W_t dt + \beta_t dZ_t^a + \delta_t(dN_t - pdt1_{N_t=0}) - \lambda_t a_t dt - dU_t. \tag{18}$$

□

*Proof.* of Proposition 2
We follow the proof of Proposition 2 in Hoffmann and Pfeil (2010) that consists in two steps. First, we prove the concavity of the value function $V_0$ prior to the shock on the agent's benefit of cash-flow diversion. Then, we apply the verification theorem to ensure that $V_0$ corresponds to the principal's value function.

**Concavity**
Consider the total surplus $U_0(w) = V_0(w) + w$ generated by the contractual relationship for any level of continuation value $w$. Its first-derivative satisfies :

$$(r-\gamma)U_0'(w) = (r-\gamma) + (\gamma w - \delta(w)p)U_0''(w) + \frac{1}{2}\bar{\lambda}^2 U_0'''(w), \tag{19}$$

together with $U(0) = L$, $U'(\bar{W}_0) = 0$, and $U''(\bar{W}_0) = 0$. Hence, there exists $\epsilon > 0$ such that

$$U'''(w - \epsilon) > 0, \tag{20}$$
$$\text{and } U'''(w + \epsilon) < 0. \tag{21}$$

If we assume that $\exists\, \hat{W} := \{\sup w \mid U_0''(w) >= 0\}$, then by continuity, $U_0''(\hat{W}) = 0$, and from (19), $U_0'(\hat{W}) > 1$.

As $\delta$ satisfies $V_0(w) = V_1(w + \delta(w))$, we get by differentiation that $\delta'(\hat{W}) = -1$. Now, consider two points $W_1 < \hat{W} < W_2$ in the neighborhood of $\hat{W}$, such that $U_0''(W_1) > 0 > U_0''(W_2)$ and $W_1 U_0'(W_1) = W_2 U_0'(W_2)$. We note that

$$\begin{aligned}(r+p)U_0(w) = \mu + (r-\gamma)w + (\gamma + p)wU_0'(w) + \frac{1}{2}\bar{\lambda}^2 U_0''(w) \\ + p(U_1(w + \delta(w)) - (w + \delta(w))U_1'(w + \delta(w)))\end{aligned} \tag{22}$$

Hence $U(W_1) > U(W_2)$, which contradicts with $U'(\hat{W}) > 1$. Consequently, $U_0$ and hence $V_0$ are concave.

**Verification**

Let us evaluate the process $(e^{-r(\tau_N \wedge \tau)} V_0(W_{t\wedge\tau}))$ when the shock occurs, i.e., where $\tau_N$ is such that $dN_{\tau_N} = 1$. Applying Itô's lemma, we find that :

$$V_0(W_{0^-}) = e^{-r(\tau_N \wedge \tau)} V_0(W_{\tau_N \wedge \tau}) - A - B - C, \tag{23}$$

where :

$$\begin{aligned}A = \int_0^{\tau_N \wedge \tau} e^{-rt} \Big[ (\gamma W_{t^-} p\delta_t) V_0'(W_{t^-}) + \frac{1}{2}\bar{\lambda}^2 V_0''(W_{t^-}) \\ + p(V_1(W_{t^-} + \delta_t) - V_0(W_{t^-}) - rV_0(W_{t^-}) \Big],\end{aligned} \tag{24}$$

$$B = -\int_0^{\tau_N \wedge \tau} e^{-rt} V_0'(W_{t^-}) dU_t, \tag{25}$$

and

$$C = \int_0^{\tau_N \wedge \tau} e^{-rt} V_0'(W_{t^-}) \bar{\lambda} dZ_t + \int_0^{\tau_N \wedge \tau} e^{-rt} (V_1(W_{t^-} + \delta_t) - V_0(W_{t^-}))(dN_s - pds) \tag{26}$$

From 10, we have that

$$A <= -\int_0^{\tau_N \wedge \tau} e^{-rt}\mu dt. \tag{27}$$

From the inequality $V_0'(W_{t^-} \geq -1$, we have that

$$B \leq \int_0^t e^{-rt} dU_t. \tag{28}$$

Finally, given the martingale property of the processes $Z$ and $(N_t - \int_0^t pdt)_t$, $\mathbf{E}[C] = 0$. Consequently, we can rewrite 29 and we get

$$V_0(W_{0^-}) \geq \mathbf{E}\left[\int_0^{\tau_N \wedge \tau} e^{-rt}(\mu dt - dU_t) + e^{-r(\tau_N \wedge \tau)} V_0(W_{\tau_N \wedge \tau})\right], \tag{29}$$

and it holds with equality for the contract characterized in Proposition (2). $\square$

# Summary of Chapter III

This paper explores a continuous-time principal-agent model where the agent can divert cash flow, and its benefit is subject to an exogenous and persistent shock. This can be interpreted as a new regulation on the executive pay that limits the usage of fringe benefits or perquisites out of the owner's sight. First, our result suggests that the compression of the bonuses at the advent of the shock: the reduction (respectively, increase) of the expected bonus of good (respectively, poor) performers. Second, our analysis also predicts the regulation-induced retention of a poor performer, defined as maintaining an agent in place while his poor performance would have induced his dismissal in the absence of the shock on the benefit of cash-flow diversion.

# Chapter IV

# Mandatory Compensation Disclosure and the CEO Dismissal Decision

**Abstract**

We establish that a change in mandatory compensation disclosure impacts the dismissal decision. We analyze how the forced CEO dismissal decision has evolved following the Compensation Discussion and Analysis introduction in the 2007 proxy season. The effect is potent for the poor performers, suggesting that those at the bottom of the performance distribution and thus at high risk of being dismissed are the prime beneficiaries of the reform. While the empirical literature already presents evidence that changes in the industry or at the market level impact the CEO compensation and dismissal decision, we observe that it is also the case for new regulations. Our results are consistent with the predictions of a dynamic contracting model, where exogenous shocks beyond the agent's control but affecting the firm's future profitability must be taken into account when designing contracts.

> *"Simply put, our rules are out of date. It's high time we updated the rules on executive compensation. [...] Over the last decade and half, the compensation packages awarded to directors and top executives have changed substantially. Our disclosure rules haven't kept pace with changes in the marketplace, [...]."*
>
> – SEC Chairman Christopher Cox. January 17, 2006

# 1 Introduction

The regulatory authorities try to keep pace at circumscribing executive malpractices, and SEC Chairman Christopher Cox announced in January 2006 that rules had to be updated. Indeed, one can interpret the compensation package decision as to the output of a non-cooperative game between firms and the regulatory authorities. On the one hand, executive pay adapts to a changing regulatory environment by becoming increasingly sophisticated. On the other hand, regulators tailor new rules to limit excessive pay emerging from such new practices. However, Cox acknowledges that "the SEC lacks statutory authority to impose salary caps on corporate executives and we'd be out of bounds to attempt that through indirection".[1] Thus, the authorities' objective is to mitigate excessive or controversial pay indirectly, but such a regulatory mechanism may have undesirable effects. First, the empirical literature (see, among others, Murphy 2013, Mas 2019, and Gipper 2021) show that the reforms on executive compensation have mixed results. Second, new regulations targeting executive pay may also affect other decisions, such as the executive dismissal decision. Indeed, monetary incentives and dismissal are two faces of the same coin and aim to provide incentives to the agent. Hence, the adaptation of an incentive contract to changes in the mandatory compensation disclosure remains unclear.

