Essays on Corporate Financial Risk Management: Theory and Evidence

by

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Declarations

I declare that any material contained in this thesis has not been submitted for a degree to any other university or academic institution.

I further declare that Chapter 2 of this thesis is a product of joint work with Professor Andrea Gamba. Specifically: the initial idea was proposed by Professor Gamba; as for the two-period model, the development and derivation is attributable to me, we both contributed to the writing of the text of the model, and I wrote the main results; we derived the dynamic model together, I wrote the text that describes the model, and I wrote the numerical routines and the numerical analysis.

Wenrui Zhang

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Abstract

The thesis comprises three essays on corporate financial risk management. In particular, it studies theoretically and empirically the determinants of the firm–level financial hedging in distinct market conditions, as well as with various managerial compensation schemes.

In Chapter 2, we re-examine the conventional models of corporate hedging in the presence of external financing frictions and asymmetric information on asset value. We emphasize that in the presence of external financing needs and information asymmetry issues, a firm should consider both the value- and information-enhancing aspects of hedging. With market learning, firms with an under-estimated profitability would have more incentive for hedging, especially when they obtain favorable profitability shocks or in a market boom. Hedging is more sensitive to the profitability shocks than predicted by the complete information models, and is more sensitive to the market belief when the firm realizes an unfavorable profitability shock. The results also provide a possible explanation on the mixed empirical evidence on corporate hedging policies.

Chapter 3 reconciles the conventional theories and mixed evidence of corporate incentives for hedging in the presence of growth options and external financing frictions using recent oil and gas firms data. My theoretical model makes testable predictions for the following empirical regressions. Using panel data for commodity price hedging, I show that hedging decision positively relates to the asset's profitability, the severity of information asymmetry, and the potential of expansion due to the prospective growth opportunities, and negatively relates to the inherent hedging costs. Further, I find decreasing marginal effects of informational asymmetry and growth potential on hedging decision.

In Chapter 4, I theoretically explore the association between managerial compensation scheme for derivative earnings and the alignment of interests of firm managers and outside investors. I find that, as investors treat the derivative gains as a measure of a manager's financial skill, there is an effective conflict between managers and shareholders in respect of determining corporate financial hedging policy. I find a V-shape of contracting efficiency against the price of firm product and the price of the underlying asset of hedging derivatives. I conclude that cash compensation for profitable derivatives is the key distorting the manager's objective, under the fair-value based accounting criteria for hedge.

Chapter 1

Introduction

Financial risk management has been one of the most important corporate objectives. This doctoral thesis comprises of three essays on the topic of corporate financial risk management. Chapter 2 studies the corporate incentives for financial hedging with costly external financing and asymmetric information between the controller of the company and the outside investors. We reconcile some seemingly contrasting notions in the conventional theoretical models regarding how the optimal risk management strategies can be designed. Chapter 3 constructs a model in a two–period framework and makes predictions that have empirical implications on corporate financial hedging strategies. Next, by using hand–collected data, I examine the empirical implications of the model and find evidence on how firm characteristics affect hedging policies. Chapter 4 proposes a calibrated model to analyze the association between managerial compensation scheme and corporate risk management decisions, under the fair value accounting standards for financial derivatives.

The rationale for my research leans on the philosophy that pricing corporate financial claims is crucially depended on the variability in the cash flows generated by assets in place. In a hypothetical frictionless market in which Modigliani–Miller Theorem applies, managing financial risk cannot add values to the asset, since a company can always return to the capital market and raise cost-less funds by issuing new securities when receiving an adverse shock to its cash flows.[1] However, as market frictions are inevitable in practice, returning to the capital market cannot ensure the company raises enough liquidity without any sunk costs. Consequently, the shortage of cash could actually end up depriving the assets of the company from the liquidity it needs to finance ongoing business or start new projects. Hence, as ongoing entities, companies are concerned that they may in the future be deprived of the funds that facilitate expansion projects, strengthen existing investments, or simply stay alive. Therefore, calculating the likelihood and evaluating the consequence of each type of events that may impact on cash flows enable the stakeholders of the company to take advantage of the most probable risks. Thus, corporate financial risk management can protect the interests of stakeholders through specific measures to control risks.

In this doctoral thesis, corporate financial risk management is mainly referred to as derivatives hedging, though, companies may have various methods to manage the financial risks exposed to their operations.[2] Early survey papers found evidence on corporate usage of financial instruments for hedging. For instance, as Rawls III and Smithson (1990) suggest, the increased volatility of exchange rates and interest rates in the 1970s put many companies out of business and led them to seriously recognize their risk exposures. The survey shows that a majority of corporate management has been forced to pay attention to the potential effect of the volatility in, say, interest rates, foreign exchange rates, and commodity prices, on the value of the firm.

Corporate financial hedging policies are, in principle, determined by external and internal frictions. As in the prior literature, companies have (at least) the following incentives for using financial instruments to hedge exogenous risks, as a result of market imperfections. First, to reduce the frequency of costly external financing, as in Froot, Scharfstein, and Stein (1993). Second, to mitigate information asymmetry

[1] See Modigliani and Miller (1958, 1963) and textbooks such as Tirole (2010).

[2] Gamba and Triantis (2014) explore the complex interactions among various risk management strategies.

in cash flows, as in DeMarzo and Duffie (1991, 1995). Third, to reduce the convex taxation and bankruptcy costs, as suggested by Smith and Stulz (1985). Fourth, to reduce borrowing costs, as in Leland (1998). Fifth, as analyzed by Purnanandam (2008), to reduce potential financial distress costs. Sixth, to reduce contracting costs, such as with creditors, suppliers, and customers, as in Bessembinder (1991). Last but not least, the managerial motivations for revealing latent labour qualities, as modeled in Breeden and Viswanathan (2016) and empirically examined by Tufano (1996).

