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Impacts of Managerial Overconfidence and Agency Costs on Cash Holdings Within Blockchain Firms

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ABSTRACT We study the effects of managerial overconfidence and agency costs on cash holdings of blockchain firms, where the overconfidence is defined as a cognitive bias that a manager will underestimate volatility in an uncertain environment. We develop a real-options game model that incorporates both overconfidence and agency costs. The theoretical results show that future investment opportunities are necessary for holding cash when agency costs are within the firm. Expected returns from blockchain projects decrease with managerial overconfidence. The level of corporate cash holdings increases with overconfidence and decreases with agency costs. Using the data of Chinese listed firms from 2010 to 2019, we find that the regression results are consistent with our theoretical findings. Moreover, we find that the blockchain firms' cash holdings are higher than their peers. Our results shed some light on the impacts of behavioral characteristics on cash holdings.

INDEX TERMS Agency costs, blockchain, corporate cash holdings, managerial overconfidence.

I. INTRODUCTION

The decision of cash holdings is a key financing strategy in corporate finance, especially when firms are involved in blockchain projects. Because each block in a blockchain contains the cryptographic hash of the previous block, transaction data, and timestamp, blockchain technology could ensure the integrity of the transaction data stored on the blockchain [11]. Chedrawi and Howayeck [10] argue that blockchain technology shares four characteristics: decentralized, distributed, disruptive, and divine. With these features, blockchain technology can solve information asymmetry and lay the foundation for establishing trust between sellers and buyers [9], [29]. Moreover, the blockchain has rich application scenarios that enable collaborative trust and consistent action among multiple individuals. For example, blockchain technology has more significant advantages in reducing risks and information asymmetry than traditional auditing [10]; it can also allow personal data to be accessed to help policymakers improve the provision of public services [13]. However, these characteristics make it difficult to assess the value of the blockchain project. Therefore, firms should be more cautious in arranging their cash policies when facing investment opportunities in blockchain projects.

Traditionally, the literature has analyzed the determinants of cash holdings from a rational and unbiased perspective. Some of the critical studies within the cash holdings topic have argued that one of the essential rationales for holding cash reserves is to address contingent risk, referred to as the precautionary motive [19], [23], [32]. However, with the development of behavioral finance research in recent years, some studies have found that managers' irrational behaviors significantly impact corporate financial decisions [1], [12], [15]. More specifically, among such behaviors, the cognitive bias caused by managerial overconfidence is a typical one [30]. The cognitive bias caused by overconfidence makes managers behave and make decisions in uncertain environments as if they were in a much lower volatility environment. However, the uncertainty of reality still governs the outcome of those behaviors [24], [26], [35].

Literature on many topics provides empirical evidence for managerial overconfidence, including operations [27] and finance [1], [12]. Malmendier and Tate [30] documented that managers are more prone to cognitive bias of overconfidence when faced with more complicated tasks. Therefore, considering the difficulty of blockchain technology, we argue that it is necessary to account for the impact of overconfidence when

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investigating firms' cash policies involved in blockchain projects.

Agency costs arising from the misalignment of interests between shareholders and managers can also impact the decision-making of cash holdings [22]. The shareholders expect the managers' behaviors to maximize their wealth, while the managers tend to engage in issues from their interests, especially free cash flows within the firms. The shareholders have to incur agency costs to address the free cash flow problems. The complexity of blockchain projects drives up the information asymmetry between the managers and the shareholders. Therefore, agency costs cannot be neglected when studying blockchain firms' cash strategies.

This study investigates the impacts of managerial overconfidence and agency costs on cash holdings within blockchain firms. Accordingly, the firm's cash policy involving a blockchain project is characterized mainly by two managerial behaviors: a cognitive bias when the manager estimates the market demand of the blockchain project and an agency behavior when the manager pursues his interests in operating the firm. This study differs from the traditional scenario where managers are rational and unbiased. We first develop a cash management model that incorporates managerial overconfidence and agency costs into a firm. A geometric Brownian motion governs the cash flows generated by the existing assets of the firm. A shareholder decides how much cash should be retained from the cash flow into the firm. The shareholder has to trade off the agency costs of retaining cash within the firm against the opportunity costs of implementing the blockchain project. Expressly, we assume that the agency costs are a power function concerning the cash retention proportion.

Furthermore, a manager jointly determines when to initiate a blockchain project and raise external funds from a financier. Based on the estimation of the market demand, the manager decides whether implement the blockchain project. When there is uncertainty in market demand for the blockchain project, overconfidence bias leads the manager to make decisions as if he faced a more certain demand. Meanwhile, the manager can have access to external financing from a financier in a competitive capital market. Although external financing allows more flexibility in timing blockchain project implementation, it must be subject to the financier's monitoring that the manager perceives as costly. Accordingly, the financier perceives that his monitoring improves the blockchain project's value, but he also has to pay the monitoring cost that relies on transparency. Our model consists of two phases: cash retention from cash flow and the implementation of the blockchain project. The cash retention process engages the shareholder and the manager, while the blockchain project implementation process mainly involves the manager and the financier.

We then derive the model's equilibrium and find that the firm's future investment opportunities are necessary to retain cash internally when agency costs exist. In other words, if no investment opportunities are available in the future, the firm should not retain any cash in the context of shareholder wealth maximization. All cash flows generated by the firm's assets should be paid back to shareholders as dividends. Otherwise, if there are possible investment opportunities within the framework of agency costs in power function form, the optimal cash retention ratio for the shareholder's decision makes the evolution of the cash holdings the level also subject to a geometric Brownian motion. Both the mean and volatility of the cash holding growth rate increase with the agency cost. Overconfidence results in the manager underestimating the uncertainty of the market demand for the blockchain project. When the market demand is uncertain, this underestimation of volatility decreases the blockchain project's expected return. We find that the optimal level of cash holdings for firms that invest in blockchain projects increases with managerial overconfidence and decreases with agency costs. Further, when managers also choose the firm's transparency when raising external financing, the more overconfident the manager is, the more transparent the firm is.

We also apply data on Chinese listed companies over 2010-2019 to provide empirical evidence for the theoretical analysis. Based on the existing literature [20], [32], [33], we control a battery of corporate finance variables and governance in the regression analysis. In particular, the regression results show that the level of cash holdings is positively and negatively related to overconfidence and agency costs, respectively. These results are consistent with our theoretical findings. Further, compared to their peers, the firms that have announced participating in blockchain have significantly higher cash holdings levels. Managerial overconfidence positively moderates this positive correlation, but not significantly. In conclusion, our regression results are generally consistent with the theoretical analysis. These findings contribute to the literature investigating the determinants of cash holdings for one behavioral characteristic prevalent among managers [30].

Section II reviews the related literature. Section III presents the model setup. Section IV shows the equilibrium solutions of our model. Section V provides the empirical evidence of the equilibrium, and Section VI concludes.

II. LITERATURE REVIEW

This study is related to two literature streams: managerial overconfidence and determinants of cash holdings. The emerging literature of managerial overconfidence highlights that the impact of irrational and biased behaviors on financial decisions cannot be non-negligible since these decisions are made by human beings whose cognitive abilities are limited. Schweitzer and Cachon's seminal study [39] finds a pull-to-center effect in a lab experiment, suggesting that the subjects choose an order size between the mean and the optimal quantity. Since then, multiple studies have found that this effect holds even when changing the experimental setup [5], [17]. Ren *et al.* [35] argue that overconfidence can reasonably account for the pull-to-center effect. In empirical studies, due to the critical work of Malmendier and Tate [30], a growing body of literature relates managerial overconfidence to corporate behaviors, including investment efficiency [21], dividend policy [15], and cash holdings [1], [12]. Salehi *et al.* [36] argue that overconfidence leads a manager to believe himself is at a higher level than his peers, and the biased belief, in turn, contributes to take more risks. Using the Tehran Stock Exchange sample, Salehi *et al.* [36] obtain empirical evidence and find that managerial overconfidence positively affects corporate risk-taking. Because of irrational cognitive biases, overconfident managers believe financial markets undervalue their companies' investment returns and stock prices. Therefore, they are likely to delay recognition of losses and useless the conditional conservatism in accounting. Salehi *et al.* [37] find a negative relationship between managerial overconfidence and conditional conservatism. Overconfident managers tend to invest with internal funds, in which operating cash flow has higher priority and is likely to be exhausted rapidly. In such a situation, the managers have strong incentives to adjust cash flow levels to avoid negative operating cash flows. Yang and Kim [41] find that overconfident managers are more likely to adjust negative operating cash flow to positive and engage in higher discretion of operating cash flow than their rational peers. Overconfident cognitive bias leads management to expect the firm to enjoy a good growth prospect in the near term and to believe that cash flow is stable and abundant. Therefore, managerial overconfidence might lead the firm to increase dividend payments. However, suppose a firm is faced with good investment opportunities. In that case, managerial overconfidence might instead yield lower dividend payments, as the firm will prioritize retained earnings to meet investment needs. Using a Vietnamese sample, Nguyen *et al.* [31] find that managerial overconfidence positively impacts dividend payout. Overconfident managers overestimate the return on investment projects while perceiving the cost of external financing to be too high. As a result, they may overinvest when internal funds are sufficient; when internal funds are insufficient, they are reluctant to engage in external financing due to the unduly perceived cost of financing. Notably, cash flow can be one of the sources of project financing, which implies that adequate cash flow can mitigate the underinvestment problem. Therefore, the relationship between investment and cash flow is higher in firms run by overconfident managers. Bukalska [8] finds that managerial overconfidence is positively associated with the investment-cash flow sensitivity. Despite the irrationality of managerial overconfidence, it still might exert some positive consequences. Salehi and Moghadam [38] use return on assets to measure firm performance and find that managerial overconfidence is positively associated with performance, and agency costs did not significantly affect performance. Seifzadeh *et al.* [40] find a significantly positive relationship between managerial overconfidence and financial statement readability.