In this paper, we examine the effect of new compensation disclosures on the probability of forced CEO dismissal for S&P 500 non-financial firms. Following the definition of Parrino (1997), a forced dismissal occurs when the CEO is "fired, forced out, or retires or resigns due to policy differences or pressure". We use the expansion of mandatory compensation disclosure associated with the Compensation Discussion and Analysis (CD&A) intended to "put into perspective for investors the numbers and narrative that follow it".[2] This reform on executive pay is the most important since 1992 (Yeaton (2007)), and it became mandatory for the 2007 proxy season. We observe firms monthly over the period 2006-2007, and we study how the CD&A

[1] Speech by SEC Chairman. January 17, 2006. https://www.sec.gov/news/speech/spch011706cc.htm

[2] https://www.sec.gov/rules/final/2006/33-8732a.pdf

act impacts the probability of forced dismissal using the exogenous difference in the adoption timing, which depends on their fiscal year-end date.

We find that the introduction of the CD&A act has significantly reduced the probability of forced CEO dismissal: The average change in the implied probability of a forced CEO dismissal is - 2.26 ‰ (significant at the 10% level), so we estimate that about 8 CEOs of S&P 500 firms have remained active in 2007 thanks to the introduction of the act. Furthermore, the effect is potent for the poor performers, suggesting that those at the bottom of the performance distribution and thus at high risk of being dismissed are the prime beneficiaries of the reform. This contrasts with Hermalin and Weisbach (2012), who argue about disclosure that "if management has any bargaining power, then it will capture some of the increased benefits via greater compensation".

This result complements the prior literature that studies the effect of extending the mandatory compensation disclosure. Greenstone et al. (2005) show that following the 1964 Securities Acts Amendments, the most impacted firms experienced large abnormal excess returns. This result suggests that reforming executive pay has a great value for shareholders, but the literature also finds that it may not achieve the intended results. While the IRS section 162(m) passed by U.S. Congress as part of the Omnibus Budget Reconciliation Act of 1993 aimed at limiting excessive compensation by limiting deductibility, its result was a significant increase in CEO pay (Murphy 2013). Gipper (2021) also finds that following the CD&A reform, the pay of S&P 1500 firms CEO increased by 11% on average. However, an average increase in pay does not preclude these regulations from impacting negatively the pay of those earning the most. Indeed, Mas (2019) shows that while the 1934 mandated pay disclosure has also made the average CEO compensation increase, the CEOs at the top of the earnings distribution have seen their pay reduced.

To the best of our knowledge, no empirical investigation has addressed the impact of compensation disclosure on the propensity of forced dismissal, and its economic effect remains unclear. First, standard contract theory suggests that the manager's contract should filter out what is beyond the CEO's control (Hölmstrom 1979). Thus, the dismissal decision should solely be taken based upon the observation of the CEO quality or on signals about the CEO performance that may be unobservable in the presence of agency friction. However, one can see regulatory reforms as a persistent shock that is exogenous to firm performance, and dynamic contract theory shows that optimal contracts should be contingent on such a change when anticipated (see, e.g., Hoffman and Pfeil 2010; and DeMarzo, Fishman, He, and Wang 2012). Second, there is a lack of empirical evidence because the prior literature has focused on executive pay. This is probably because such reforms specifically target CEO pay, and also because CEO pay is subject to close scrutiny by the public, the shareholders, and the politics.

As aforementioned, one potential channel to explain such a result relies upon dynamic contracting theory. When a reform expands the compensation disclosure, we argue that it makes the severity of the agency friction decrease. Indeed, the reform makes mandatory the production of a narrative description of the compensation package awarded to executives, outlining the usage of performance metrics, targets and detailing the incentive scheme. Hence, we can interpret such a regulatory reform as a negative shock on the CEO's ability to divert cash flow out of sight of shareholders. Importantly, we can also argue that firms foresee such a regulatory change.[3] Indeed, the SEC implemented four reforms on executive pay in the 1970-2011 period (see, e.g., Murphy, 2013). Therefore, firms anticipate that when a new reform occurs at an uncertain time, they will have to adapt their incentive scheme. Mitigating the agency friction makes the contractual delegation more valuable and the CEO dismissal less efficient. In the second paper of this thesis, we show that after a shock on the ability to divert cash flow, it is optimal to reduce the threat of dismissal for poor performers, so the incentives remain constant. In this paper, we are testing this empirical prediction.

An alternative channel that may be at play is that limiting the executive compensation reduces the risk of dismissal. Indeed, there exists a positive relation between dismissal risk and executive compensation. Kaplan and Minton (2012) find a link between dismissal risk and compensation in the time series. However, we reject this hypothesis because it is instead the insecurity of the position that negatively affects the CEO pay. Peters and Wagner (2014) and Jenter and Kannan (2015) show that shocks at the industry level impact the dismissal decision. Peters and Wagner also find that CEOs receive a premium for bearing an incremental risk of dismissal due to changes in the industry conditions and that the volatile industry condition is an important determinant of the dismissal decision. Consistent with their findings, our paper provides evidence that changes in the regulatory environment form another set of exogenous shocks to the firm performance that affect the dismissal decision.

To shed light on how the effect of mandatory compensation disclosure on the probability of forced dismissal evolves with CEO performance, we follow Jenter and Kannan (2015) and adopt a two-stage approach. In the first-stage regression, we separate the firm performance into a systematic component that assesses the market performance from a firm-specific component that reflects the CEO performance (see, e.g., Gibbons and Murphy (1990)). While the firm-specific component may also

[3]In dynamic contract theory, the assumption that shocks are anticipated is crucial to derive such a result.

be driven by luck rather than the CEO's skill or the CEO's effort, we claim that this is mitigated by computing the past performance over the last six months and controlling for the firms' market capitalization and 2-digit SIC code. We find that the firm-specific component is right-skewed, suggesting that the distribution of our estimate is not symmetric and instead has a long right-tail. First, it may suggest that few CEOs are strongly outperforming their peers. One possible explanation could be the presence of *superstars*, which according to Rosen (1981) are a "relatively small number of people [who] earn enormous amounts of money and dominate the activities in which they engage". The presence of superstar CEOs in the U.S. is confirmed by Malmendier and Tate (2009), even if their definition is not based on past performance but rather on earnings, status, and press coverage. Alternatively, this result could reflect the existence of superstar firms, i.e., highly productive firms on the market (see, e.g., Autor et al. (2019); or Ayyagari et al. (2019)). Also, we argue that the absence of a long left-tail is attributable to the ability of firms to dismiss a CEO after a poor performance. Another explanation could be that firms performing poorly are excluded from the S&P 500, and thus are no longer observed in our sample.

In the second-stage regression, we regress the probability of forced CEO dismissal on a dummy variable accounting for the adoption of the CD&A reform by the firm. We also include our estimates for the market performance and the CEO's performance over the last semester. Finally, we add firm past return over the penultimate semester to test if lagged performance is also a determinant of the forced dismissal. Our results suggest that peer performance has no impact on the probability of forced dismissal. Hence, our results support a *strong-form* relative performance (see, e.g., Janakiraman et al. 1992 and Albuquerque 2009 ) of non-financial S&P 500 firms during the period 2006-2007 because the CEO dismissal is independent of the market performance. This result contrasts with the findings of Jenter and Kannan (2015), who find that peer performance significantly impacts the dismissal decision when observing all firms in the S&P Execucomp universe over the period 1993-2009.

This paper is divided into four sections. Section 2 establishes a theoretical background and describes our predictions; Section 3 presents our empirical analysis, and Section 4 concludes this paper.

# 2 Theoretical Background

While the SEC has updated its regulation of executive compensation several times since 1934, the effect of new compensation disclosures on executive dismissal is not apparent. This section describes what would be predicted by contract theory regarding this concern.