Chapter 2 focuses on the first two motives for hedging, although other motives could be easily accommodated by extending the model. In particular, we re-examine the conventional models of corporate hedging in the presence of external financing frictions and asymmetric information on firm's profitability to reconcile some seemingly contrasting notions regarding the hedging incentives. Our research contributes to the literature on corporate incentives for financial hedging.

We develop a discrete–time dynamic framework in which a firm has a growth option that can be exercized subject to financing constraints in each period. If the reserved cash is insufficient to finance the investment, the firm must raise external capital to cover the funding gap. We assume that the external capital is costly, and that the firm's hedging decisions endogenize the likelihood of tapping external capital and the per–unit cost of flotation through influencing outsiders' belief on the firm's profitability. Because an exogenous risk factor makes the firm's cash flow noisy, outside investors cannot directly observe the profitability and deduce the quality of the firm if the risk is unhedged. Thus, in each period, outsiders must update their belief on the firm's profitability through the observed cash flow and hedging decisions. Methodologically, our theory belongs to the growing literature on dynamic corporate risk management and real investment. However, unlike a full information setting, our model provides a rationale for why and when firms will undertake hedging activities in an imperfect capital market with asymmetric information.

We show that optimal hedging trades off the benefits of less–frequent and less–costly external financing with a better ability to finance investment. Before induce the general dynamic model, we firstly propose a simple two–period model which shows that, in equilibrium, hedging could not be a costly signal of the firm's quality. The general dynamic model further makes some testable predictions that may have empirical implications. First, firms with an under–estimated profitability would have more incentive for hedging, especially when they obtain favorable profitability shocks, or in the boom market states, and vice versa. Second, corporate hedging policies are more sensitive to the profitability shocks and market states than the one predicted by the complete information models. Third, hedging is more sensitive to the belief of outsiders when the firm realizes an unfavorable profitability shock. The results of our dynamic model emphasize the importance of information asymmetry on corporate incentives for financial hedging and provide a possible explanation on the mixed empirical evidence on corporate hedging policies.

In Chapter 3, I develop and test a theory of corporate risk management in the presence of growth options and external financing frictions. To make testable model predictions, I propose a two–period model in which a firm with a growth option can hedge its exogenous risk by using financial instruments. The model is in line with the simple model in Chapter 3 but instead of solving a signalling game model, I assume that the controller of the firm share identical information set with the outside investors at the starting point. In words, the insider and outsiders have the same expectation on the future uncertainties. I also abstract from managerial agency issues, which are inessential to my argument in this chapter.

By numerically solving the model, I make some predictions that may have empirical implications. Specifically, the model shows that hedging incentives increase with the ability of generating cash flows of the firm, the severity of informational asymmetry problem, and potential expansion opportunity, respectively. In contrast, the costs imposed on the firm by hedging activities, e.g. opportunity cost of forgoing upside gains, reduces the firm's hedging incentive.

Based on the model predictions, I empirically test corporate hedging in the presence of growth options and external financing frictions by using recent oil and gas firms data. I perform a sample of hand-collected data comprising 62 oil and gas firms in the United States from 2009 through 2018. The data sample contains 557 firm–year observations. I use the nominal amount of hedging in my definition of a continuous dependent hedging variable. Specifically, I hand collect information on the volume of crude oil and equivalence products hedged by financial derivatives, and scale the hedged volume by the firm's production volume in the same year to construct hedge ratio. I supplement the financial hedging data with accounting information from Compustat and CRSP databases. The panel structure of the data allows me to exploit both cross–sectional and within-firm variation to assess the relationship between financial hedging and the focused variables. Many previous studies use only cross-sectional data and hardly exploit within–firm variation because they largely rely on dummy variables for financial hedging activities that have only limited within–firm variation. From the regressions of the essay, I find evidence that supports my model predictions.

Chapter 4 explores how managerial rent influences corporate hedging policy under current fair value based accounting standards for derivatives. In particular, I theoretically analyze how a compensation scheme for gains from derivatives impacts contracting efficiency. The contracting efficiency is defined as the alignment of the interests of risk manager and shareholders. In practice, a corporate risk manager is usually a multi–disciplinary professional with an understanding of internal business processes and financial instruments. She performs practices to prevent loss exposure through internal controls and financial hedging activities.

The motivation of this work is from the association between reward scheme for profitable derivatives and agency conflict. The aim of my research is mainly to analyze the effect of the managerial compensation mechanism on hedging policy and on any stakeholder's interests. Previous researches using dynamic models mainly focus on the rationale of managing risk and optimal hedging strategy,[3] but a few of them have analyzed the managerial incentive to deviate from the optimal hedging ratio for shareholders. Researches discussing agency problems, like DeMarzo and Duffie (1995) compare different levels of transparency of information, but do not well fit current compensation scheme used by most firms. The authors propose a model with a perfect separation of ownership and control, in which manager acts like a normal employee. In practice, however, top managers can usually act both as an executive and a member of the board of directors, which means managerial rent generally comprises both cash-based and equity-based compensations.

The basic assumption of Chapter 4 builds on the empirical evidence provided by empirical studies that firms reward their risk managers for profitable derivatives, such as in Dechow, Myers, and Shakespeare (2010), Livne, Markarian, and Milne (2011), and Manchiraju, Hamlen, Kross, and Suk (2016). In their studies, the performance of derivatives is directly observed from the separate account of hedging activity required by the current fair-value based accounting standards. Some of my results are in line with the conclusion of Manchiraju, Hamlen, Kross, and Suk (2016) that reward for gains from derivatives can reduce contracting efficiency.