This study is also related to the literature on the determinants of cash holdings. Previous studies show that the precautionary motive is the driver for the buffer-construction behavior of maintaining excess liquidity for coping with the unexpected future contingency [20], [23], [28], [32], [34]. The precautionary motive stems from asymmetric information in capital markets [23]. In a frictionless world, the optimal level of cash holdings is zero because firms would always raise any funds needed with fair costs. However, in the real world, the information asymmetry between firms and capital markets forces up the cost of raising funds. The unfair external financing cost is on the higher side, which increases the cost of financial distress [23]. Therefore, firms hold precautionary cash to cope with this situation and hedge against future adverse events [4], [28]. Even firms with access to capital markets might not choose to raise external funds when informational asymmetry is high and firms are undervalued [16]. Based on the precautionary motive, the existing literature has summarized several determinants, including financial characteristics, corporate governance, and the macroeconomic environment. Opler *et al.* [32] demonstrate that many financial characteristics can be regarded as the determinants of cash holdings, including growth opportunities, cash flow risks, firm size, and access to capital markets. Pinkowitz *et al.* [34] are also concerned about this secure increasing issue but focus on multinational firms. Benjamin *et al.* [6] have shown that the level of waste disclosure is positively related to cash holdings. They argue that holding precautionary cash reserves can be regarded as the ability to meet future environmental demands. We extend the literature by taking managerial overconfidence and agency costs into a cash holdings model to investigate their theoretical impacts and management insights. Moreover, we incorporate the empirical evidence into the management insights.

Our study's most closely related studies include Boot and Vladimirov [7], and Datta [14]. We differ from them as follows. Boot and Vladimirov [7] investigate the optimal level of cash holdings for investments when the firm has access to external financing. However, they assume that the evolution of cash holdings follows a geometric Brownian motion. Their study focuses on the changes in cash holdings themselves while there are no agency costs. We incorporate the cash retention stage into our model, i.e., the changes of cash holdings stem from two sources: the risk-free growth of cash holdings themselves and the retention from cash flows. Although Datta [14] takes managerial overconfidence and agency problems into the investing timing model, his model is established on the belief updating. Our model focuses on the decision-making of the optimal cash holdings when the firm faces investment opportunities. Moreover, our theoretical analysis is supported by empirical evidence from Chinese listed firms.

III. MODEL SETUP

This section considers a model with three players: a shareholder, a manager, and a financier. Our model features a setting in which a firm generates stochastic cash flows. The firm is owned by the shareholder and run by the overconfident manager. The shareholder bears agency costs because of the free cash flow problem. Also, there is a future investment opportunity for the firm to implement a risky blockchain project. The manager has an option to delay the implementation and can raise external funds from the financier.

A. AGENCY COSTS AND CASH HOLDINGS

Suppose that the firm's existing assets generate stochastic cash flows ω_t governed by a geometric Brownian motion:

$$\mathrm{d}\omega_t = \mu\omega_t \mathrm{d}t + \sigma\omega_t \mathrm{d}z_t, \tag{1}$$

where $\mu > 0$ and $\sigma \geq 0$ are the mean and volatility of the growth rate of ω, and $\mathrm{d}z_t$ is a standard Brownian motion. Assume that $\mu < r$, where r is the risk-free interest rate [7].

The shareholder would accumulate cash holdings to prepare for the demands of future investment opportunities. There are two main ways of accumulation. First, the reservation of cash flows. If cash flows are not paid out or invested, they are reserved within the firm as cash holdings. Second, the risk-free growth of cash holdings. The firm's reserved cash is put on a cash account and could earn a risk-free return r. Since raising external funds is costly, it seems like that the shareholder should keep all the generated cash flows within the firm to avoid cash shortage.

However, retaining cash is also costly for the shareholder because of the free cash flow problem [22]. The manager might abuse cash for his private profits, which results in value-destroying consequences upon the firm when the level of cash holdings is high. To prevent the manager from that, the shareholder has to implement monitoring and therefore bear agency costs. Previous literature argues that only the instantaneous increment of the retained cash flows must be monitored regarding the relationship between cash holdings and agency costs. This argument's main reason is that the previously retained cash flows and the risk-free growth of cash holdings have already been allocated to a cash account [2], [25]. Namely, the manager cannot abuse cash holdings all as he wishes.

Denoting the retained fraction of cash flows as α, we assume that agency costs are $C(\alpha)$, where $C'(\alpha) > 0$ and $C''(\alpha) > 0$. Specifically, we assume that

$$C(\alpha) = \alpha^{\theta} c, \tag{2}$$

where $0 \leq \alpha \leq 1$ and $\theta \geq 1$. The parameter θ reflects the ease of shareholder monitoring. A larger θ represents more ease for the shareholder to monitor the manager. Easier monitoring implies a greater convergence of objectives between the shareholder and the manager. In this case, the agency costs borne by shareholders are lower. Given the cash retention ratio α, the agency costs $C(\alpha)$ decrease in the shareholder's monitoring ease θ.

Furthermore, the specification of power function in (2) assumes that agency costs are convex increasing in the retained fraction of cash flows. It captures the intuition that if there is a positive cash flow shock to the firm, more cash is retained, and the manager is more likely to misuse the cash holdings. Hence, the shareholder's agency costs are higher.

Moreover, the specification of agency costs in our model encompasses two different forms as exceptional cases. If $\theta = 1$, we obtain the agency costs in the linear form [18]. The agency costs are assumed to be a fixed ratio of the retained cash flows in this form. Expending the cost form to a non-linear one considers the agency problem in the financial policies' decision-making. If $\theta = 2$, we obtain the agency costs in the quadratic form [25]. Our specification differs in that the agency problem could be more severe.

Let h_t denote the cash holdings and s_t denote the retained cash flows. Combining with the stochastic process of cash flows in (1), we could get that

$$\mathbb{E}[\mathrm{d}h_t] = s_t \mathrm{d}t + rh_t \mathrm{d}t, \tag{3}$$

where $s_t = \alpha\omega_t - \alpha^{\theta} c$. The left-hand part serves the expected increment of cash holdings, while the right-hand part covers the two sources of the increment. The first term on the right-hand part represents the cash retained from cash flows and stored in the firm, and the second term represents the risk-free growth of the cash holding itself.

B. MANAGERIAL OVERCONFIDENCE AND EXTERNAL FUNDS

The firm owns an option to initiate a risky blockchain project with an investment of K. The blockchain project requiring an investment of K produces productions with a random demand X and a unit variable cost v. The distribution function (CDF) of X is $F_X(\cdot)$. As a price-taker, the expected profit of the blockchain project is

$$\pi = p\mathbb{E}[X \wedge q] - vq, \tag{4}$$

where $x \wedge y = min\{x, y\}$ and p is the price of selling each unit of the production. Our model features managerial overconfidence by a distorted demand perception [26], [27]. Specifically, the manager should have determined the optimal quantity q^* according to the corresponding first-order condition to maximize the profits. However, the manager exhibits the cognitive bias of overconfidence by making the quantity decision as though the demand distribution were $F_D(\cdot)$ rather than $F_X(\cdot)$, where

$$D = \beta\mathbb{E}[X] + (1-\beta)X, \tag{5}$$

for $\beta \in [0, 1]$. That is, the overconfident manager determines the optimal quantity $\hat{q}(\beta)$ as though he were maximizing $\pi_D = p\mathbb{E}[D \wedge q] - cq$. However, the corresponding profits of the blockchain project are $\hat{\pi}(\beta) = p\mathbb{E}[X \wedge \hat{q}(\beta)] - v\hat{q}(\beta)$.

The timeline of our model is illustrated in Figure 1. In the beginning, the firm does not have enough cash in hand to fund the blockchain project internally, but the investment opportunity can be postponed. The manager has discretion about the timing of initiating the blockchain project. Also, there is a financier from whom the firm can raise external funds in equity. Considering the financial market is competitive, the manager needs to promise the financier an equity fraction of γ.