Consider a representative shareholder who delegates on the long-term the management of a firm to an agent, and that a moral-hazard problem arises because the agent can divert cash flows out of the owner's sight. Because the owner cannot observe the agent's action directly, the optimal contract would steadily tie the agent's expected wealth to the reported cash flow and align the agent's objectives with those of the owner. In the presence of such an information asymmetry, the owner would compensate the agent when the project generates enough cash flow and would terminate the contract after a poor performance. Indeed, when both parties fully commit to the contract, and when limited liability protects the agent, it is optimal to terminate the contract when the agent's expected wealth becomes zero. Let us now consider that the agent's ability to divert cash flow is subject to discrete, unpredictable shocks that make diversion less valuable for the agent. Arguably, such shocks can occur when regulatory reforms on executive compensation are adopted (Murphy, 2013). It leads us to the following question: Should the owner takes this information into account if he anticipates that such shocks may occur at an uncertain time?

Standard contracting models have focused on creating a proper incentive scheme for the agent in his unobservable activity, and they do not provide a positive answer to that question. Indeed, Holmstrom (1979) shows in his seminal paper that information is only valuable if it concerns the agent's action. The compensation scheme, the dismissal decision, or any other implicit incentives such as his reputation or his career development should not be impacted by what is beyond the manager's control.[4] Consequently, we may expect that the occurrence of any exogenous shocks does not affect the dismissal decision. Several empirical investigations support such a result. Antle and Smith (1986) provide empirical evidence that the performance evaluation of executives does not take into account the industry performance. Barro and Barro (1990) support this result for CEOs in the banking industry.

However, we also argue that the occurrence of such a persistent and negative shock on the agent's ability to divert cash flow leads to a better agent's responsiveness to the incentives provided by the owner. The dynamic contracting model presented in the preceding chapter of this thesis studies this setting and provides testable implications. When the owner anticipates the shock at the contracting stage, the advent of such an exogenous change leads to the compression of the agent's expected wealth. Consequently, good performers (respectively, poor performers) experience a drop (respectively, a rise) in their expected wealth. This result is consistent with

[4]See also Harris and Raviv (1979), Shavell (1979), and Diamond and Verrecchia (1982).

Mas (2019)[5] who finds that the pay of CEOs above the $97^{th}$ percentile of the earnings distribution has dropped following the 1934 SEC reform on the CEOs compensation, while the rest of the CEOs have experienced gains following this reform. While Mas considers "intriguing" the drop in compensation for the CEOs at the right-tail of the distribution, contract theory provides a comprehensive theoretical framework to explain this phenomenon. Mas (2017) also finds that pay disclosure leads to wages cut in the public sector for managers earning the most. To the best of our knowledge, the literature has not yet investigated how regulating CEO pay impacts the risk of dismissal. We predict that the adoption of expanded compensation disclosure lessens the risk of dismissal, particularly for CEO performing poorly.

Given the above conflicting arguments, whether mandatory compensation disclosure affects CEO dismissal remains an open question.

# 3 Empirical Analysis

In this section, we analyze empirically whether the introduction of the Compensation Discussion and Analysis for the 2007 proxy season has impacted the CEO dismissal decision.

## 3.1 Empirical Strategy

Our investigation borrows from Gipper (2021) who study the impact of Compensation Discussion and Analysis (CD&A) on CEO pay. This act aims to expand the volume of executive compensation information available to the shareholders and require details on the incentive scheme and the use of performance metrics and targets. Thus, we introduce a dummy variable denoted CD&A to indicate when this SEC reform impacts the firm.[6] It is notable that firms' compensation committee may have provided to shareholders such details before the 2006 disclosure extension, but Gipper (2021) shows that the cases of voluntary adoption of such disclosures before the introduction of the CD&A were "extremely rare" (14 firms over the entire Equilar database). Thus, we interpret the introduction of the CD&A as an exogenous shock.

[5] see figure 9 & 10, pp.43–44 in Mas (2019).

[6] The CD&A reform requires extended disclosures in the statements made on or after December 15, 2006. Thus, the dummy variable CD&A takes the value one if the firm holds the annual shareholder meeting while being subject to the CD&A reform. Unfortunately, we cannot implement a difference-in-differences design due to the lack of dismissals. Indeed, solely eight forced dismissals had occurred in 2007, and 7 are for firms with a fiscal year's ending date in December or January.

Second, Jenter and Kanaan (2015) show that CEO dismissals depend on industry performance, which is out of the firm's scope. We follow their two-stage regression approach, and we use the S&P500 performance as an instrument for firm performance. It lets us separate a systematic component in the firm performance due to the market performance and a firm-specific component that may reflect the CEO's performance according to our theoretical framework. We refer to the latter component as the CEO-induced firm performance. In the second stage, we predict the probability of CEO dismissal on these two components, on a lagged return component to account for autocorrelation, and on the dummy variable CD&A. We also include year, firm, and industry fixed effects.

Specifically, we follow Jenter and Kanaan (2015) and perform the following estimation :

$$\text{First-Stage : } r_{i,t-1} = \beta_0 + \beta_1 \cdot r_{SP500,t-1} + \beta_2 \cdot \hat{r}_{SP500,t-2} + \nu_{i,t-1}$$

$$\begin{gathered}\text{Second-Stage :}\\ \text{Probability}(\text{Dismiss}_{i,t}) = \gamma_0 + \gamma_1 \text{CD\&A}_{i,t} + \gamma_2 \cdot \hat{r}_{i,t-1} + \gamma_3 \hat{\nu}_{i,t-1} + \gamma_4 r_{i,t-2} + \zeta_{i,t}\\ \text{where : } \hat{r}_{i,t-1} = \beta_0 + \beta_1 \cdot \hat{r}_{SP500,t-1} + \beta_2 \cdot \hat{r}_{SP500,t-2} \end{gathered} \tag{1}$$

In our second-stage regression, we regress the probability of forced dismissal on several factors accounting for performance. $Dismiss_{i,t}$ is a dummy variable that takes the value one if the CEO dismissal occurs during the month t. One of the novelties compared to Jenter and Kanaan (2015) is to introduce the dummy variable $\text{CD\&A}_{i,t}$ to assess if the firm $i$ is subject to the CD&A act at month t. As developed in our theoretical background, we hypothesize that the introduction of the CD&A act negatively impacts the probability of forced dismissal. We also include $\hat{r}_{i,t-1}$, the estimated effect of the market performance on the firm performance as extracted from the first-stage regression. Jenter and Kanaan (2015) show that market performance or industry performance drives firm performance. Finally, $\hat{\nu}_{i,t-1}$ is a idiosyncratic component that may be attributable to CEO performance. Our theoretical model suggests that termination occurs to punish a CEO after a poor performance, and thus we expect $\hat{\nu}_{i,t-1}$ to negatively impact the probability of dismissal.

Importantly, we acknowledge that alternative analyses may be more suitable to capture the effect of the introduction of the SEC act. However, the small number of CEO dismissal guides us in our strategic choice. For example, Gipper (2021) implements a difference-in-differences design to study the impact of CD&A on CEO compensation. As CEO compensation is a quantitative variable, the author can compare the variation in CEO compensation for a treated group of December firms (firms ending their fiscal year during December and thus impacted by the CD&A reform at its introduction in December 2006) to the control group of September-November firms(firms ending their fiscal year in September, October, or November and thus impacted by the reform almost a year after). Such a control group of firms only represents about 12% of our observations, and none of these firms have dismissed by force its CEO during the period of interest.[7] Thus, we do not follow Gipper (2021), and we do not split our observations into two groups.

## 3.2 Data

We are grateful to Dirk Jenter, Alexander Wagner, and Florian Peters, who provide the data on CEO forced dismissal. They have created a data set on CEO dismissal for firms in the S&P ExecuComp database over the period 1993 to 2018 used in Peters and Wagner (2014) and Jenter and Kannan (2015). Following Parrino (1997), a forced CEO dismissal occurs when the press reports that the CEO is "fired, forced out, or retires or resigns due to policy differences or pressure". For example, the data set excludes CEOs who have retired or resigned for personal reasons and CEOs who have resigned before a merger or an acquisition. As noted by Jenter and Kanaan (2015), "this careful classification scheme is necessary since CEOs are rarely openly fired from their positions". Because we are interested in the impact of the CD&A reform, we only consider the period 2006-2007. We observe monthly S&P 500 non-financial firms, and we retain firms that have joined the S&P 500 for at least one year to compute past returns.[8] We extract the accounting information from Compustat and returns from the CRSP database. We use the 2-digit SIC codes to classify firms into industries, and we aggregate all the data per month.