The dynamic model in Chapter 4 continues a line of Gamba and Triantis (2014). I consider an unlevered firm (*the firm*) in absence of taxation with the separation of ownership and control in my model. I use a discrete-time infinite-horizon framework to model the operating process, hedging decisions, and payout policy of a firm. Any cash flows of the firm are obtained at the end of each period when the state is observed. The firm's manager (*the manager*) holds a fixed fraction of claim on the firm's cash

[3]See Bolton, Chen, and Wang (2011), Gamba and Triantis (2014), Rampini and Viswanathan (2010), and Rampini, Sufi, and Viswanathan (2014), for example.

flow. In practice, a firm may be able to design in a higher managerial equity holding in order to strengthen the manager's incentives or a lower managerial equity holding to increase access to capital. The manager is, however, maximizing the present value of his compensation package. Please note that I do not derive any form of an optimal career contract, but instead, approximate a contract that practitioners use and that may or may not be optimal. Hence, I do not consider any information asymmetry or signaling problems in my model.

The results of the essay show that, as investors treat the derivative performance as a measure of firm manager's financial skill, there is an effective conflict between firm manager and shareholders in respect of determining corporate financial hedging policy. I find a V–shaped relation of contracting efficiency against the price of firm product and the price of the underlying asset of hedging derivatives. Because the cash compensation for profitable derivatives is the key factor distorts the manager's objective function, I conclude that the conflict is essentially caused by such a managerial incentive scheme under the fair value based accounting standards for hedge.

Finally, Chapter 5 concludes with a discussion of the findings and contributions of this doctoral thesis, and discusses future potential research questions.

Chapter 2

Corporate Incentive for Financial Hedging with Costly Financing and Informational Asymmetry

2.1. Introduction

We re–examine the conventional models of corporate hedging in the presence of external financing frictions and asymmetric information on firm's profitability to reconcile some seemingly contrasting notions regarding the hedging incentives.

First, since Froot, Scharfstein, and Stein (1993) the prevailing literature shows that hedging can help a firm avoid costly external financing, by making its cash flows less volatile. Hence, by hedging a firm can finance the investment opportunities using less costly internal resources, or can invest more, ultimately increasing its value. The value effect of hedging has been examined empirically (e.g., MacKay and Moeller, 2007 and Pérez-González and Yun, 2013), but results are mixed. At the very best, the value effect of financial derivatives is modest, as evidenced by Guay and Kothari

(2003), among others. While these inconclusive results may be due to empirical challenges, it may be also the case that hedging is not value-increasing. For instance, Babenko and Tserlukevich (2017) argue that if a firm's growth opportunities are positively correlated with the cash flows and the prospects are good, hedging actually jeopardizes the potential of expansion by eliminating the chance of high cash flows. In this case, hedging reduces the value of the growth options and of the firm. More generally, firms using financial derivatives normally incur various endogenous costs (such as transaction costs, negotiation costs, etc.) related to hedging activities, which offset its benefit (see for instance, Gamba and Triantis, 2014). Hence, there is a case for a more thorough re-examination of hedging as a way to create value.

Second, hedging can have a direct effect on external financing costs by alleviating adverse selection issues. A consequence of informational asymmetry is that outside investors require a discount when they buy newly issued securities when firms raise external funds, as argued by Myers and Majluf (1984). Antunovich (1996) further argues that firms with higher informational asymmetries have greater dispersion of slack due to their difficulties accessing capital markets.[1] In this aspect, firms can hedge to make their business more transparent, ultimately reducing the underpricing cost of information sensitive securities, like equity. More precisely, by reducing the amount of noise, hedging increases the informativeness of cash flow realizations for outside investors, who can thereby make a more accurate inference on the value of the firm. Hence, adverse selection costs for seasoned equity issuance will be lowered when the firm taps the capital markets. However, also in this respect hedging may have a drawback. As illustrated by DeMarzo and Duffie (1995), by eliminating a source of noise, hedging makes cash flows more informative and the public perception of a firm's value more sensitive to its performance. Holding fixed the variability of cash flows, this implies that financing costs may become more variable. As they are typically

[1] Opler and Titman (1994) empirically find that firms with more research and development (R&D) expenses expect higher financial distress, since R&D expenses are a form of investment where informational asymmetry is most important.

convex, this increases their present value, negatively affecting the value of the firm. Overall, this result in a negative incentive to hedging. In addition, as suggested by Breeden and Viswanathan (2016), firms with bad news or low–quality projects might prefer to increase risk exposure and hope for a lucky draw. In that case, revealing the true quality makes low–quality firms worse–off. In sum, asymmetric information is not *per se* an obvious hedging motive.

As Babenko and Tserlukevich (2017), we propose a model of a firm with a growth option, which is exercised subject to financing constraints. If the reserved cash is insufficient to finance the investment, the firm must raise external capital to cover the funding gap. Because an exogenous risk factor makes the firm's cash flow noisy, outside investors cannot directly observe the profitability and deduce the quality of the firm if the risk is unhedged. In our model, in line with Wilson (1980), investors are assumed to be risk-neutral with respect to the firm's profitability. It is exactly when the profitability is high (and investment likely), that the firm will be most exposed to the undervaluation costs triggered by security issuance. Hence, it is key that a high-quality firm makes sure that its profitability is correctly understood by the market, and that the exposure to the exogenous risk is managed. Hedging is inherently costly because it requires part of the resources used to finance the investment, in line with Rampini and Viswanathan (2010). In this respect, the opportunity cost of hedging is higher for a high–quality firm. In addition, in some states, hedging would lower the value of the growth option as described above, which in turn has a negative impact on the hedging incentive. Unlike a full information setting, our model thus provides a rationale for why and when firms will undertake hedging activities in an imperfect capital market with asymmetric information. In this respect, our model is closely related to DeMarzo and Duffie (1991) and Breeden and Viswanathan (2016), although differently from them we do not need to discuss the firm's reputation concerns.

We show that, when making hedging decisions, the firm should consider the perspective on its profitability, the severity of informational asymmetry, the perspective of its growth opportunity, and all inevitable (opportunity) costs caused by hedging. Optimal hedging trades off the benefits of less–frequent and less–costly external financing with a better ability to finance investment. Consequently, while it can be achieved, perfect hedging (i.e. elimination) of the exogenous risk is usually not optimal. Through a simple two–period model, we show that, without learning, firms could not influence market belief or alter the price of external financing by optimizing their hedge ratios. It thus provides some necessary intuitions for the assumptions of the dynamic model.