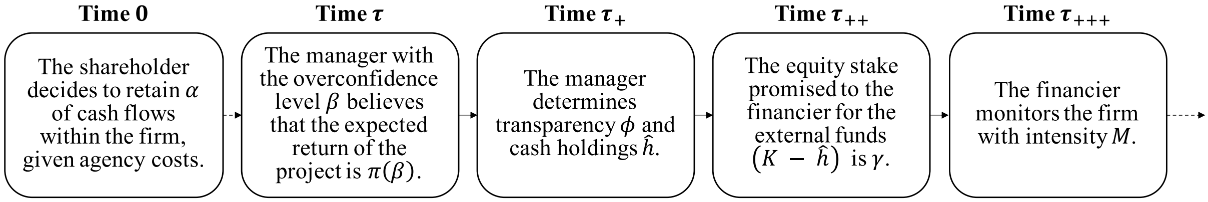

FIGURE 1. **Timeline of the model.**

The external funds are expensive for the manager due to the discrepancy in the blockchain project's value between the manager and the financier [7]. In the financier's perspective, the blockchain project's value increases in the monitoring intensity M, so his overall value is $M\pi$. Meanwhile, there is a cost to the financier of $M^2/(2\phi)$ for monitoring and interference. The parameter ϕ reflects the ease of the financier's monitoring, determined by the manager's transparency policy. A higher ϕ implies the manager makes the firm more transparent and comfortable for the financier to monitor. Therefore, the financier's monitoring costs decrease in ϕ. From the manager's perspective, the financier's interference is costly, so that the manager might prefer a lower level of transparency. Denote the costs from the manager's perspective as $\psi(M)$, increasing and convex in the amount of interference from the financier M. Specifically, we assume that $\psi(M) = (M^2/2)\lambda$, where $\lambda > 0$.

IV. EQUILIBRIUM

This section applies the real-option game framework to find the model's equilibrium solution and provides several propositions on the equilibrium solution sensitivity analysis. The formalized proofs corresponding to each proposition are presented in the appendix.

A. EVOLUTION PROCESS OF CASH HOLDINGS

Given the agency costs within the firm, the shareholder's problem is retaining the optimal fraction of cash flows to take the opportunity to initiate the blockchain project. Suppose there are no future investment opportunities and there are no new blockchain projects in the short term. The shareholder, therefore, is reluctant to retain and store cash in the firm since the retention would cause him to suffer additional agency costs. Alternatively, suppose the blockchain project has not yet been implemented. In that case, the shareholder needs to trade off the benefit of reducing the external funding costs against the loss from the agency costs. Then, the shareholder's objective is shown as follows.

$$s_t = \max_{\alpha}\{\alpha\omega_t - \alpha^{\theta}c\}. \tag{6}$$

Therefore, given the shareholder's monitoring parameter θ, the optimal retaining fraction α^* can be derived according to the first-order condition as follows:

$$\alpha^* = \left(\frac{\omega_t}{c\theta}\right)^{\frac{1}{\theta-1}}, \tag{7}$$

and the corresponding level of cash saving s_t^* is

$$s_t^* = \kappa\omega_t^{\eta}, \tag{8}$$

where $\kappa = \left(1 - \frac{1}{\theta}\right)\left(\frac{1}{c\theta}\right)^{\frac{1}{\theta-1}} > 0$ and $\eta = \frac{\theta}{\theta-1} > 1$.

Considering the stochastic process of cash flows in (1) and the relationship between cash flows and cash holdings in (3), we can derive that the following equation governs the level of cash holdings h_t:

$$\frac{1}{2}\sigma^2\omega_t^2\frac{\partial^2 h_t}{\partial\omega_t^2} + \mu\omega_t\frac{\partial h_t}{\partial\omega} - rh_t - s_t = 0. \tag{9}$$

Proposition 1 represents the equilibrium level of cash holdings.

Proposition 1: Because agency costs exist, the optimal cash-retaining policy for the shareholder is contingent upon whether the blockchain project has been implemented or not:

(a) If the blockchain project has already been implemented, the optimal policy retains no cash and pays all the cash flows as dividends.

(b) If the blockchain project has not been implemented yet, the optimal cash holdings are governed by the following geometric Brownian motion:

$$\mathrm{d}h_t = \mu_h h_t \mathrm{d}t + \sigma_h h_t \mathrm{d}z, \tag{10}$$

where $\mu_h = \frac{1}{2}\sigma^2\eta(\eta - 1) + \mu\eta > \mu$ and $\sigma_h = \sigma\eta > \sigma$ are the mean and volatility of cash holdings, respectively. In addition, both μ_h and σ_h are decreasing in the shareholder's monitoring ease θ.

The management implications of Proposition 1 are as follows. In the absence of a free cash flow problem, the manager's objectives are aligned with those of the shareholder. In this scenario, the optimal cash holdings strategy should be retaining and storing all the generated cash flows to cope with future investment opportunities. In contrast, if the shareholder has to bear agency costs, retaining and storing the entire cash flows in the firm is not the optimal decision because the manager may use the free cash for private gain, resulting in a loss of shareholder benefit. In such a case, the shareholder tends to allocate a portion of cash flows to dividend payments and keep the remaining cash flows for future investment opportunities. Proposition 1 implies that agency costs are why firms pay dividends even when there are future investment opportunities.

The agency costs also influence the evolution process of cash holdings. Considering $\theta > 1$ and combining the expressions of μ_h and σ_h in Proposition 1, we can obtain $\mu_h > \mu$ and $\sigma_h > \sigma$, which documents that the mean and volatility of growth rate of cash holdings are higher than those of cash flows. Moreover, as mentioned, the easier it is for the shareholder to monitor the manager, the lower the agency cost that the shareholder has to bear, i.e., $\partial C/\partial\theta < 0$. Intuitively, this would drive up the rate of cash retentions, which would lead to an evolutionary process of cash holdings with a higher mean and volatility of cash holdings' growth rate. However, the reverse is the case. The counter-intuitive results are because cash holdings' evolution process includes retained cash flows and risk-free growth. In the scenario where the shareholder's monitoring is easier, the effect of retained cash flows on cash holdings is not sufficient to offset the risk-free growth. Therefore, the final result shows that both the mean and volatility decline with the ease of monitoring. That is, $\partial\mu_h/\partial\theta < 0$ and $\partial\sigma_h/\partial\theta < 0$.

B. MANAGERIAL OVERCONFIDENCE

Since the firm does not need to hold any cash when the risky blockchain project has already been implemented, we focus on the alternative case where the opportunity to implement the risky blockchain project still exists. In this scenario, the firm needs to maintain a certain level of cash holdings rather than paying all cash flows as dividends. Moreover, the manager's decision on the cash holdings threshold depends mainly on the blockchain project's amount of investment versus its expected profits. In particular, the expected profits resulting from the blockchain project output that meets the market demand. However, the manager's estimate of market demand is distorted by his overconfidence. Therefore, the key to determining the optimal cash holdings threshold is the project's expected profits implemented by the overconfident manager.

Given (4) and (5), Proposition 2 summarizes the optimal output and resulting expected profits.

Proposition 2: Given the distribution function $F_X(\cdot)$, its inverse function $F_X^{-1}(\cdot)$, and the level of managerial overconfidence β, the manager optimally chooses his quantity as $\hat{q}(\beta) = \beta\mathrm{E}[X] + (1-\beta)q^*$ and obtains the corresponding profits $\hat{\pi}(\beta)$, where $q^* = F_X^{-1}(\zeta)$ and $\zeta = (p-v)/p$. In addition, $\hat{\pi}(\beta)$ is decreasing in β.

The management insights of Proposition 2 are shown below. It illustrates the equilibrium output determined by the overconfident manager when the market demand is uncertain and the blockchain project's expected profit at that output level. The results also show that the expected profit decreases in managerial overconfidence. The reason is that the manager's overconfidence makes his estimate of market demand deviate from the actual level. According to (5), under the condition of random market demand, the manager's overconfidence does not affect his estimation of the mean. Still, it causes his estimation of the variance to be biased. In particular, the overconfident manager underestimates the market demand variance. This underestimation leads to a deviation from the real situation in the first-order condition of the blockchain project's expected profit to output, leading to non-optimal blockchain project output decisions. The realized profit is affected as well. Consequently, as the level of overconfidence increases, the expected profit of the blockchain project decreases.

C. CASH HOLDINGS THRESHOLD AND TRANSPARENCY

1) THE SIMPLE MODEL

We abstract from the transparency decision for clarity in our analysis and focus on the relationship between agency costs, managerial overconfidence, and cash holdings. To this end, we assume that the financier's monitoring intensity is binary: either no monitoring or complete monitoring, i.e., $M \in \{0, 1\}$. With this setup, there are only two scenarios. The manager can only fund the blockchain project with cash holdings if $M = 0$. Alternatively, if $M = 1$, the manager has access to the financier's external funds. In the latter case, the value of the blockchain project in the financier's perspective is $\hat{\pi}(\beta)$. As for the manager's transparency decision, it is optimal to be infinity, i.e., $\phi \to \infty$. The reason is that greater transparency allows the manager for a more significant proportion of the blockchain project's equity stake when raising a given amount of external funds.

The manager obtains the external funds $K - h_t$ by selling an equity stake of the blockchain project to the financier. Since in the competitive market, the financier can only earn a retained return at the break-even point by purchasing the equity stake. Specifically, the proportion of promises to the financier is

$$\gamma = \frac{K - h_t}{\pi}. \tag{11}$$

Therefore, the manager's net payoff is

$$Y(h_t, \beta) = \left(1 - \frac{K - h_t}{\pi}\right)\hat{\pi}(\beta) - \frac{\lambda}{2} - h_t. \tag{12}$$

As $\hat{\pi}(\beta) \le \pi$ and $0 \le \gamma \le 1$, the manager's payoff $Y(h_t, \beta)$ is decreasing in the level of cash holdings h_t.