## 3.3 Empirical Results

### 3.3.1 Descriptive Statistics

Table 1, 2, and 3 describe our data set, and highlight differences in performance when a CEO dismissal occurs. Table 12 reports the exhaustive list of dismissals we have observed. In Table 1, we report the number of forced dismissal observed during the period 2006-2007 in S&P 500 non-financial firms. Our data set comprises

[7]Due to the lack of observation for September-November firms, we would not be for instance able to test the parallel trend assumption that is critical in difference-in-differences settings.

[8]For instance, Amazon joined the S&P 500 in November 2005, so its first firm-month observation in our database is in November 2006.

6350 firm-month observations for 310 firms, so each firm provides on average 21.3 observations. We observe a total of 19 forced CEO dismissals: 5 CEO dismissals have occurred after the adoption of the CD&A, and 8 dismissals concern December firms. It represents a dismissal in 2.99 ‰ of our firm-month observations. We remark that the frequency of forced dismissals in our data set ($\frac{19}{620}$= 3% per firm-year observation) is similar to the one for all firms in the S&P ExecuComp universe over the period 1993 to 2009 (2.79% per firm-year observation) as reported by Jenter and Kanaan (2015). Over 2006-2007, 129 forced CEO dismissal (2.11% per firm-year observation) are reported for all firms in the S&P ExecuComp universe, so the magnitude of forced CEO dismissal seems comparable among the two sets of firms.

In Table 2, we describe the firm and industry performance. On average, the stock return in the semester preceding a forced CEO dismissal is −3.23%, while it is on average 6.32% for firms that have not dismissed their CEO by force.[9] However, there is no significant difference in the average return on the S&P 500 in the presence and the absence of dismissal, and it contrasts with Jenter and Kanaan (2015), where the industry stock return differs significantly. Several factors may explain such a difference, yet it is probably imputable to the absence of recession periods in our dataset (Jenter and Kanaan include the 2002-2002 period with an average return on the S&P 500 of −14.3%, or the year 2008 with an average return of −37.00%).

Also, we report in Table 3 the fraction of observed dismissal per CEO performance quartile. As expected, the probability of CEO dismissals is lower for outperformers (CEOs in the top two quartiles, i.e., over the median). For instance, forced CEO dismissal is 40% more likely in the first quartile than in the fourth quartile. We test and confirm this downward trend in our two-stage regression.

In Table 4, we provide the distribution of our observations per month where the firm ends its fiscal year. We remark that about 70% of the firm in our dataset end their fiscal period in December. Hence, the CD&A act has impacted a substantial fraction of the firm since its introduction in December 2006.

### 3.3.2 Main Empirical Result

Table 5 reports the results of the first-stage regression. We begin by examining the effect of the current and past market performance on the firm stock return and find that the coefficients are both positive and statistically significant. As expected, the effect of the current market performance on the current firm performance (1.158, robust z-stat. of 22.13) is stronger and more significant than the effect of the past

[9] We observe a similar difference in yearly stock returns, as the yearly stock return of firms where forced CEO dismissal has occurred is 4.51%, while it is on average 13.58% when no dismissal occurs.

market performance on the current firm performance (0.111, robust z-stat. of 1.98). Then, the residual variation of the firm return estimates the firm idiosyncratic performance, which we refer to as the CEO performance. Indeed, this component may be attributable to the CEO's ability to manage the firm.[10] We illustrate the distribution of the estimated CEO performance in Figure 1 and present detailed descriptive statistics in Table 6. We estimate this component as the residual of our first-stage regression, so it is equal to zero in expectation. More notably, our estimate for the CEO performance component is right-skewed, and it suggests that few CEOs are outperforming significantly from their peers. Such an asymmetry in the distribution of the CEO performance may be capturing differences in skills, suggesting that there exist *superstar* CEOs (Rosen 1981, and Malmendier and Tate 2009). It may also suggest differences at the firm level, as our sample of S&P 500 firms may also contain *star* firms (see, e.g., Autor et al. 2019, Ayyagari et al. 2019). In further research, we could investigate over a longer period if it is due to the presence of star firms or star CEOs who persistently outperform their peers. Finally, the absence of a long left-side tail may be simply attributable to the ability of firms to dismiss their CEO after a poor performance. Alternatively, this may be explained by the exclusion of firms performing poorly from the SP 500.

In Table 7, we present our main results: the effect of the introduction of the CD&A act on the probability of forced CEO dismissal is statistically significant and economically meaningful. Column (1) provides the results for a univariate regression where the introduction of the CD&A act negatively impacts the probability of forced dismissal (-0.366, z-stat of -1.72). Column (3) concerns the second-stage regression where we regress the probability of forced dismissal on (1) the introduction of the CD&A act, (2) the CEO performance component over the past semester, (3) the estimated firm return induced by the current and past market performance over the past semester, and (4) lagged firm returns over the penultimate semester, and where we control for firm (market capitalization), industry (2-digit SIC Code) and year fixed effects.[11] We include both variables for semesters t-1 and t-2 because a poor history of returns may also affect the current dismissal decision independently from recent returns. Our regression shows that the introduction of the CD&A act significantly reduces the probability of forced dismissal (-0.337, robust z-stat. of -1.74), and the economic effect is stable compared to the univariate regression. We find that CEO performance reduces the probability of forced CEO dismissal (-1.174, z-stat.

[10]We acknowledge that other factors than the CEO performance (e.g., luck, market imperfection) may influence the idiosyncratic variation of the firm performance.

[11]See Table 7, Column (2) for estimates without industry fixed-effects. In that regression, the CD&A act still impacts the probability of forced dismissal significantly (-0.362, z-stat of -1.92).

of -2.87) strongly. Unsurprisingly, the CEO performance is the factor that impacts the most the probability of forced dismissal, so the best performers are at a lesser risk of forced dismissal. However, we do not find that the firm return component due to the market performance and the past firm performance significantly impact the probability of forced dismissal, which contrasts with the results of Jenter and Kenaan (2015). Consequently, our results support the hypothesis of *strong-form relative performance*, a situation where peers' performance has no significant impact on the CEOs (see, among others, Albuquerque 2009).

Table 9 reports the change in the implied probabilities of forced CEO dismissal estimated from the two-stage regression model. On average, the change in probability of forced CEO dismissal due to the introduction of the CD&A act is 2.26 ‰. We also compute the implied probabilities per quartile of CEO performance. It confirms our theoretical prediction that the impact of the CD&A act on the probability of forced dismissal decreases with the CEO's performance. The implied probability of forced dismissal for the CEOs in the first quartile of performance (the 25% poorer performers) significantly decreases by 3.22 ‰(z-stat. of -1.73) following the introduction of the CD&A act. Such a drop is severe compared to the average fraction of forced CEO dismissal observed in this quartile ( 3.81 ‰) and reported in Table 3. For those in the second quartile, the probability of forced dismissal decreases by 2.42 ‰ (z-stat. of -1.71, the average probability of forced dismissal in this quartile equals 4.05‰) with the introduction of the CD&A act. The impact of the CD&A act for CEOs in the third and fourth quartiles is no longer significant, probably due to the few dismissals in these quartiles. Finally, we also confirm that underperforming CEOs are more sensitive to the introduction of the CD&A act than outperforming CEOs by re-estimating in our second-stage regression the marginal effects of CD&A separately for underperformers and for outperformers.[12] The results of this regression are presented in Table 8. While underperformers are still negatively impacted by the introduction of the CD&A act, we do not find any significant impact for outperformers. Consequently, the effect of the introduction of CD&A on the probability of forced CEO dismissal is entirely attributable to its impact on underperformers. Again, this is in line with the predictions of our theoretical model.