Our dynamic model, which proposes the outsiders' learning process, allows to make some testable predictions. First, firms with an under–estimated profitability would have more incentive for hedging, especially when they obtain favorable profitability shocks, or in the boom market states, and vice versa. Second, corporate hedging policies are more sensitive to profitability shocks and market states than predicted by the complete information models. Third, hedging is more sensitive to the belief of outsiders when the firm realizes an unfavorable profitability shock, or when the market is in recession. The results of our dynamic model emphasize the importance of information asymmetry on the incentives to hedge and provide a possible explanation on the mixed empirical evidence on corporate hedging policies.

These results contribute to the literature on corporate incentives for financial hedging. The received theory shows that financing and hedging are intrinsically intertwined, which creates conflicting incentives for hedging, as suggested by Stulz (1996). Positive effects of hedging on corporate financing include (i) reduction in costly external financing, as in Froot, Scharfstein, and Stein (1993); (ii) mitigation of information asymmetry in cash flows, as in DeMarzo and Duffie (1991) and DeMarzo and Duffie (1995); (iii) reduction in expected (convex) taxation and bankruptcy costs, as in Smith and Stulz (1985); (iv) reduction of borrowing costs, as in Leland (1998);

(v) reduction in expected distress costs, as in Purnanandam (2008); (vi) reduction in contracting costs (with creditors, suppliers, and customers), as in Bessembinder (1991); and (vii) the managerial motivations, as in Breeden and Viswanathan (2016) and Tufano (1996). This chapter focuses on the first two motives for hedging, although the other motives could be easily accommodated by extending the theoretical model. Differently from the other models, we account for two negative economic forces that may reduce the hedging incentive. First, hedging is suboptimal when cash flow is positively correlated with lumpy profitable investment opportunities, as in Babenko and Tserlukevich (2017). Second, in the spirit of DeMarzo and Duffie (1995) and Breeden and Viswanathan (2016), a firm (and its executives) may not always intend to eliminate the informational asymmetry with outside financiers. Indeed, we show that a high hedge ratio is suboptimal when the firm's profitability is low, in line with Fehle and Tsyplakov (2005).

Methodologically, our theory belongs to the growing literature on dynamic corporate risk management and real investment. Rampini and Viswanathan (2010) propose a real investment model in which collateral constraints limit both financing and risk management. Bolton, Chen, and Wang (2011) and Bolton, Chen, and Wang (2013) build a continuous-time structural model with capital adjustment cost and derive the optimal hedging and saving policy. Gamba and Triantis (2014) consider an integrated framework in which operating flexibility, liquidity management, and financial hedging jointly create values to a firm that faces several market frictions. Decamps, Gryglewicz, Morellec, and Villeneuve (2017) study optimal risk management policies, including asset substitution and financial hedging, of firms whose cash flows are subject to both permanent and transitory shocks in a continuous-time framework. Albeit in different economic settings, the information and learning assumptions in this chapter are similar to Holmström (1999), Moyen and Platikanov (2012), Yang (2013), Acharya and Lambrecht (2015), DeMarzo and Sannikov (2016), and He, Wei, Yu, and Gao (2017). We propose the learning process, however, in quite a different fashion from the existing papers. In particular, instead of a steady-state learning, we construct a framework in which the firm controls the amount of noise in cash flows through hedging activities in each period. Consequently, the speed of the learning process of outsiders is eventually controlled by the firm, which is a novel setting that distinguishes us from the existing models.

This chapter is organized as follows. Section 2.2 introduces a two–period model, by illustrating the time line of events, the outsiders' belief on the firm's profitability, and the equilibrium hedging strategies that solves the firm's value–maximization problem and satisfies outside investors' belief. Section 2.3 constructs a general dynamic model with an infinite time horizon. Section 2.4 shows and discusses the numerical implementation of the dynamic model. Section 2.5 concludes the chapter.

2.2. Simple two–period model

To illustrate our main arguments, we introduce a simple model of firm investment decisions with financing frictions. The key assumption, which will be maintained also in a more general dynamic model, is that there is informational asymmetry on firm's profitability between the controller (*insider*) and public investors (*outsiders*). For simplicity, we make debt a sub–optimal financing tool by assuming that the firm has a higher cost for accessing to debt.[2] Because external equity is more expensive than internal funding, all financing needs are met by first using up all internal cash reserves and, only after that, by raising equity capital from the outsiders. Insider can hedge against some of the firm's risk to control the extent to which asymmetric information impacts the cost of external financing. By endogenizing the financing cost and the outsiders' inference on firm's profitability, we determine the equilibrium exercise of the investment option and the optimal hedging policy.

[2]Because, for instance, the insider can abscond with all cash flows, which therefore makes assets cannot be pledged. See Rampini and Viswanathan (2010), for instance.

Three dates, $t = 0, 1, 2$, define two periods. At $t = 0$, insider's initial net worth is given as w_0 which will be held until $t = 1$ when an exogenous shock is received. The exogenous shock yields a cash flow φ and has mean equal to zero. Specifically, we assume that $\varphi \in [-w_0, w_0]$ is uniformly distributed. At $t = 0$, insider can hedge against the exogenous risk φ by purchasing one–period Arrow–Debreu securities with unit price zero and a transaction cost $c > 0$ per unit of nominal values, which must be paid in advance.[3] Specifically, insider can take position in $h \in [0, 1]$ shares of the Arrow–Debreu security, in exchange for the delivery of $h\varphi$ at $t = 1$. Because of the transaction cost, hedging uses part of the initial cash endowment. This implies that, given w_0, there is a budget constraint $ch < w_0$, and the net worth reserved initially is $w_0 - ch > 0$.[4] Thus, with the hedging decision h and the realization of φ, the firm's net worth at $t = 1$ is

$$w_1(h) = w_0 - ch + \varphi(1 - h), \tag{2.1}$$

with support $\big[w^l(h), w^u(h)\big]$, where $w^l(h) = h(w_0 - c)$ and $w^u(h) = 2w_0 - h(w_0 + c)$. We denote by $f(w_1; h)$ and $F(w_1; h)$ as the probability density function (p.d.f.) and the cumulative distribution function (c.d.f.) of $w_1(h)$, respectively. It is noteworthy that w_1 distributes symmetrically about $w_0 - ch$. Hence, it can be shown that hedging directly influences the firm's cash flow by reducing its mean and variance.