We now derive how the agency costs and the managerial overconfidence affect the timing of investing and the cash policy. The manager's objective is to determine the optimal level of cash holdings $\hat{h}$ to implement the blockchain project and maximize the value of the option to invest U. The manager's expected payoff is

$$U(h_t, \hat{h}) = max\,\mathbb{E}\left[\frac{1}{1 + r\mathrm{d}t}[U(h_t + \mathrm{d}h_t, \hat{h})]\right]. \tag{13}$$

Applying Ito's lemma, we obtain

$$rU = \mu_h h_t \frac{\partial U}{\partial h_t} + \frac{1}{2}\sigma_h^2 h_t^2 \frac{\partial^2 U}{\partial h_t^2}. \tag{14}$$

The equation is solved with respect to the following boundary conditions:

$$U(0, \hat{h}) = 0, \tag{15}$$

$$U(h_t, \hat{h})|_{h_t=\hat{h}} = Y(\hat{h}, \beta), \tag{16}$$

$$U_{\hat{h}}(h_t, \hat{h})|_{h_t=\hat{h}} = Y_{\hat{h}}(\hat{h}, \beta), \tag{17}$$

where the subscript of U denotes the corresponding partial derivative.

The first condition in (15) states that if the level of cash holdings reaches zero, there is no value of the option. The evolution process of cash holdings is governed by geometric Brownian motion. If the level of cash holdings is zero at any time, it remains zero in the subsequent period. In this case, the investment of the blockchain project relies entirely on external financing. Therefore, the value of the option equals zero. The second condition in (16) is the value-matching condition, which implies that the value of the option should be equal to the payoff of investment when the level of cash holdings reaches the threshold. The last condition in (17) is the smooth-pasting condition, which ensures that the threshold exists and maximizes the option's value.

Proposition 3: If the manager has access to the external funds, the optimal level of cash holdings is given by

$$\hat{h} = \frac{\delta_h}{\delta_h - 1} \frac{2(\pi - K)\hat{\pi}(\beta) - \lambda\pi}{2\left(\pi - \hat{\pi}(\beta)\right)}, \tag{18}$$

where $\delta_h = \frac{1}{2} - \frac{\mu_h}{\sigma_h^2} + \sqrt{\left(\frac{\mu_h}{\sigma_h^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma_h^2}}$. *The level of cash holdings increases in the managerial overconfidence and decreases in the agency costs, i.e.,* $\partial\hat{h}/\partial\beta > 0$ *and* $\partial\hat{h}/\partial\theta > 0$.

Naturally, the cost of postponing investment timing weighs less when there is more ease of the shareholder's monitoring, raising cash holdings. Moreover, if the overconfidence is more severe, the lower the cost of delaying the execution of the option. Firms with greater managerial overconfidence tend to invest later, implying a positive relationship between cash holdings and overconfidence.

2) THE SOPHISTIC MODEL

When the firm's cash holdings are insufficient to cover the blockchain project's investment needs, the manager needs external financing to fill the funding gap. The manager signals the need for external funds to the financier in a competitive financial market and finances the funds in the form of shares. Therefore, the financier has to decide on the percentage of shares γ and the monitoring intensity M.

Given γ, the financier decides his monitoring intensity M:

$$M = \arg\min_{M} \left(\gamma M\pi - \frac{M^2}{2\phi}\right). \tag{19}$$

As mentioned, the financier is in a competitive financial market. Hence, when the manager raises funds $K - \hat{h}$, the financier can only obtain the payoff at the break-even condition:

$$\gamma M\pi - \frac{M^2}{2\phi} - (K - \hat{h}) = 0. \tag{20}$$

Proposition 4: The optimal monitoring intensity of the financier M^* *is as follows*:

$$M^* = \sqrt{2\phi(K - \hat{h})}. \tag{21}$$

The equilibrium equity fraction of the financier γ^* *is as follows*:

$$\gamma^* = \frac{\sqrt{2\phi(K - \hat{h})}}{\phi\pi}. \tag{22}$$

The manager's expected payoff when he implements the blockchain project by investing cash holdings h_t and raising external funds $(K - h_t)$ is

$$\bar{Y}(h_t) = (1 - \gamma^*)\hat{\pi}(\beta) - \psi(M^*) - h_t, \tag{23}$$

where M^* and γ^* are presented in (21) and (22).

Similar with the simple model, the cash holdings threshold $\hat{h}^*$ and the level of transparency ϕ^* are determined by

$$\max_{\phi,\hat{h}} \left(\frac{h}{\hat{h}}\right)^{\delta_h} \bar{Y}(\hat{h}). \tag{24}$$

Proposition 5: The optimal levels of cash holdings $\hat{h}^*$ *and transparency* ϕ^* *increase in the managerial overconfidence, that is,* $\partial\hat{h}^*/\partial\beta > 0$ *and* $\partial\phi^*/\partial\beta > 0$.

V. EMPIRICAL EVIDENCE

A. DATA

We obtained Chinese listed firms' data from the Chinese Research Data Services Platform (CNRDS) database from 2010 to 2019. We exclude the sample by the following criteria:

1. Firms in the financial industry;
2. Firms under delisting procedures (ST/ST* firm);
3. Firms with missing values.

Also, all continuous variables are winsorized at the 1% and 99% levels of their distributions.

B. VARIABLES AND DESCRIPTIVE STATISTICS

The dependent variable, cash holdings (denoted as *cash*), is computed as the ratio of cash and equivalents to assets [32], [33].

Our proxy for managerial overconfidence (denoted as *oc*) is constructed based on the change in managerial shareholding. The measure of managerial overconfidence equals one if management increases the shareholdings and excesses the 75th percentile; otherwise, the measure equals zero. The measure of agency costs (denoted as *ac*) is calculated as the ratio of managerial costs to operating profits.

We derive the control variables at the firm level from the previous literature on the determinants of cash holdings [3], [32]. The firm-level control variables are shown as follows. The financing constraints index (*fc*) is calculated as the absolute value of the SA index, and the larger it is, the stronger the degree of financing constraint a firm faces. The market to book ratio (*m2b*) is computed as the total book value of assets less the book value of equity plus the market value of equity divided by total assets. The capital expenditures (*capex*) are denoted as the cash paid to acquire fixed assets, intangible assets, and other long-term assets divided by assets. The liabilities ratio (*tl*) is calculated as the total liabilities divided by total assets. The cash flow (*cflow*) is computed as the net cash flows generated from operating activities divided by assets. The size (*size*) is calculated as the logarithm of the assets. The net-working capital (*netwc*) is denoted as the working capital less cash and cash equivalents divided by assets. *salegr* denotes the growth rate of the operating revenue. *div* stands for the dummy, which equals one when the firm pays dividends.

We also control some corporate government variables. *topone* measures the share proportion of the largest shareholder. *hhi* presents the Herfindahl index of the share proportion of the largest five shareholders, and a larger *hhi* indicates a higher concentration of equity. *MShrRat* gives the management shareholding ratio. *InDrcRat* shows the percentage of independent directors on the board. *gpay* is calculated as the natural logarithm of the total compensation of the top three executives.

TABLE 1. Descriptive statistics.

	Mean	S.D.	25th	Median	75th	N
cash	0.161	0.111	0.084	0.133	0.208	11910
oc	0.029	0.168	0.000	0.000	0.000	11910
ac	0.086	0.085	0.039	0.064	0.101	11910
fc	1.348	0.069	1.312	1.353	1.391	11910
m2b	3.553	4.102	1.599	2.415	3.835	11910
capex	0.043	0.043	0.012	0.030	0.062	11910
tl	0.492	0.204	0.337	0.497	0.647	11910
cflow	0.046	0.072	0.006	0.046	0.087	11910
size	22.645	1.403	21.698	22.510	23.502	11910
netwc	-0.007	0.215	-0.143	-0.010	0.135	11910
salegr	0.182	0.602	-0.035	0.084	0.224	11910
div	0.565	0.496	0.000	1.000	1.000	11910
topone	36.835	15.622	24.570	35.070	48.050	11910
hhi	17.735	12.594	7.929	14.864	24.914	11910
MShrRat	2.891	9.919	0.000	0.003	0.111	11910
InDrcRat	38.447	10.024	33.333	37.500	43.750	11910
gpay	14.389	0.735	13.918	14.372	14.809	11910

Table 1 depicts the descriptive statistics. The mean and median levels of cash holdings are 16.1% and 13.3% of the total assets, respectively. The standard deviation is 0.111, which indicates a substantial variation in the level of cash holdings over firms.

Figure 2 consists of three groups of box plots, each representing the distribution of cash holdings across rational and overconfident firms. The left and right adjacent lines denote each box plot's 10th and 90th percentile, and the left and right hinges indicate the 25th and 75th percentile, respectively. The median of each group is depicted in the middle of each box. The horizontal coordinates in Figure 2 are arranged based on the descriptive statistical characteristics of cash holdings (*cash*) in the whole sample.