[12]We say that CEOs are underperforming (respectively, outperforming) when the firm-specific residual performance in the first stage regression is negative (respectively, positive). Jenter and Kanaan (2015) do a similar analysis to show that the sensitivity of CEO dismissal to peer performance is also depending on whether the CEO is underperforming or outperforming.

### 3.4 Robustness check

This section presents a robustness test to see if estimating the first-stage regression per industry (here, using the 2-digit SIC code) would modify our results. To do so, we conduct one of the robustness tests performed in Jenter and Kanaan (2015). First, we re-estimate the first-stage regression and split our 6 350 firm-month observations in their industry (construction, manufacturing, wholesale trade, and services). Then, we repeat the second-stage probit regression, using the sector-specific betas from the first-stage regression. Table 10 and 11 report our results. The effect of the introduction of the CD&A act on the probability of forced CEO dismissal is still significant (-0.329, z-stat of -1.73) and very close to our first estimation. It is also the case for the CEO performance (-1.17, z-stat of -2.94) that is again the main factor reducing the probability of forced dismissal, even if the estimate is slightly lower than in the main regression.

## 4 Conclusion

We confirm our prediction based on a dynamic contract theory that a change in mandatory compensation disclosure impacts the dismissal decision. Indeed, optimal contracts should adapt to exogenous shocks that may occur at an uncertain time when they impact the future value of the contractual delegation. Hence, firms do not filter out exogenous shocks to CEO performance from the dismissal decision. While prior literature already found that this prediction is valid when the shock is a change in the industry (Jenter and Kanaan 2015), we show that it is also true when the shock concerns the regulatory environment.

We leave further to research the inclusion of additional manager's characteristics (e.g., an indicator for whether the CEO is the founder, the CEO tenure, or an indicator for whether the CEO holds a large equity stake) in our empirical exploration. Then, we could use Cox hazard regressions as in Jenter and Kanaan (2015) because it would be more suitable than probit models to look directly at the effect of such factors on the firm decisions. While Graham et al. (2020) show that powerful CEOs are at a lesser risk of forced dismissal, we could also test whether they are more affected by introducing the mandatory compensation disclosure because they are arguably those using the more their ability to divert cash flow.

Finally, our two-year panel design may not be able to capture any effect of the CD&A that would occur on a long horizon or a broader set of managers. Indeed, the CD&A act concerns not only the CEO and but also the other four highest-paid executives. We could test on an expanded group of managers after constructing a database containing the information about the dismissal of board members. However, our theoretical framework should be adapted to study an agency problem with one principal and multiple agents.

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Table 1: **Frequency of forced dismissal**

| Number of observations | Number of firms | Number of forced dismissals | % of firm-month observations with forced dismissal |
|---|---|---|---|
| 6,350 | 310 | 19 | 2.99 ‰ |

Table 2: **Firm and Industry Performance by CEO Forced Dismissal Decision**

| | | | |
|---|---|---|---|
| Stock return in the semester before the CEO Dismissal | -3.23% | Market return in the semester before a CEO Dismissal | 5.72 % |
| Stock return in the semester before no CEO Dismissal | 6.32% | Market return in the semester before no CEO Dismissal | 5.31 % |
| Stock return in the year before the CEO Dismissal | 4.51 % | Market return in the year before no CEO Dismissal | 10.94 % |
| Stock return in the year before no CEO Dismissal | 13.58 % | Market return in the year before no CEO Dismissal | 10.67 % |

Table 3: **Forced CEO dismissal by Market performance quartile**

| Quartile of Idiosyncratic stock return over the last semester | Fraction of forced CEO dismissal |
|---|---|
| 1 | 3.81 ‰ |
| 2 | 4.05 ‰ |
| 3 | 2.86 ‰ |
| 4 | 2.26 ‰ |

Table 4: **Distribution of the firm-month observation per fiscal end's month**

| Fiscal end month | Frequency | Percentage |
|---|---|---|
| 1 | 47 | 1.13% |
| 2 | 48 | 1.15% |
| 3 | 99 | 2.38% |
| 4 | 48 | 1.15% |
| 5 | 102 | 2.45% |
| 6 | 318 | 7.65% |
| 7 | 48 | 1.15% |
| 8 | 60 | 1.44% |
| 9 | 293 | 7.05% |
| 10 | 174 | 4.19% |
| 11 | 24 | 0.58% |
| 12 | 2 895 | 69.66% |

Table 5: **First-stage regression of firm performance on Market performance**

| | (1)<br>Firm stock return semester - 1 |
|---|---|
| Market return semester -1 | 1.158*** |
| | (22.13) |
| Market return semester -2 | 0.111** |
| | (1.98) |
| Constant | -0.006 |
| | (-0.96) |
| $R^2$ | 0.111 |

$z$ statistics in parentheses

* significant at 10%, ** significant at 5%, *** significant at 1%

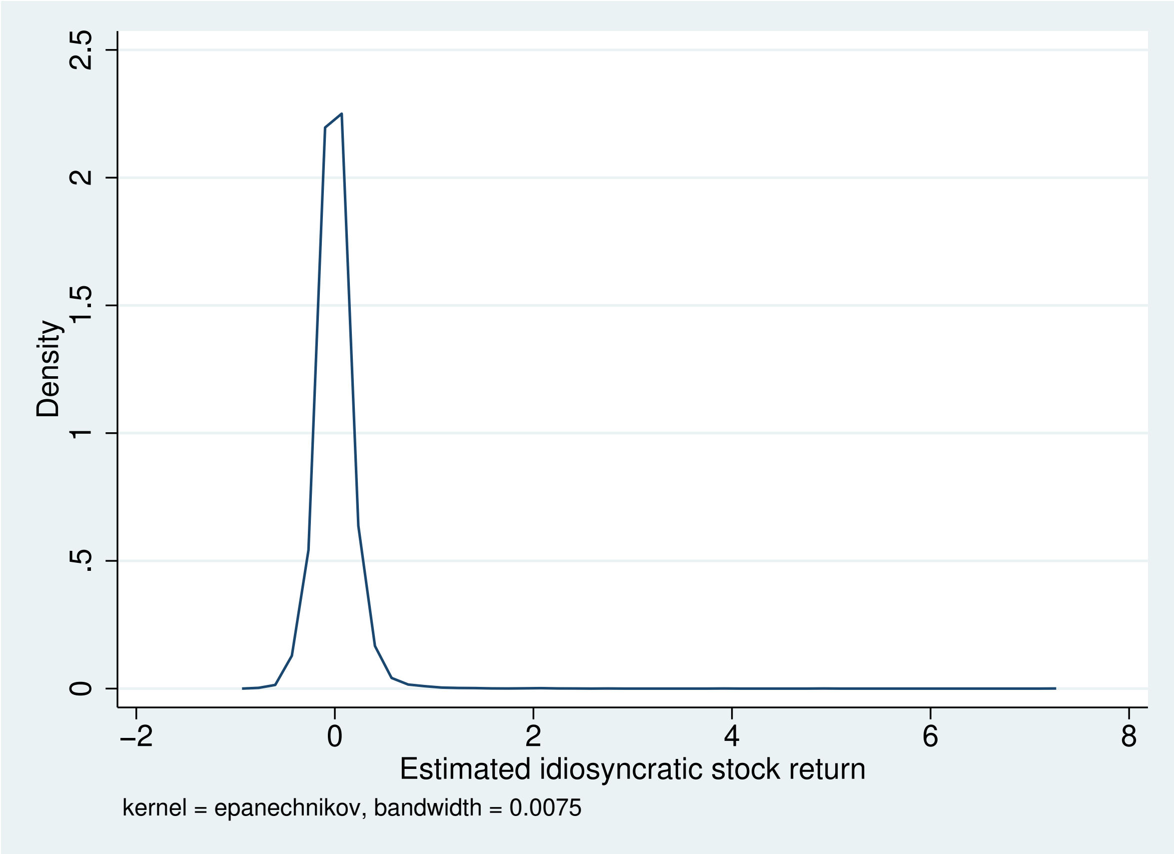


Figure 1: Distribution of the idiosyncratic stock return, first-stage regression residuals.