At $t = 0$, the firm obtains a growth opportunity for investing in a productive technology with a constant returns to scale, which fully depreciates in one period. The project can be implemented at $t = 1$ and requires a fixed investment, k, which may be financed by raising external capital. However, the project's profitability, $\theta > 1$, is privately known by insider since $t = 0$. In turn, insider makes the investment decision conditional on the net present value (NPV) of asset being positive and depending of the net worth available at $t = 1$ to finance such an investment. We assume that the

[3]Although we do not need to endogenize this cost to derive our results, one can interpret c as the cost to negotiate with the dealer or the interest charged on the margin account.

[4]Bolton and Oehmke (2015) study the seniority for financial derivatives in bankruptcy. However, as we assume the hedging instrument in our model as default-free, we abstract from bankruptcy.

investment's payoff, received at $t = 2$, is uniformly distributed with support $[0, 2\theta k]$, which is non-hedgeable. That is, absent financing frictions, the NPV of the project at $t = 1$ is positive (i.e. $-k + \theta k$) for any $k > 0$. To make the problem non-trivial, we assume $w_0 < k < 2w_0$, so that, absent (or fully hedging against) the shock φ, the firm would require external financing. Note that, since the payoff is risky, insider cannot issue risk–free debt to finance the project at $t = 1$. As illustrated later, by assuming external financing frictions, we will show that issuing debt to finance k is suboptimal in our model.

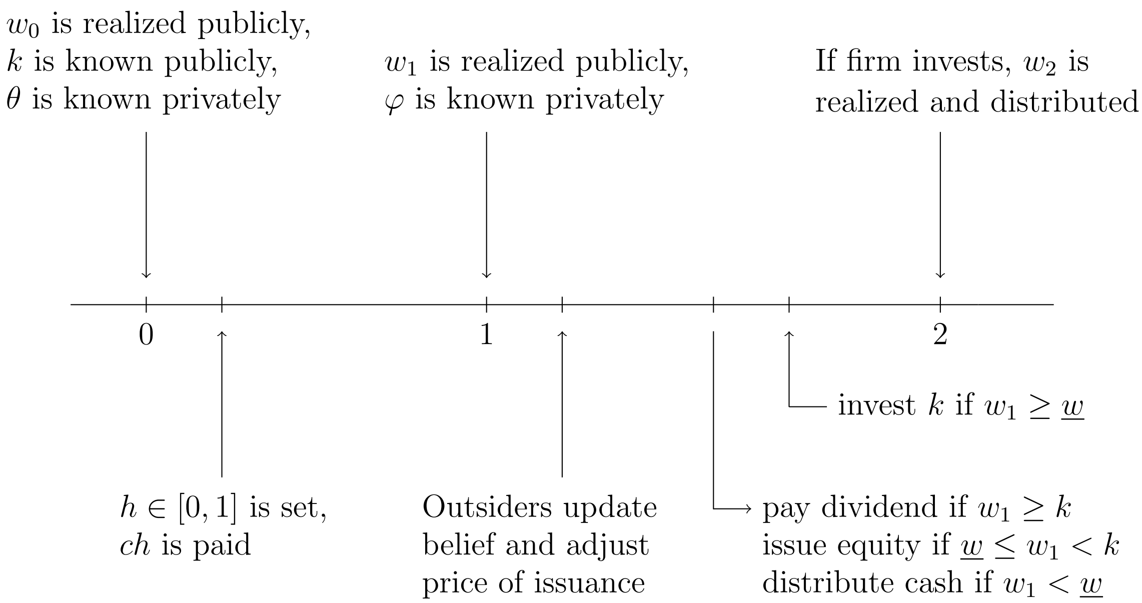

Figure 2.1: **Timeline for the two-period example**

Notes: At $t = 0$, the firm makes hedging decision h, based on the endowment w_0, and the growth opportunity k that can be exercised at $t = 1$. At $t = 1$, the firm observes φ and thus obtains w_1; the investment decision depends on w_1 and k, and $\underline{w}$ denotes the threshold for investing; no hedging is made. At $t = 2$, if the investment k is made at $t = 1$, the firm obtains w_2, and all cash will be distributed to shareholders.

Figure 2.1 depicts the timeline. At $t = 1$, as k is fixed, the investment decision is affected by financing frictions. Specifically, the case $w_1(h) \geq k$ is frictionless, and insider uses the net worth up to k and payouts $w_1(h) - k$ as dividends. Otherwise, if $w_1(h) < k$, insider raises $k - w_1(h)$ from outsiders in exchange of a fraction $\alpha \in (0, 1)$ of the firm's equity after the investment and incurs an amount of external financing cost. However, if the financing cost is greater than the profit obtained from investment, making the NPV negative, insider will forgo the investment.

In what follows, we begin by analyzing the benchmark scenario with symmetric information, and next we examine the equilibrium for the asymmetric-information case. Note that, in the latter case, the financing options are affected by informational asymmetry, and the hedging decision h might have signaling potential at $t = 0$.