In Figure 2, we can observe that the right whiskers of all box plots are longer than the left ones, suggesting that all the groups' distributions are right-skewed. The box of the overconfident group is more to the right than its counterpart of the rational group. The result suggests that cash holdings are higher in the overconfident group than in the rational group.

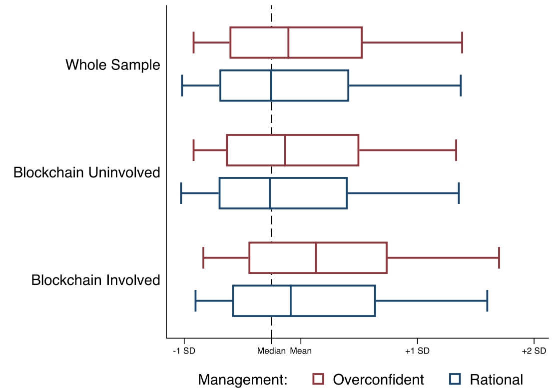

FIGURE 2. Distribution of cash holdings across rational and overconfident groups.

When focusing on the intra-group distributions among the blockchain-involved and the blockchain-uninvolved groups, we find that the overconfident boxes are more to the right than the rational boxes in Figure 2. This result can be interpreted as the overconfident sample has an overall higher level of cash holdings than the rational, regardless of whether they are involved in blockchain projects. Figure 2 also shows that the overconfident blockchain-involved firms have more cash holdings than their overconfident blockchain-uninvolved counterparts. When we focus on the extra-group differences of rational firms, we can find similar results. The extra-group results in Figure 2 reflect, to the descriptive extent, the tendency of firms involved in blockchain projects to keep a higher level of cash holdings.

C. REGRESSION MODELS

We augment the model suggested by Opler *et al.* [32] with the proxy for managerial overconfidence as the baseline model. Specifically, we estimate the following specification:

$$\begin{aligned} cash_{i,t} &= a_0 + a_1 \cdot oc_{i,t-1} + a_2 \cdot ac_{i,t-1} \\ &\quad + \Gamma' \cdot control_{i,t-1} + \epsilon_{i,t} \end{aligned} \tag{25}$$

where the dependent variable is $cash_{i,t}$, the ratio of cash and cash equivalents to net assets of firm i at the end of year t. $oc_{i,t-1}$, the independent variable of interest, reflects whether the manager of firm i is overconfident at the end of year $t-1$.

In equation (25), a_1 reports the effect of managerial overconfidence on cash holdings. A significantly positive a_1 suggests that firms raise cash holdings when their managers are overconfident. Similarly, a_2 represents the effect of agency costs on cash holdings. A significantly negative a_2 indicates that firms decrease cash holdings when agency costs are high. Significance levels for estimated coefficients of equation (25) are adjusted to reflect robust standard errors with clustering at the firm level.

TABLE 2. Regression results.

	(1) F.cash	(2) F.cash	(3) F.cash	(4) F.lncash	(5) F.lncash	(6) F.lncash	(7) F.lncash	(8) F.lncash
oc	0.0123*	0.0125*	0.0111*	0.1015***	0.0992**	0.0905**		0.0713*
	(1.93)	(1.94)	(1.68)	(2.62)	(2.55)	(2.21)		(1.65)
ac	-0.0616**	-0.0573**	-0.0657**	-0.6136***	-0.5915***	-0.6512***	-0.6702***	-0.6678***
	(-2.13)	(-1.97)	(-2.34)	(-3.16)	(-3.03)	(-3.56)	(-3.64)	(-3.64)
fc	-0.0322	-0.0227	-0.0281	-0.2419	-0.2725	-0.2206	-0.2351	-0.2370
	(-0.90)	(-0.60)	(-0.76)	(-1.02)	(-1.07)	(-0.90)	(-0.97)	(-0.97)
bkc							0.1392**	0.1316**
							(2.36)	(2.19)
ocbkc								0.1580
								(1.26)
m2b	0.0032***	0.0034***	0.0032***	0.0154***	0.0156***	0.0134***	0.0130***	0.0130***
	(5.44)	(5.39)	(5.26)	(4.04)	(3.78)	(3.41)	(3.30)	(3.30)
capex	-0.5259***	-0.5359***	-0.4067***	-3.0874***	-3.0897***	-2.1739***	-2.1572***	-2.1576***
	(-12.31)	(-12.28)	(-9.86)	(-10.75)	(-10.55)	(-7.39)	(-7.31)	(-7.31)
tl	-0.1500***	-0.1518***	-0.1818***	-0.7447***	-0.7279***	-0.9125***	-0.9138***	-0.9160***
	(-9.74)	(-9.44)	(-10.77)	(-7.57)	(-7.10)	(-8.37)	(-8.37)	(-8.39)
cflow	0.1043***	0.1048***	0.1287***	0.4560***	0.4507***	0.6421***	0.6474***	0.6472***
	(4.18)	(4.19)	(5.30)	(2.87)	(2.82)	(4.22)	(4.28)	(4.27)
size	-0.0103***	-0.0095***	-0.0068***	-0.0868***	-0.0887***	-0.0686***	-0.0722***	-0.0719***
	(-4.27)	(-3.62)	(-2.71)	(-5.27)	(-5.00)	(-4.11)	(-4.32)	(-4.30)
netwc	-0.0865***	-0.0867***	-0.1155***	-0.3415***	-0.3426***	-0.5350***	-0.5394***	-0.5395***
	(-7.05)	(-7.06)	(-8.37)	(-4.33)	(-4.34)	(-5.99)	(-6.04)	(-6.05)
salegr	0.0019	0.0017	0.0009	0.0057	0.0056	0.0035	0.0033	0.0036
	(0.99)	(0.86)	(0.48)	(0.40)	(0.39)	(0.25)	(0.24)	(0.26)
div	0.0087***	0.0110***	0.0102***	0.0906***	0.1081***	0.1007***	0.1009***	0.1003***
	(2.84)	(3.25)	(3.05)	(4.15)	(4.35)	(4.23)	(4.25)	(4.23)
topone	0.0008*	0.0008*	0.0007	0.0057*	0.0056	0.0044	0.0045	0.0045
	(1.76)	(1.76)	(1.61)	(1.69)	(1.64)	(1.35)	(1.38)	(1.41)
hhi	-0.0007	-0.0007	-0.0005	-0.0066	-0.0064	-0.0040	-0.0042	-0.0042
	(-1.12)	(-1.14)	(-0.83)	(-1.51)	(-1.47)	(-0.96)	(-1.00)	(-1.01)
MShrRat	-0.0002	-0.0002	-0.0003**	-0.0009	-0.0012	-0.0026***	-0.0025**	-0.0027***
	(-1.25)	(-1.25)	(-2.27)	(-0.91)	(-1.26)	(-2.62)	(-2.53)	(-2.72)
InDrcRat	0.0001	0.0002	0.0000	0.0010	0.0015	0.0005	0.0004	0.0004
	(0.91)	(1.12)	(0.12)	(1.13)	(1.53)	(0.49)	(0.47)	(0.46)
gpay	0.0185***	0.0179***	0.0113***	0.1451***	0.1405***	0.0939***	0.0936***	0.0927***
	(5.36)	(5.07)	(3.28)	(6.33)	(6.05)	(4.11)	(4.11)	(4.07)
_cons	0.2281***	0.2106**	0.2611***	-1.5790***	-1.4391***	-1.1404**	-1.0524**	-1.0447**
	(3.04)	(2.49)	(3.19)	(-3.34)	(-2.71)	(-2.24)	(-2.06)	(-2.05)
N	10163	10163	10163	10163	10163	10163	10163	10163
Fixed	None	Year	Year-Industry	None	Year	Year-Industry	Year-Industry	Year-Industry
Cluster	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Adj.R2	0.1354	0.1365	0.1896	0.1060	0.1070	0.1690	0.1706	0.1710

In Table 2, we estimate three specifications of the baseline equation for two kinds of dependent variables, i.e., *cash* and *lncash*, to accommodate the unobserved fixed effects. The first three columns report the results where the dependent variable is *cash*. Columns (1) to (3) show that the coefficients a_1 and a_2 are significantly positive and negative, respectively. The dependent variables in columns (4) to (6) are *lncash*. The results are not substantially different from the first three columns. Therefore, the firm holds more cash when the manager is overconfident or has fewer agency costs. These results are consistent with Propositions 3 and 5.

We also estimate the incremental impacts of participation in blockchain projects on cash holdings in the last three columns of Table 2. The variable *bkc* equals one when the firm announces its involvement in blockchain-related projects; otherwise, *bkc* equals zero. The variable *ocbkc* denotes the interaction between managerial overconfidence (*oc*) and blockchain involvement (*bkc*). Columns (6) to (8) show that blockchain involvement makes the firm hold more cash. The interaction between managerial overconfidence and blockchain involvement has a positive but insignificant impact on cash holdings.

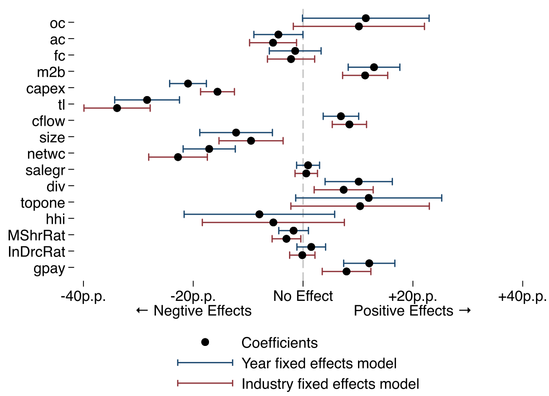

FIGURE 3. The coefficients and corresponding 95% confidence Intervals of the standardized variables.