Table 6: **Descriptive statistic of the estimated idiosyncratic stock return component.**

| | |
|---|---|
| Mean | 0.00056 |
| Variance | 0.034 |
| Skewness | 1.418 |
| Kurtosis | 14.787 |

Table 7: **Second-stage probit regression of CEO's forced dismissal on market-induced and idiosyncratic firm performance**
In Column (1), we report the results of the univariate probit regression of forced CEO dismissal on the CD&A dummy variable. The second stage probit regressions are shown in Column (2) and Column (3) predicts forced dismissal using (1) a market-induced component, an idiosyncratic component of firm stock returns, and a component from past return over the semester - 2, respectively. Firm and industry fixed-effect are included in the regression presented in Column (3). Z-statistics are with robust standard errors clustered at the sector level following the Standard Industrial Classification.

| | (1)<br>Forced dismissal | (2)<br>Forced dismissal | (3)<br>Forced dismissal |
|---|---|---|---|
| CD&A | -0.366* | -0.362* | -0.337* |
| | (-1.72) | (-1.92) | (-1.74) |
| Market-induced return period t-1 | | 1.410 | 1.505 |
| | | (1.06) | (1.14) |
| Idiosyncratic stock return period t-1 | | -1.206*** | -1.174*** |
| | | (-2.95) | (-2.87) |
| Past return period t-2 | | 0.135 | 0.179 |
| | | (0.23) | (0.32) |
| Constant | -2.793*** | -2.902*** | -2.797*** |
| | (-14.30) | (-11.21) | (-8.86) |
| Year fixed effect | Yes | Yes | Yes |
| Firm & industry fixed effects | No | No | Yes |

*z* statistics in parentheses
* significant at 10%, ** significant at 5%, *** significant at 1%

Table 8: **Second-stage probit regression of CEO's forced dismissal on outperformers and underperformers, and on market-induced and idiosyncratic firm performance**
We report the second stage probit regressions. It predicts forced dismissal using the CD&A dummy splited for outperformers and underperformers, a market-induced component, an idiosyncratic component of firm stock returns, and a component from past return over the semester - 2, respectively. Underperformers (respectively, outperformers) are defined as CEOs with negative (respectively, positive) idiosyncratic stock return estimated in the first-stage regression. Year, firm and industry fixed-effect are included. Z-statistics are with robust standard errors clustered at the sector level following the Standard Industrial Classification.

| | Forced dismissal |
|---|---|
| CD&A (outperformers) | -0.445 |
| | ( -1.32 ) |
| CD&A (underperformers) | -0.329* |
| | ( -1.68 ) |
| Market-induced return period t-1 | 1.400 |
| | ( 1.06 ) |
| Idiosyncratic stock return period t-1 | -1.140*** |
| | (-2.60) |
| Past return period t-2 | 0.127 |
| | (0.22) |
| Constant | -2.900*** |
| | (-11.22) |
| Year fixed effect | Yes |
| Firm & industry fixed effects | No |

$z$ statistics in parentheses
* significant at 10%, ** significant at 5%, *** significant at 1%

Table 9: **Change in Implied probabilities of forced CEO dismissals by idiosyncratic stock return quartile**. In this table, we present the discrete change in implied probabilities from the base level.

| Change in implied probability of a forced CEO dismissal | |
|---|---|
| $1^{st}$ quartile of idiosyncratic stock return | -3.22 ‰* [-1.73] |
| $2^{nd}$ quartile of idiosyncratic stock return | -2.42‰* [-1.71] |
| $3^{rd}$ quartile of idiosyncratic stock return | -1.07 ‰[-] |
| $4^{th}$ quartile of idiosyncratic stock return | -0.00 ‰[-0.34] |
| Base case | -2.26 ‰* [-1.80] |

$z$ statistics in parentheses

* significant at 10%, ** significant at 5%, *** significant at 1%

Table 10: **First-stage regression of firm performance on market performance per industry**

| | Firm stock return semester - 1 |
|---|---|
| Market return semester -1 * Agriculture | 0.376 (0.79) |
| Market return semester -1 * Mining | 0.961 (1.18) |
| Market return semester -1 * Construction | 0.355** (2.03) |
| Market return semester -1 * Manufacturing | 2.064*** (6.72) |
| Market return semester -1 * Transportation | 1.229*** (18.92) |
| Market return semester -1 * Wholesale Trade | 0.907*** (7.93) |
| Market return semester -1 * Retail Trade | 0.907***(7.93) |
| Market return semester -1 * Services | 1.507*** (12.84) |
| Constant | -0.00194 (-0.34) |
| $R^2$ | 4.48% |

$z$ statistics in parentheses

* significant at 10%, ** significant at 5%, *** significant at 1%

Table 11: **Second-stage probit regression of CEO's forced dismissal on industry-specific estimates for the market-induced and idiosyncratic stock return components.**
We report the result of our second stage probit regressions where the market-induced component and the idiosyncratic stock return component are industry-specific. Z-statistics are with robust standard errors clustered at the sector level following the Standard Industrial Classification.

| | Forced dismissal |
|---|---|
| CD&A | -0.329* |
| | (-1.73) |
| Market - induced return period t-1 | 1.332 |
| | (1.18) |
| Idiosyncratic stock return period t-1 | -1.170*** |
| | (-2.94) |
| Past return period t-2 | 0.183 |
| | (0.33) |
| Constant | -2.818*** |
| | (-8.79) |
| Year fixed effect | Yes |
| Firm & industry fixed effects | Yes |

*z* statistics in parentheses
* significant at 10%, ** significant at 5%, *** significant at 1%

Table 12: **List of the S&P 500 non-financial firms that have forced the dismissal of their CEO over the period 2006-2007.** Data extracted from the database created by Dirk Jenter, Alexander Wagner, and Florian Peters. For more details about the data set on CEO forced dismissals, please refer to Peters and Wagner (2014), and Jenter and Kanaan (2015).

| Firm Name | Date of Forced Dismissal |
|---|---|
| NIKE INC. | 23 January 2006 |
| GATEWAY INC. | 10 February 2006 |
| RADIOSHACK CORP. | 21 February 2006 |
| WENDYS INTERNATIONAL INC. | 18 April 2006 |
| COMVERSE TECHNOLOGY INC. | 01 May 2006 |
| NOVELL INC. | 22 June 2006 |
| PFIZER INC. | 28 July 2006 |
| BRISTOL MYERS SQUIBB CO. | 12 September 2006 |
| WRIGLEY WILLIAM JR CO. | 23 October 2006 |
| K B HOME | 10 November 2006 |
| AFFILIATED COMPUTER SERVICES INC. | 27 November 2006 |
| HOME DEPOT INC. | 03 January 2007 |
| GAP INC. | 22 January 2007 |
| DELL INC. | 31 January 2007 |
| STARWOOD HOTELS & REST WLDWD INC. | 02 April 2007 |
| JONES APPAREL GROUP INC. | 12 July 2007 |
| HERSHEY CO. | 01 October 2007 |
| TELLABS INC. | 08 November 2007 |
| MOTOROLA | 30 November 2007 |

# Summary of Chapter IV

In this study, we test the empirical prediction made in the preceding chapter on this thesis. We establish that a change in mandatory compensation disclosure impacts the dismissal decision. We analyze how the forced CEO dismissal decision has evolved following the Compensation Discussion and Analysis introduction in the 2007 proxy season. The effect is potent for the poor performers, suggesting that those at the bottom of the performance distribution and thus at high risk of being dismissed are the prime beneficiaries of the reform. While the empirical literature already presents evidence that changes in the industry or at the market level impact the CEO compensation and dismissal decision, we observe that it is also the case for new regulations. Our results are consistent with the predictions of a dynamic contracting model, where exogenous shocks beyond the agent's control but affecting the firm's future profitability must be taken into account when designing contracts.