2.2.1. Complete information case

We first analyze the problem under a complete–information condition as a benchmark model. In this case, insider and outsiders have the same information set and thus the firm's equity is correctly priced. At $t = 1$, if internal reserves are insufficient to make investment, the financing gap can be bridged by external funds. However, if funds are raised externally, insider must incur the financing cost which is proportional to the scale of issuance. Specifically, we denote the dollar cost of external equity financing as

$$\Lambda(h) \equiv \Lambda(w_1, \theta, k, h) = \frac{a}{\theta} \cdot \max\{k - w_1(h), 0\}, \tag{2.2}$$

where a is a positive constant.[5] To make the problem non–trivial, we further assume that the total cost of debt financing is greater than $\Lambda(h)$ for the same amount of issuance $k - w_1(h)$, which makes debt a sub–optimal financing instrument in our model, and thus capital structure will not be concerned.[6] In turn, external equity will be the optimal financing tool for insider.

[5] We assume the external financing cost is negatively related to θ. As suggested by Altinkilic and Hansen (2000), the underwriting fees of the lower–quality seasoned equity offerings are on average higher than the higher–quality ones.

[6] As w_2 is not risk–free, one may think that debt could cause a potential financial distress cost as an addition to the issuance cost, which is beyond the scope of our model. See Purnanandam (2008) for the discussion on how financial distress cost affects corporate hedging.

We determine α, the share of equity sold to outsiders, by solving the break–even condition: $\alpha \mathbb{E}_1[w_2] = \alpha\theta k = k - w_1(h)$, or

$$\alpha(h) = \frac{k - w_1(h)}{\theta k}. \tag{2.3}$$

Hence, by substituting $\alpha(h)$ as in (2.3), the NPV of insider's investment at $t = 1$ is

$$-w_1(h) - \Lambda(h) + \theta k(1 - \alpha(h)) = -k + \theta k - \Lambda(h).$$

It thus shows that, if insider raises $k - w_1(h)$ externally by issuing equity, the NPV of her investment at $t = 1$ will be equal to the value of entire project *minus* the external financing cost. Investment with external financing is thus equivalent to raising funds from shareholder and incurring a flotation cost. That gives the firm's internal reserves a higher priority than external funds for making investment. Setting insider's NPV equal to zero yields a threshold for w_1 below which no investment occurs at $t = 1$. We denote such a threshold by $\underline{w}$, which can be written as

$$\underline{w} = \frac{k[a - \theta(\theta - 1)]}{a}. \tag{2.4}$$

That is, insider would only make investment and incur the financing cost if $w_1(h) \geq \underline{w}$. We assume $a \geq \theta(\theta - 1)$ to ensure $\underline{w} \geq 0$, making the problem non–trivial. Therefore, insider's equity value at $t = 1$ is the cash flow *plus* the NPV of the growth project:

$$V_1(\theta, w_1, k, h) = w_1(h) + \begin{cases} -k + \theta k & \text{if } k \leq w_1, \\ -k + \theta k - \Lambda(h) & \text{if } \underline{w} \leq w_1 < k, \\ 0 & \text{if } w_1 < \underline{w}, \end{cases}$$

In the first case, k is fully financed by the firm's internal reserves. In the second case, insider invests w_1 and raise external capital $k - w_1$ to finance k, as the NPV of investment is positive. In the third case, however, the growth opportunity is forgone and $w_1(h)$ is directly distributed to insider. From the above expression, we see that, by limiting the effect of φ, the hedge ratio h influences the investment decision at $t = 1$ through w_1, resulting in a trade–off between the hedging cost and the increase in probability of making investment.

Therefore, at $t = 0$, insider's problem is to maximize her equity value by optimally choosing the hedge ratio:

$$V_0(\theta, w_0, c, k) = max\big\{0, \max_h v_0(\theta, w_0, c, k, h)\big\},$$

where the objective function is written as

$$\begin{aligned} v_0(\theta, w_0, c, k, h) &\equiv \mathbb{E}_0[V_1(\theta, w_1, k, h)] \\ &= (w_0 - ch) + k(\theta - 1)\int_{max\{\underline{w}, w^l(h)\}}^{w^u(h)} f(w_1; h)dw_1 \\ &\quad - \frac{a}{\theta}\int_{max\{\underline{w}, w^l(h)\}}^{min\{k, w^u(h)\}} (k - w_1(h)) \cdot f(w_1; h)dw_1. \end{aligned} \tag{2.5}$$

On the right-hand side of equation (2.5), the first term $(w_0 - ch)$ is the expected cash flow from the initial investment in the technology, the second term is the expected profit from the follow-on investment, and the third term denotes the expected dollar cost of external financing. Note that, as h increases, $w^l(h)$ could become higher than $\underline{w}$. In that case, $w_1(h)$ is greater than $\underline{w}$ for any φ so that the growth opportunity will be taken for certain. Hence, the lower limits of integrations of the second and the third terms are the maximum between $\underline{w}$ and $w^l(h)$. By equating $\underline{w}$ and $w^l(h)$, we have a threshold for h above which insider can always invest in the growth project and obtain a positive NPV at $t = 1$:

$$h^l(w_0, c, \underline{w}) = \frac{\underline{w}}{w_0 - c}. \tag{2.6}$$

Similarly, as h increases, $w^u(h)$ could become lower than k, implying a threshold for h above which $w_1(h)$ is always smaller than k:

$$h^u(w_0, c, k) = \frac{2w_0 - k}{w_0 - c}. \tag{2.7}$$

In other words, with $h > h^u$, insider must raise external funds, in addition to her reserves, to invest in the growth project, if the investment is made, because $w^u(h) < k$. Defining $h^l(w_0, c, \underline{w})$ and $h^u(w_0, c, k)$ helps identifying the optimal hedge ratio. The following lemma that describes the optimal hedge ratio of insider in the complete–information case. The proof of the lemma is in Appendix 2.6.1.