We standardize the continuous variables in the regression models in terms of year-fixed effects and industry-fixed effects to investigate the discrepancies in the degree of influence of each variable on cash holdings. By standardization, we can transform each continuous variable into a variable with a mean of zero and a standard deviation of one. The standardization allows the coefficients to represent the degree of their influence on the cash holdings. If the independent variable is continuous, the magnitude of its regression coefficient indicates the extent to which one standard deviation of its change affects cash holdings. If the independent variable is a dummy, the value of its coefficient suggests the magnitude of the effect of category difference on cash holdings.

The estimated coefficients with 95% confidence intervals for the regression analyses are reported in Figure 3. The markers represent the estimated coefficients while the ranges show their 95% confidence intervals, and the capped spikes exhibit the corresponding upper and lower limits. In Figure 3, each variable matches two ranges: the upper blue range results from the regression model accounting for year-fixed effects, while the lower red range considers industry-fixed effects. The dashed line in the middle of Figure 3 represents that a variable has no impact on cash holdings. The left and right sides of the dashed line denote negative and positive effects, respectively. The farther the estimated coefficient is from the dashed line, the more significant the impact of the variable on cash holdings. Suppose a range with capped spikes does not intersect with the dashed line. In that case, non-intersection can regard that the effect of the independent variable on cash holdings is statistically significant at the 95% level.

We can observe from Figure 3 a positive and negative relationship between managerial overconfidence and agency costs with cash holdings, respectively. Take the results considering year-fixed effects as an example. The coefficient of managerial overconfidence (*oc*) is 0.1143, which means that cash holdings in a corporate with managerial overconfidence are 11.43 percentage points of a standard deviation higher than its peer with managerial non-overconfidence, ceteris paribus. The coefficient of agency costs (*ac*) is -0.0449, which suggests that a one-standard-deviation increase in agency costs is associated with a decrease of 4.49 percentage points of a standard deviation in cash holdings with other conditions unchanged. Similarly, the model's coefficients of managerial overconfidence (*oc*) and agency costs (*ac*) are 0.1017 and -0.0547, considering the industry-fixed effects.

To clearly illustrate the effects of the variables of interest on cash holdings, we suppress the results of other variables in Figure 4. There are three subfigures in Figure 4. The left subfigure depicts the effect of the variables of interest (*bkc*, *oc*, and *ac*) on cash holdings, and the remainder investigates the marginal impact on cash holdings by heterogeneity in blockchain involvement.

The left subfigure depicts the impacts of blockchain involvement (*bkc*), managerial overconfidence (*oc*), and agency costs (*ac*) on cash holdings. All three ranges with

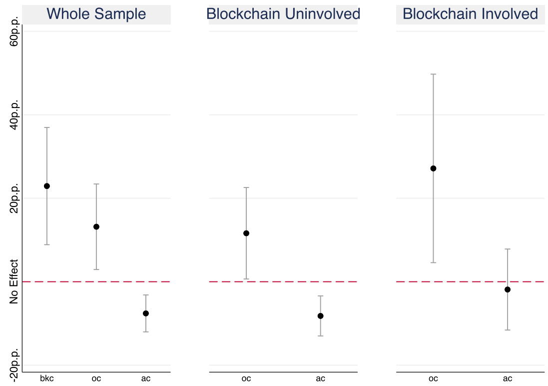

FIGURE 4. **Effects of the variables of interest on cash holdings.**

spikes in the left subfigure do not cross the no-effect line, which indicates that the effects of the three variables of interest on cash holdings are statistically significant at the 95% level. Specifically, the coefficient of involvement in a blockchain project (*bkc*) is 0.2292, which means that if a firm is involved in a blockchain project, it increases cash holdings by 22.92 percentage points of a standard deviation. The coefficient of managerial overconfidence (*oc*) is 0.1317, which suggests that cash holdings in a corporate with managerial overconfidence is 13.17 percentage points of a standard deviation higher than its counterpart with managerial non-overconfidence. The coefficient of agency costs (*ac*) is -0.0758, which suggests that a one-standard-deviation increase in agency costs is associated with a decrease of 7.58 percentage points of a standard deviation in cash holdings.

The middle and right subfigures in Figure 4 show the marginal effects on cash holdings considering the heterogeneity in blockchain involvement. Both subfigures show that the ranges with spikes for managerial overconfidence (*oc*) are above the no-effect line. It means that managerial overconfidence within a firm (*oc*) has a significant positive effect on cash holdings, regardless of whether it is involved in a blockchain project. The coefficients of managerial overconfidence (*oc*) in the blockchain-uninvolved and blockchain-involved samples are 0.1162 and 0.2715, respectively. It means that cash holdings are 11.62 percentage points of a standard deviation higher in firms with managerial overconfidence than their non-overconfident peers when they are not involved in blockchain projects; this compares to 27.15 percentage points of a standard deviation when they involve in blockchain projects.

As for the effect of agency costs on cash holdings, the results of the middle and right subfigures do not precisely match. The range with spikes for agency costs (*ac*) in the middle subfigure is below the no-effect line, but its counterpart in the right figure has a crossover with the no-effect line. The results indicate that the effect of agency costs on cash holdings is significantly negative in the blockchain-uninvolved sample; however, it is negative but not significant in the blockchain-involved sample.

The coefficients of agency costs (ac) in the blockchain-uninvolved and blockchain-involved samples are -0.0819 and -0.0187, respectively. It indicates that an increment of one standard deviation in agency costs (ac) results in 8.19 percentage points of a standard deviation decrease in cash holdings when the firms are not involved in blockchain projects; this comes out to 1.87 percentage points among the blockchain-involved firms. We also use seemingly unrelated estimation to test the blockchain-involvement heterogeneity in the marginal effects on cash holdings. The results show that the difference in the marginal effect of managerial overconfidence (oc) on cash holdings is not significant (p-value $=$ 0.18). Still, the difference in the marginal effect of agency costs (ac) is significant (p-value $= 0.06$).

VI. CONCLUSION

The impacts of managerial overconfidence and agency costs on corporate financial decisions have recently received a tremendous amount of attention. This study contributes to the literature by investigating the relationship between managerial overconfidence, agency costs and cash holdings, and the theoretical mechanism thereof. We build the cash holdings model based on the real-option game theory considering managerial overconfidence and agency costs. Our model's equilibrium suggests that cash holdings increase with managerial overconfidence and decrease with agency costs.

Using Chinese listed firm data from 2010 to 2019, we find that the regression results provide empirical evidence for the theoretical predictions. There is a significant positive relationship between managerial overconfidence and cash holdings; however, there is a significant negative relationship between agency costs and cash holdings. When we focus on firms that disclose their participation in blockchain projects in their announcements, the above relationships persist. Moreover, the level of cash holdings of the blockchain-involving firms is significantly higher than their peers.

Our findings shed light on the impacts of behavioral characteristics on cash holdings. Since the seminal study of Opler *et al.* [32], there have been extensive discussions on the determinants of cash holdings. The perspectives have expanded from firm characteristics to behavioral ones. We complement the literature by showing that managerial overconfidence, one of the most critical behavioral characteristics among managers, affects cash holdings due to the overconfident cognitive bias.

APPENDIX I. PROOFS

Proof of Proposition 1: The shareholder determines the optimal level of cash savings based on the first-order condition of (6) with respect to α:

$$\frac{\partial s_t}{\partial \alpha} = \omega_t - c\theta\alpha^{(\theta-1)} = 0. \tag{A.1}$$

The second-order condition is

$$\frac{\partial^2 s_t}{\partial \alpha^2} = -c\theta(\theta-1)\alpha^{(\theta-2)} < 0. \tag{A.2}$$

Combining the first and second order conditions, we can obtain that the optimal saving fraction α^* is as follows:

$$\alpha^* = \left(\frac{\omega_t}{c\theta}\right)^{\frac{1}{\theta-1}}. \tag{A.3}$$

Plugging (A.3) into (6), the expression of cash savings can be re-stated as

$$s_t = \kappa\omega_t^{\eta}, \tag{A.4}$$

where $\kappa = \left(1-\frac{1}{\theta}\right)\left(\frac{1}{c\theta}\right)^{\frac{1}{\theta-1}}$ and $\eta = \frac{\theta}{\theta-1} > 1$.