# General Conclusion (V)

# 1 Discussion

To this end, we conducted three studies that explore both the theoretically and empirically the adaptation of contracts to exogenous and persistent shocks. The first paper explore the advent of automation technologies in the asset management industry. In the second paper, we investigate how a negative shock on the agent's ability to divert cash flow affects the provision of incentives. Our last investigation is empirical, and aims at understanding the effect of the expansion of mandatory compensation disclosure on the CEO dismissal decision.

This concluding chapter aims first to summarize the main results obtained in each of the studies. Next, we will develop general contributions to this thesis work before outlining its limitations. Finally, we will consider avenues for future research.

# 2 Main results and contribution to the literature

The first study examines how the advent of robots is impacting the long-term contracts of asset managers. Our main contribution is to offer an unified framework where a frictionless and valuable substitute for the agent emerge during the contractual relationship. Through the construction of a dynamic contracting model that embed the advent of a technology that can substitute for the agent, we show that the principal adjusts the provision of incentives according to the availability of automation, so that the contract is impacted by this opportunity even before it emerges. As it is optimal to smooth the changes on the principal's value induced by the advent of robots, it is optimal to substitute robots for a poor performer even if the agent may be better at managing the asset. This prediction offers a potential explanation of empirical observation on the adoption of robots in the industry, strikingly illustrated by BlackRock's decision to substitute A.I. algorithms for 7 out of their 53 stock pickers in 2017. Then, we present two extension to this model to examine richer settings.. First, we offer to the principal the ability to invest prior to the contracting date to increase the value of the forthcoming automation technology, as a prerequisite to an efficient usage of the technology. We show that in the situation where the automation technology is more efficient than the agent at managing the asset, then we can separate the investment problem and the contracting problem. Second, we investigate how contracts adapt when the automation technology can either replace or enhance the agent. Our main prediction is this setting is the *hollowing out* of asset managers given their performance. While poor performers are substituted by machines, good performers are enhanced and consequently benefit from the advent of robots.

In the second study, we present a dynamic model that allows for an exogenous and persistent change in the agent's benefit for cash-flow diversion. Our contribution is to show in a simple dynamic contracting framework how a shock on the agent's benefit of cash-flow diversion produces complex effects on the provision of incentives. Such changes can be interpreted as the reinforcement of the regulation that aims at mitigating excessive CEO pay. Our main finding is a negative shock on the agent's benefit of cash-flow diversion benefits a poor performer and disadvantages a good performer. However, adjusting incentives at the advent of such a shock increases the contract efficiency, and thus it is valuable for the principal. This study highlights the crucial role of the design of regulatory acts and the complexity of the effects they can have on the incentives provided to executives. Our study may also warn policy makers on the indirect effect of the regulation of executive compensation.

The third paper is written in the light of the testable predictions of our second model. We empirically investigate the impact of the expansion of mandatory compensation disclosure on the CEO Dismissal decision. To the best of our knowledge, no empirical investigation has addressed the impact of such novels regulation on the dismissal decision, and while our second theoretical paper provide novel insights. We find that the introduction of the Compensation Discussion and Analysis rules for the 2007 proxy season has significantly reduced the probability of forced CEO dismissal, and we estimate that about 8 CEOs of S&P 500 firms have remained active in 2007 thanks to that act. Furthermore and as predicted by our theoretical model, the effect is potent for the poor performers, suggesting that those at the bottom of the performance distribution and thus at high risk of being dismissed are the prime beneficiaries of the reform.

These three studies highlight the complex impact of exogenous shocks on the provision of incentives. They are complementary, as they either explore different sources of shocks, and also investigate both theoretical and empirical dimensions.

## 3 Limitations

We acknowledge that our thesis has several limitations. While our choice of design or methodology allow us to contextualize our results, it lets us identify new avenues of research to explore.

## 3.1 First study : will asset managers survive the advent of robots? An optimal contracting approach

### 3.1.1 Methodological limitations

In our first study, we consider moral hazard as the sole agency friction. However, it would have been interesting to also embed adverse selection. For instance, we could consider two agents with a different ability to work in synergy with robots: a high type agent would be able to see its productivity enhance by robots, while the other type would not. While we provide in an extension insights on the importance of such a synergy parameters, we do not study a model where two types of agent coexist. Ultimately, the principal may provide two contracts aimed at the two types, such that they "self-select" and reveal their own type. A separating equilibrium could exist, and each type of agents would be impacted differently by the robots.

A second limitation of our first paper is to consider the principal with unlimited wealth. If it were not the case, then it would be relevant to explore how a sunk cost of adopting the technology would impact our results. We believe that financial slack, not cash flow, would be then the relevant determinant for the technology adoption.

One potential channel to explore a richer model is to embed ambiguity on the inherent "black-box nature" of the automation technology. We could consider a model where delegating to an agent is not ambiguous, because firms are used to delegate to humans, but ambiguous-averse toward the technology of automation. Szydlowski and Yoon (2021) study an optimal dynamic contracting framework where the agent's cost of effort is unknown to the principal and subject to ambiguity. Here, the ambiguity would be on the uncertain component of the cash flows when the technology management a fund.

Finally, we could also internalize the technology's development within the firm. Then, the principal's investment in the research and development of the technology of automation would be increasing the threat of substitution the agent for the machine. Another channel that provides incentives would then emerges.

### 3.1.2 Theoretical limitations

We acknowledge that a principal-agent setting only aims understanding the microeconomics effect of the emergence of automation technologies. While we draw predictions on its effect on the contractual relationship, it is difficult to assess macroeconomics effects (e.g., unemployment and competition among workers). Hence, we cannot infer how the labor market will adapt to this technological change. We believe that jobs creation will also accompany the emergence of automation technologies, and that training programs will adapt in order to enhance the agent's ability to work in this changing environment. In addition, our work may not address important policy questions, such as the optimal taxation of robots. In a model where robots substitute for routine labor and complement non-routine labor, Thuemmel (2018) shows that robots may be either taxed or subsidized.

Moreover, our one principal - one agent setting cannot offer implications on the competition with new entrants in the asset management industry that would directly using employ machines from the outset (as example of such a firm in asset management is EquBot). While the literature has explore the "race between machine and man" (Acemoglu and Restrepo (2017)), we could also explore the race between incumbents on the asset management industry and FinTechs.

Finally, we depart from the financial literature á la Berk and Green (2004) and that examines investor learning about fund manager skills. While our purposeis to study the design of an optimal contracting, they consider a simple compensation scheme, and derive insightful results that concern the impact of the heterogeneity of skills among fund managers on the flow-performance relationship. However.

## 3.2 Second study : mandatory compensation disclosure and the CEO dismissal decision

First, we note that in a model where the firm value at the contract termination would be associated to employing a new agent, the drop in the agent's benefit of cash-flow diversion may have more complex effects. Indeed, we show that the exogenous shock would lead to fewer dismissals. Hence, as executives are a scarce resource, it may decrease the value associated to the contract termination. In such a richer setting, the principal's value after the reduction in the agent's benefit of cash-flow diversion would not dominate anymore the value function before the shock, and that would increase the complexity of the analysis.