Lemma 2.1. *Absent asymmetric information, then, for $h > 0$, depending on the parameters setting, the local maximum of $v_0(\theta, w_0, c, k, h)$ occurs when $h = h^0$ where*

$$h^0 \equiv h^0(\theta, w_0, c, k) = 1 - \sqrt{\frac{a(k - w_0 + c)}{a(w_0 - c)^2 - 4\theta w_0 c}}. \tag{2.8}$$

Insider's optimal hedge ratio at $t = 0$ is h^0 if $c \leq \bar{c}$, or zero if $c > \bar{c}$, where

$$\bar{c} = \frac{\theta w_0 M}{(\theta + a)(2w_0 - k) - \theta M}, \tag{2.9}$$

where

$$M = \frac{\underline{w}k(\theta - 1)}{2w_0} - \frac{a(k - w_0)}{\theta} + \frac{a(k - \underline{w})^2}{4\theta w_0}.$$

Figure 2.2 plots two examples of v_0 against the hedge ratio h in the complete–information case, with different levels of c. The upper panel depicts a case where the equity value is maximized by choosing $h^0 = h^u$. It is noteworthy that, in our model, it is never optimal to fully hedge ($h = 1$), as this would jeopardize the chance of getting a high cash flow from φ. In the lower panel, as the equity value is maximized when the hedge ratio is zero, insider would not hedge.

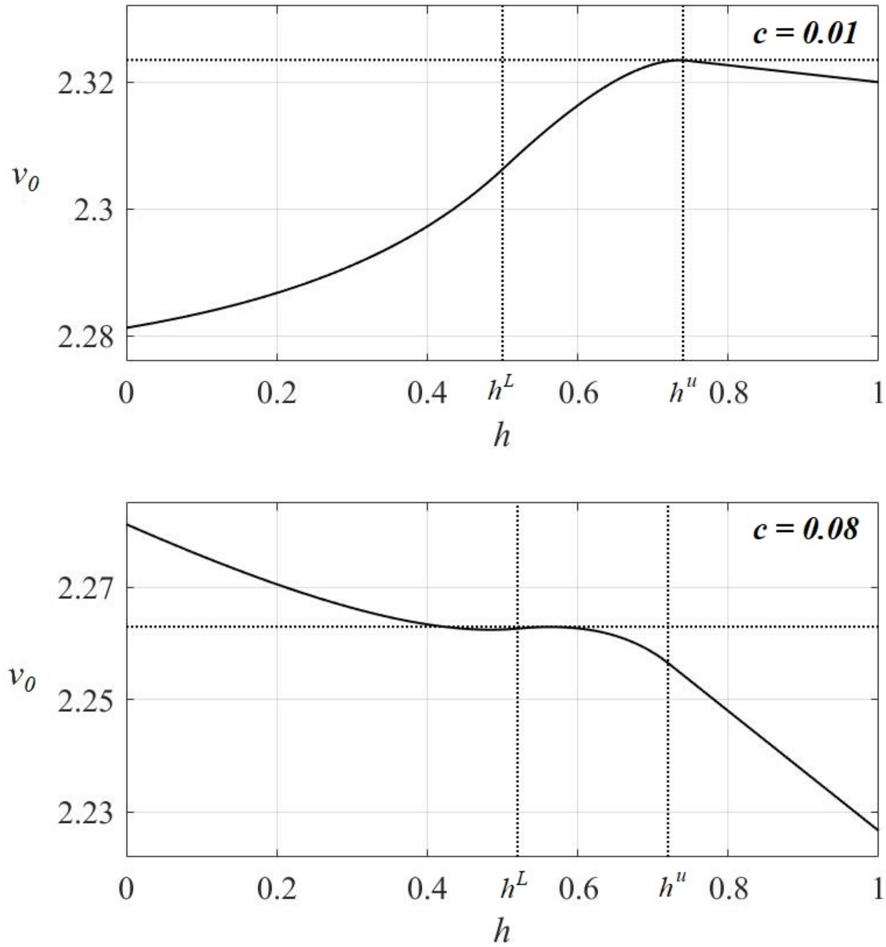

Figure 2.2: **Value effect of the hedge ratio (Static)**

Notes: The upper panel of the figure depicts the value of insider's equity, v_0, against the hedge ratio, h, given $c = 0.01$. The lower panel of the figure depicts v_0 against h, given $c = 0.08$. The hedge ratio h takes values from zero to one. The parameterization is: (i)$\theta = 1.2$, (ii) $w_0 = 2$, (iii) $c = 0.01$, (iv) $k = 2.5$, and (v) $a = 0.4$.

Note that we denote $\bar{c}$ as a threshold for c above which insider will choose to not hedge. Figure 2.3 plots $\bar{c}$ against θ in the complete-information case. From the numerical result, it is noteworthy that $\bar{c}$ is weakly monotonically increasing in θ. Notably, in Figure 2.3, $\bar{c}$ crosses the horizontal axis, implying that not all firms would hedge even if $c = 0$. Taking the baseline case in the upper panel as an example, if a firm has profitability lower than 1.0, then no hedging position would be taken for any $c \geq 0$. Henceforth, in this chapter, to avoid the trivial case in which no hedging is optimal, we will consider only the case where transaction cost is relatively small (i.e., $c \le \bar{c}$). This is consistent with Fehle and Tsyplakov (2005) and Gamba and Triantis (2014). In practice, the costs of trading the hedging instruments would be even lower if highly liquid and standardized financial derivatives are used.