Applying Ito's lemma to (3), we can obtain the following partial differential equation with respect to the level of cash holdings h_t:

$$rh_t + s_t = \frac{1}{2}\sigma^2\omega_t^2\frac{\partial^2 h_t}{\partial \omega_t^2} + \mu\omega_t\frac{\partial h_t}{\partial \omega_t}. \tag{A.5}$$

Assume that the solution is $h_t = \kappa_1\omega_t^{\eta}$, where κ_1 is an undetermined coefficient. Plugging $\kappa_1\omega_t^{\eta}$ into (A.5), we can obtain that $\kappa_1 = \kappa/\left(\frac{1}{2}\sigma^2\eta(\eta-1)+\mu\eta-r\right)$. That is, the solution of the partial differential equation is as follows:

$$h_t = \frac{\kappa\omega_t^{\eta}}{\frac{1}{2}\sigma^2\eta(\eta-1)+\mu\eta-r}. \tag{A.6}$$

Applying Ito's lemma, we obtain

$$\mathrm{d}h_t = \mu_h h_t \mathrm{d}t + \sigma_h h_t \mathrm{d}z, \tag{A.7}$$

where $\mu_h = \frac{1}{2}\sigma^2\eta(\eta-1)+\mu\eta$ and $\sigma_h = \sigma\eta$. □

Algorithm 1 Algorithm for Proposition 1

Input: s_t.

1: compute α^*; where $\frac{\partial s_t}{\partial \alpha}|_{\alpha=\alpha^*}$;

2: $s_t \leftarrow \kappa\omega_t^{\eta}$; where $\kappa = \left(1-\frac{1}{\theta}\right)\left(\frac{1}{c\theta}\right)^{\frac{1}{\theta-1}}$ and $\eta = \frac{\theta}{\theta-1} > 1$;

3: compute h_t; where $rh_t + s_t = \frac{1}{2}\sigma^2\omega_t^2\frac{\partial^2 h_t}{\partial \omega_t^2} + \mu\omega_t\frac{\partial h_t}{\partial \omega}$;

4: $\mathrm{d}h_t \leftarrow \mu_h h_t \mathrm{d}t + \sigma_h h_t \mathrm{d}z$; where $\mu_h = \frac{1}{2}\sigma^2\eta(\eta-1)+\mu\eta$ and $\sigma_h = \sigma\eta$.
Proposition 1 can be proved.

Proof of Proposition 2: Given the probability density function (PDF) $f_X(\cdot)$, the expected return of the blockchain project in the unbiased scenario can be re-written as:

$$\pi = p\left(\int_{-\infty}^{q} Xf_X(X)\mathrm{d}X + \int_{q}^{+\infty} qf_X(X)\mathrm{d}X\right) - vq. \tag{A.8}$$

Hence, the manager determines his quantity according to the first-order condition:

$$p\int_{q}^{+\infty} f_X(X)\mathrm{d}X - v = 0. \tag{A.9}$$

Solving the first-order condition, we can derive the unbiased manager's optimal quantity $q^* = F_X^{-1}(\zeta)$, where $\zeta = (p-v)/p$.

In the overconfident scenario, the manager regards the PDF of X as $f_D(\cdot)$, rather than $f_X(\cdot)$ and believes the expected return of the blockchain project is

$$\pi = p\left(\int_{-\infty}^{q} X f_D(X)\mathrm{d}X + \int_{q}^{+\infty} q f_D(X)\mathrm{d}X\right) - vq. \quad \text{(A.10)}$$

Therefore, his optimal quantity is $\hat{q}(\beta) = F_D^{-1}(\zeta)$, which can be re-expressed as $\hat{q}(\beta) = \beta\mathbb{E}[X] + (1-\beta)q^*$. However, the expected return of the blockchain project in the overconfident scenario is still governed by the real CDF of X; i.e., $F_X(\cdot)$. Hence, the corresponding profits of the blockchain project are $\hat{\pi}(\beta) = p\mathbb{E}[X \wedge \hat{q}(\beta)] - v\hat{q}(\beta)$. Then, we can derive

$$\frac{\partial \hat{\pi}}{\partial \beta} = \left(p\bar{F}_X(\beta\mathbb{E}[X] + (1-\beta)) - v\right)(\mathbb{E}[X] - q^*), \quad \text{(A.11)}$$

where $\bar{F}_X(\cdot) = 1 - F_X(\cdot)$.

If $q^* > \mathbb{E}[X]$, then $\beta\mathbb{E}[X] + (1-\beta)q^* < q^*$. As $\bar{F}_X(\cdot)$ is a decreasing function, we can obtain $p\bar{F}_X(\beta\mathbb{E}[X] + (1-\beta)) - v > 0$. That is, $\frac{\partial\hat{\pi}}{\partial\beta} < 0$. If $q^* < \mathbb{E}[X]$, $\frac{\partial\hat{\pi}}{\partial\beta} < 0$ still holds. Therefore, $\hat{\pi}(\beta)$ is decreasing in β. □

Algorithm 2 Algorithm for Proposition 2

Input: $f_X(\cdot)$; $f_D(\cdot)$.

$\pi \leftarrow p\left(\int_{-\infty}^{q} X f_X(X)\mathrm{d}X + \int_{q}^{+\infty} q f_X(X)\mathrm{d}X\right) - vq$;

compute q^*; where $\frac{\partial \pi_r}{\partial q}|_{q=q^*} = 0$;

$\hat{\pi} \leftarrow p\left(\int_{-\infty}^{q} X f_D(X)\mathrm{d}X + \int_{q}^{+\infty} q f_D(X)\mathrm{d}X\right) - vq$;

compute $\hat{q}(\beta)$; where $\frac{\partial \pi_o}{\partial q}|_{q=\hat{q}(\beta)} = 0$;

$\frac{\partial\hat{\pi}}{\partial\beta} \leftarrow \left(p\bar{F}_X(\beta\mathbb{E}[X] + (1-\beta)) - v\right)(\mathbb{E}[X] - q^*)$; where $\bar{F}_X(\cdot) = 1 - F_X(\cdot)$;

if $q^* > \mathbb{E}[X]$ **then**

  $p\bar{F}_X(\beta\mathbb{E}[X] + (1-\beta)) - v > 0$ holds;

else

  $p\bar{F}_X(\beta\mathbb{E}[X] + (1-\beta)) - v < 0$ holds;

end if

$\frac{\partial\hat{\pi}}{\partial\beta} < 0$ holds;

Proposition 2 can be proved.

Proof of Proposition 3: Given $\eta = \frac{\theta}{\theta-1}$, $\mu_h = \frac{1}{2}\sigma^2\eta(\mu-1) + \mu\eta$, and $\sigma_h = \eta\sigma$, the optimal level of cash holdings can be expressed as $\hat{h} = \frac{\delta_h}{\delta_h-1}\frac{2(\pi-K)\hat{\pi}(\beta)-\lambda\pi}{2(\pi-\hat{\pi}(\beta))}$.

The expression $\hat{h}$ intuitively shows that the level of cash holdings $\hat{h}$ is negatively related to project returns $\hat{\pi}$, i.e., $\frac{\partial\hat{h}}{\partial\hat{\pi}} < 0$. According to Proposition 2, project returns $\hat{\pi}$ is positively associated with managerial overconfidence β, i.e., $\frac{\partial\hat{\pi}}{\partial\beta} < 0$. Therefore, $\frac{\partial\hat{h}}{\partial\beta} = \frac{\partial\hat{h}}{\partial\hat{\pi}}\frac{\partial\hat{\pi}}{\partial\beta} > 0$.

We then turn our attention to the relationship between the level of cash holdings $\hat{h}$ and agency costs θ. It is easy to find a positive correlation between $\hat{h}$ and δ_h, i.e., $\frac{\partial\hat{h}}{\partial\delta_h} > 0$. Moreover, $\frac{\partial\delta_h}{\partial\theta} = \frac{\sqrt{8r\sigma^2 + (\sigma^2-2\mu)^2} + (\sigma^2-2\mu)}{2\theta^2\sigma^2} > 0$. Therefore, $\frac{\partial\hat{h}}{\partial\theta} = \frac{\partial\hat{h}}{\partial\delta_h}\frac{\partial\delta_h}{\partial\theta} > 0$. □

Algorithm 3 Algorithm for Proposition 3

Input: $\eta = \frac{\theta}{\theta-1}$; $\mu_h = \frac{1}{2}\sigma^2\eta(\mu-1) + \mu\eta$; $\sigma_h = \eta\sigma$;

$\delta_h = \frac{1}{2} - \frac{\mu_h}{\sigma_h^2} + \sqrt{\left(\frac{\mu_h}{\sigma_h^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma_h^2}}$;

$\hat{h} = \frac{\delta_h}{\delta_h-1}\frac{2(\pi-K)\hat{\pi}(\beta)-\lambda\pi}{2(\pi-\hat{\pi}(\beta))}$.

$\frac{\partial\hat{h}}{\partial\beta} = \frac{\partial\hat{h}}{\partial\hat{\pi}}\frac{\partial\hat{\pi}}{\partial\beta} > 0$; where $\frac{\partial\hat{h}}{\partial\hat{\pi}} < 0$ and $\frac{\partial\hat{\pi}}{\partial\beta} < 0$;

compute $\frac{\partial\delta_h}{\partial\theta}$;

if $\sigma^2 > 2\mu$ **then**

  $\frac{\partial\delta_h}{\partial\theta} \leftarrow \frac{\sqrt{8r\sigma^2 + (\sigma^2-2\mu)^2} + (\sigma^2-2\mu)}{2\theta^2\sigma^2}$

else

  $\frac{\partial\delta_h}{\partial\theta} \leftarrow \frac{\sqrt{8r\sigma^2 + (2\mu-\sigma^2)^2} - (2\mu-\sigma^2)}{2\theta^2\sigma^2}$

end if

$\frac{\partial\delta_h}{\partial\theta} > 0$;

$\frac{\partial\hat{h}}{\partial\theta} = \frac{\partial\hat{h}}{\partial\delta_h}\frac{\partial\delta_h}{\partial\theta} > 0$ holds; where $\frac{\partial\hat{h}}{\partial\delta_h} > 0$;

Proposition 3 can be proved.