Second, it would also be useful to derive an optimal contract allowing the agent to divert cash flow, rather that focusing on contracts that implement the no-diversion strategy. Indeed, firms usually allow for perquisites and other fringe benefits. Murphy (2013) illustrates this usage with executives "taking deductions for the three-martini lunch, yachts and hunting lodges maintained to entertain business associates, first-class air travel, fees paid to social and athletic clubs and money spent on sports and theater tickets".

### 3.3 Third study : The effect of incremental mandatory compensation disclosure on the dismissal decision

Dimissals are rare events, and our methodology has to deal with this reality. Hence, the first methodological limitation of our empirical study is that we cannot employ a difference in difference analysis to compaire the CEO dismissals at firms with and without the disclosure in comparable fiscal years. To study the impact of the same regulatory act on compensation, Gipper (2021) designs on a balanced manager panel over 2006-2007, and compare CEOs in a treated group composed of December year-end firms, which were subject to the reform since December 2006 to managers in a control group containing September, October, and November year-end firms, which were impacted almost one year later. However, we have not observed any dismissal in the latter group, and thus cannot employ the same empirical strategy. This is also due to the particular distribution of firms among these two groups, as December year-end firms account for about 70% of the S&P 500 firms over that period, while September, October, and November year-end firms represents less than 12%. The absence of dismissal in the latter group of firms is not abnormal. Indeed, Jenter and Kannan (2015) finds that only 2.79% of the firms in the S&P Execucomp universe dismiss their CEO every year during the 1993-2009 period, and hence we would expect only 1,04 dismissal to occur in September, October, and November year-end firms in our data set.

Methodologically, we leave for further research the inclusion of additional manager's characteristics (e.g., an indicator for whether the CEO is the founder, the CEO tenure, or an indicator for whether the CEO holds a large equity stake) in our empirical exploration. Then, Jenter and Kannan (2015) argue that Cox Hazard regressions would be more suitable than a probit model to look directly at the effect of firm-specific and agent-specific factors on the firm decisions. While Graham et al. (2020) show that powerful CEOs are at a lesser risk of forced dismissal, we could also test whether such agents are more affected by introducing the mandatory compensation disclosure because they are arguably those using the more their ability to divert cash flow.

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# 4 Summary of Chapter V

This chapter concludes this thesis. It summarizes the main results of each study and our contribution to the literature. First, we highlight how incentives should adapt to the exogenous changes, such as the advent of automation technologies or a new mandatory compensation disclosure that decreases the agent's benefit of cash-flow diversion. Then, our empirical study shows that the introduction of the Compensation Discussion and Analysis rules for the 2007 proxy season has significantly reduced the probability of forced CEO dis-missal. In this chapter, we also acknowledge several limits in our investigations. We also propose avenues for future research that would allow us to continue exploring the effect of the exogenous changes on the optimal provision of incentives in the presence of agency friction.

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**INTRODUCTORY CHAPTER (I)**



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# Résumé

**Trois essais sur l'impact des changements exogènes et persistants sur la provision des incitations**

En présence d'une friction d'agence, les contrats d'incitation sont conçus pour aligner les objectifs du gestionnaire avec ceux du propriétaire de l'entreprise. Toutefois, l'environnement contractuel est soumis à des chocs indépendants de la volonté du gestionnaire et qui impactent la rentabilité future de l'entreprise. Ces chocs peuvent être dus, par exemple, à un renforcement de la réglementation, à des changements au niveau du marché ou à l'émergence d'une nouvelle alternative au gestionnaire. La question se pose donc de savoir comment les contrats sont conçus lorsque de tels chocs sont anticipés à la date de signature du contrat. Afin de comprendre cet effet, nous menons trois études. Dans le premier article, nous explorons comment un contrat d'incitation évolue lors de l'émergence de technologies d'automatisation qui peuvent remplacer le gestionnaire dans le contexte de la gestion d'actifs. Nous étudions un problème principal-agent en temps continu où la performance d'un actif est déterminée par l'effort non observé du gestionnaire, et où la technologie d'automatisation émerge dans un futur incertain. Notre modèle suggère que les licenciements observés empiriquement et qui accompagnent l'émergence de la technologie d'automatisation peuvent avoir un fondement contractuel. Dans la deuxième étude, nous explorons comment les changements dans la capacité de l'agent à détourner les flux de trésorerie ont un impact sur la conception d'un contrat optimal. Nous construisons un modèle principal-agent en temps continu où l'agent peut détourner les flux de trésorerie hors de la vue du propriétaire. S'il est évident que l'atténuation de la friction d'agence est valorisée pour le propriétaire de l'entreprise, son effet sur la provision d'incitations tout au long de la relation contractuelle n'est pas clair. Premièrement, notre résultat suggère que la compression des bonus au moment du choc : la réduction (respectivement, l'augmentation) des bonus espérées par les bons (respectivement, des mauvais) gestonnaires. Deuxièmement, notre analyse prédit également que ce type de réglementation entraîne la rétention des mauvais gestionnaire, définie comme le maintien en place d'un gestionnaire alors que sa mauvaise performance aurait induit son licenciement en l'absence du choc sur le bénéfice du détournement des flux de trésorerie. Dans la troisième étude, nous poursuivons l'étude précédente par une approche empirique. Nous analysons la *Compensation Discussion and Analysis* (CD&A) introduites aux USA à partir de l'année 2007. Nous nous concentrons sur l'impact de cette réforme sur la décision de licenciement dans les entreprises non-financières du S&P 500. Nous constatons que l'introduction de la loi CD&A a réduit de manière significative la probabilité de licenciement des PDG dans les entreprises non financières. Alors que la littérature a montré que les chocs exogènes au niveau de l'industrie ont un impact sur la décision de licenciement, nous documentons que les changements dans l'environnement réglementaire ont également une importance.



**Mots-clés :** Information asymétrique et privée, Systèmes de rémunération, Économie des contrats : théorie, Comportement des entreprises : Analyse empirique

# Abstract

**Three essays on the impact of exogenous and persistent changes on the provision of incentives**

In presence of an agency friction, incentive contracts are designed to align the manager's objectives with those of the owner of the firm. However, the contractual environment is subject to shocks beyond the scope of the manager that impact the future profitability of the firm. These shocks can be due for instance to a strengthening of regulations, changes at the market-level, or the emergence of a new alternative to the manager. Hence, it raises the question how contracts are designed when such shocks are anticipated at the contractual date. In order to understand this effect, we conduct three studies. In the first paper, we explore how an incentive contract evolves at the emergence of automation technologies that can replace the manager in the context of asset management. We study a continuous time principal-agent problem where the performance of an asset is determined by the manager's unobserved effort, and where the automation technology emerges in a uncertain future. Our model suggests that the empirically observed layoffs that accompany the emergence of automation technology may have a contractual foundation. For the second study, we explore how changes in the agent's ability to divert cash flow impact an optimal contract design. We build a continuous-time principal-agent model where the agent can divert cash flow out of the owner's sight. While it is straightforward that mitigating the agency friction is valuable for the firm's owner, its effect on the provision of incentives throughout the contractual relationship is unclear. First, our result suggests that the compression of the bonuses at the advent of the shock: the reduction (respectively, increase) of the expected bonus of good (respectively, poor) performers. Second, our analysis also predicts the regulation-induced retention of a poor performer, defined as maintaining an agent in place while his poor performance would have induced his dismissal in the absence of the shock on the benefit of cash-flow diversion. In the third study, we continue the previous investigation with an empirical study. We analyze the Compensation Discussion and Analysis introduced for the 2007 proxy season. We focus on how this reform has impacted the dismissal decision in S&P 500 non-financial firms. We find that the introduction of the CD&A act has significantly reduced the probability of forced CEO dismissal in S&P 500 non-financial firms. While prior literature has shown that exogenous shocks at the industry level impact the dismissal decision, we document that changes in the regulatory environment also matter.



**Keywords :** Asymmetric and Private Information, Compensation Packages, Economics of Contract: Theory, Firm Behavior: Empirical Analysis