Proof of Proposition 4: Given γ, the financier determines the monitoring intensity according to the first order condition of (19) with respect to M:

$$\gamma\pi - \frac{M}{\phi} = 0. \quad \text{(A.12)}$$

That is, $M = \gamma\phi\pi$.

As in the competitive financial market, the financier can only obtain the payoff at the break-even condition. That is, the fraction of the revenue from the blockchain project equals to the corresponding costs:

$$\gamma M\pi = \frac{M^2}{2\phi} + \left(K - \hat{h}\right). \quad \text{(A.13)}$$

Therefore, we can obtain the equilibrium equity fraction of the financier: $\gamma^* = \frac{\sqrt{2\phi(K-\hat{h})}}{\phi\pi}$. Plugging γ^* into the expression of M, we can derive $M^* = \sqrt{2\phi(K-\hat{h})}$. □

Algorithm 4 Algorithm for Proposition 4

Input: $\gamma M\pi - \frac{M^2}{2\phi}$: the financier's payoff.

compute M'; where $\frac{\partial}{\partial\gamma}\left(\gamma M\pi - \frac{M^2}{2\phi}\right)|_{M=M'} = 0$

compute γ^*; where $\frac{\partial}{\partial\gamma}\left(\gamma M'\pi - \frac{M'^2}{2\phi}\right)|_{\gamma=\gamma^*} = 0$;

$M^* \leftarrow \gamma\phi\pi$; where $\gamma \leftarrow \gamma^*$.

Proposition 4 can be proved.

Proof of Proposition 5: Given M^* and γ^* from (21) and (22), the manager's expected payoff in (13) can be re-written as

$$U = \left(\frac{h}{\hat{h}}\right)^{\delta_h}\bar{Y}(\hat{h}). \quad \text{(A.14)}$$

Then, we can derive the optimal level of cash holdings $\hat{h}$ and transparency $\hat{\phi}$.

The manager determines the optimal level of transparency $\hat{\phi}$ according to the first order condition of (A.14) with respect to ϕ:

$$U_{\phi} = \left(\frac{h}{\hat{h}}\right)^{\delta}\left(\sqrt{\frac{K-\hat{h}}{2\phi^{3}}} - \lambda(K-\hat{h})\right) = 0. \tag{A.15}$$

The second order condition is

$$U_{\phi\phi} = \left(\frac{h}{\hat{h}}\right)^{\delta}\left(-\frac{3}{2}\sqrt{\frac{K-\hat{h}}{2\phi^{5}}}\right) < 0. \tag{A.16}$$

Therefore, given the level of cash holdings $\hat{h}$, the manager determines the optimal level of transparency as

$$\phi = \left(2\lambda^{2}(K-\hat{h})\right)^{-\frac{1}{3}}. \tag{A.17}$$

The cross-partial is as follows:

$$U_{\phi\hat{h}}|_{\phi=\phi^{*}} = \left(\frac{h}{\hat{h}}\right)^{\delta}\left(\lambda - \frac{1}{2\phi\sqrt{2\phi\left(K-\hat{h}\right)}}\right) > 0. \tag{A.18}$$

Similarly, the optimal level of cash holdings $\hat{h}$ is determined by the first order condition of (A.14) with respect to $\hat{h}$:

$$U_{\hat{h}} = -\frac{\delta}{\hat{h}}U + \left(\frac{h}{\hat{h}}\right)^{\delta}\left(\frac{1}{\sqrt{2\phi(K-\hat{h})}} + \phi\lambda - 1\right) = 0. \tag{A.19}$$

(A.15) and (A.19) are the necessary conditions for the optimal level of cash holdings and transparency. The sufficient condition is that $U_{\phi\phi} < 0$, $U_{\hat{h}\hat{h}} < 0$, and

$$H \equiv \begin{vmatrix} U_{\hat{h}\hat{h}} & U_{\phi\hat{h}} \\ U_{\hat{h}\phi} & U_{\phi\phi} \end{vmatrix} = U_{\hat{h}\hat{h}}U_{\phi\phi} - U_{\phi\hat{h}}U_{\hat{h}\phi} > 0 \tag{A.20}$$

As mentioned before, $U_{\phi\phi} < 0$ holds by (A.16) while the signs of $U_{\hat{h}\hat{h}}$ and H cannot be determined in general. However, there are widely parameter ranges where the sufficient conditions are satisfied. That is, the interior solutions for $\hat{h}$ and ϕ exists.

Furthermore, within the parameter ranges, we can derive

$$\frac{\mathrm{d}\hat{h}^{*}}{\mathrm{d}\hat{\pi}} = \frac{U_{\phi\hat{h}}U_{\phi\hat{\pi}} - U_{\phi\phi}U_{\hat{h}\hat{\pi}}}{H}, \tag{A.21}$$

$$\frac{\mathrm{d}\hat{\phi}^{*}}{\mathrm{d}\hat{\pi}} = \frac{U_{\phi\hat{h}}U_{\hat{h}\hat{\pi}} - U_{\hat{h}\hat{h}}U_{\phi\hat{\pi}}}{H}. \tag{A.22}$$

As mentioned, we focus on the parameter ranges where the interior solution of $\hat{h}$ and ϕ exists; that is, $U_{\phi\phi} < 0$, $U_{\hat{h}\hat{h}} < 0$, and $H > 0$. According to (A.18), $U_{\phi\hat{h}} > 0$ at $\hat{h}$ and ϕ^{*}. In addition,

$$U_{\phi\hat{\pi}} = 0, \tag{A.23}$$

$$U_{\hat{h}\hat{\pi}} = -\frac{\delta}{\hat{h}}\left(\frac{h}{\hat{h}}\right)^{\delta} < 0. \tag{A.24}$$

Algorithm 5 Algorithm for Proposition 5

Input: $M^{*} = \sqrt{2\phi(K-\hat{h})}$, $\gamma^{*} = \frac{\sqrt{2\phi(K-\hat{h})}}{\phi\pi}$.

$\bar{Y}(h_t) \leftarrow (1-\gamma^{*})\hat{\pi}(\beta) - \psi(M^{*}) - h_t$;

$U \leftarrow \left(\frac{h}{\hat{h}}\right)^{\delta_h}\bar{Y}(\hat{h})$

compute ϕ^{*}; where $U_{\phi}|_{\phi=\phi^{*}} = 0$;

compute $\hat{h}^{*}$; where $U_{\hat{h}}|_{\hat{h}=\hat{h}^{*}} = 0$;

$H \leftarrow U_{\hat{h}\hat{h}}U_{\phi\phi} - U_{\phi\hat{h}}U_{\hat{h}\phi}$;

$U_{\phi\hat{\pi}} \leftarrow 0$;

$U_{\hat{h}\hat{\pi}} \leftarrow -\frac{\delta}{\hat{h}}\left(\frac{h}{\hat{h}}\right)^{\delta} < 0$;

if $U_{\hat{h}\hat{h}} < 0$, $U_{\phi\phi} < 0$, and $H > 0$ **then**

  $\frac{\mathrm{d}\hat{h}^{*}}{\mathrm{d}\hat{\pi}} \leftarrow \frac{U_{\phi\hat{h}}U_{\phi\hat{\pi}} - U_{\phi\phi}U_{\hat{h}\hat{\pi}}}{H}$;

  $\frac{\mathrm{d}\hat{\phi}^{*}}{\mathrm{d}\hat{\pi}} \leftarrow \frac{U_{\phi\hat{h}}U_{\hat{h}\hat{\pi}} - U_{\hat{h}\hat{h}}U_{\phi\hat{\pi}}}{H}$;

end if

$\frac{\partial\hat{h}^{*}}{\partial\beta} \leftarrow \frac{\mathrm{d}\hat{h}^{*}}{\mathrm{d}\hat{\pi}}\frac{\partial\hat{\pi}}{\partial\beta}$; where $\frac{\partial\hat{\pi}}{\partial\beta} < 0$;

$\frac{\partial\hat{\phi}^{*}}{\partial\beta} \leftarrow \frac{\mathrm{d}\hat{\phi}^{*}}{\mathrm{d}\hat{\pi}}\frac{\partial\hat{\pi}}{\partial\beta}$; where $\frac{\partial\hat{\pi}}{\partial\beta} < 0$;

$\partial\hat{h}^{*}/\partial\beta > 0$, and $\partial\phi^{*}/\partial\beta > 0$;

Proposition 5 can be proved.

Therefore, we can derive that both (A.21) and (A.22) are negative. That is, the optimal level of cash holdings $\hat{h}$ and transparency ϕ decrease in $\hat{\pi}$. Moreover, according to Proposition 2, $\hat{\pi}(\beta)$ decreases in β. Hence, the optimal levels of cash holdings and transparency increase in β. □

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