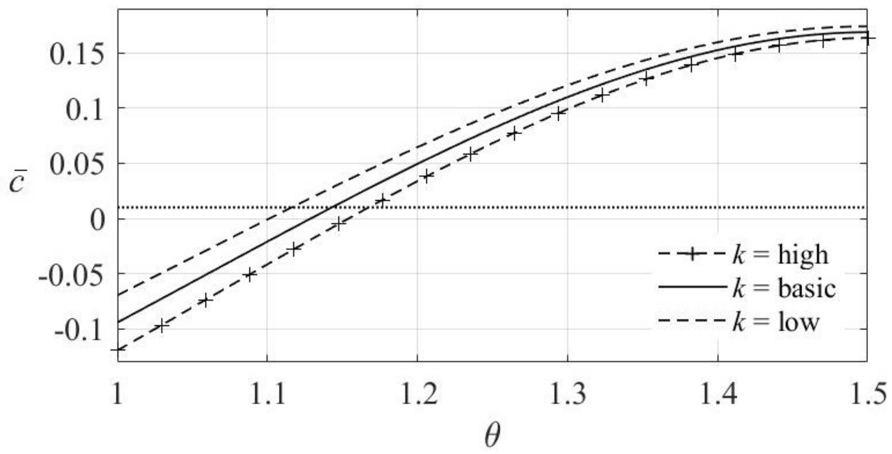

Figure 2.3: **Hedging conditions (Static)**

Notes: The figure depicts the condition for hedging, $\bar{c}$, against θ in the complete-information case. The firm with profitability θ would set a non-zero hedge ratio only if the transaction cost $c \le \bar{c}$. Otherwise, insider would not hedge. Lines with different markers assume various investment costs, k. The dash-dotted line stands for $\bar{c} = 0$. The parameterization is: (i) $w_0 = 2$, (ii) $\theta = 1.2$, (iii) $k = 2.5$, and (iv) $a = 0.4$.

Figure 2.4 depicts insider's optimal hedge ratio under the complete–information condition, h^0, as obtained in Lemma 2.1, against θ. Note that parameterization for c is set as smaller than $\bar{c}$, and thus we can focus on the case in which the optimal hedge ratio is non-zero. We also let c take various values between $(0, 0.02]$ and find that the results are nearly identical in regards to slopes and levels, which are not reported here for brevity. It is shown that h^0 is monotonically decreasing in θ. This is inconsistent with the theory of Rampini and Viswanathan (2010), whereby wealthier firms would hedge more. In our model, comparing with low-profitability ones, a firm with larger θ has smaller $\underline{w}$ given the same level of hedging, thus that it is more likely to invest in the positive–NPV growth project at $t = 1$. One may note that h^0 is not a continuous function of θ. This is because in our model, as k is exogenously given rather than optimized by insider, the investment at $t = 1$ is a discrete decision, and thus from Lemma 2.1, insider might have no hedging incentive for some θ, despite the value function v_0 has local maximum for $h > 0$.

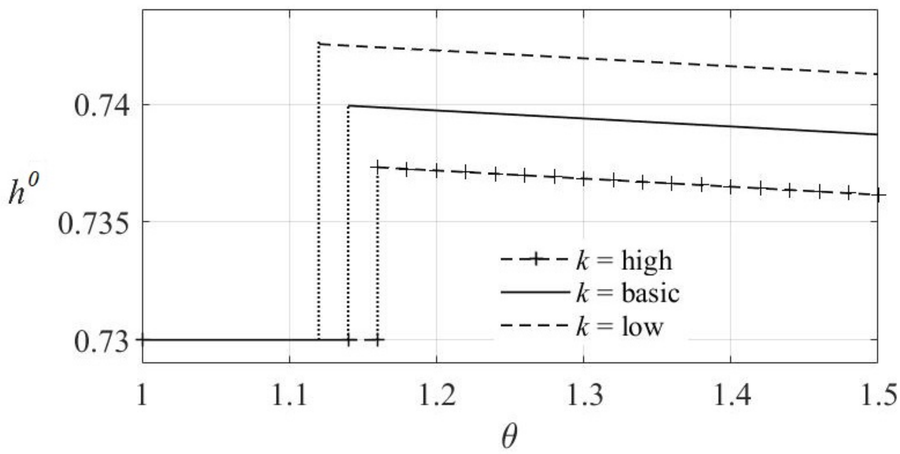

Figure 2.4: **Optimal hedging (complete information, Static)**

Notes: The figure depicts insider' optimal hedge ratio with complete information, h^0, against θ. The baseline parameterization is: (i)$\theta = 1.2$, (ii) $w_0 = 2$, (iii) $c = 0.01$, (iv) $k = 2.5$, and (v) $a = 0.4$.

2.2.2. Asymmetric information case

Now we consider the incomplete–information scenario in which the profitability and exogenous shocks can only be privately observed by insider and are therefore concealed to outsiders. In other words, when a firm's insider raises external capital $k - w_1(h)$ in the financial market at $t = 1$, public investors cannot know the profitability of project. Suppose two firms, with identical technology, exist in the market, at $t = 0$, each firm is endowed with w_0, and obtains a follow-on growth opportunity k. The good firm has profitability θ_g, and the bad firm has profitability θ_b, where $\theta_g > \theta_b$.[7]

[7] In reality, there could be a continuum of possible values for a firm's quality but the augment would not change.

We assume that, without any signals from the actions of insiders, the public prior belief that a firm has profitability θ_g is $b(\theta_g) = 1/2$, and thus $b(\theta_b) = 1/2$.

We assume that the firms' insiders disclose their hedge ratios.[8] Once the firms' hedging policies are observed at $t = 0$, outsiders would believe that the good firm chooses a *lower* hedge ratio.[9] We denote the optimal hedge ratios with complete information of the two firms as $h_g^0 \equiv h_g^0(\theta_g, w_0, c, k)$ and $h_b^0 \equiv h_b^0(\theta_b, w_0, c, k)$, respectively. We investigate possible types of perfect Bayesian equilibrium (PBE) where the firms could be differentiated by the hedge ratios they choose.

Before starting the analysis, we rule out the uninteresting cases where either or both of the two firms would not hedge, that is, the cases where $c > \bar{c}(\theta_g)$ or $c > \bar{c}(\theta_b)$. Instead, we would focus on the cases where both firms would set a positive hedge ratio. Specifically, we restrict our analysis in the cases where $c \leq \bar{c}(\theta_b) < \bar{c}(\theta_g)$.[10]

In principle, there are two possible pure–strategy separating PBEs at $t = 0$. Denote by h_g^* and h_b^* the optimal hedge ratios of the good firm and the bad firm, respectively, in the incomplete–information case. If, in equilibrium, a firm differentiates from the other by choosing a hedge ratio that matches outsiders' belief, then the outsiders correctly distinguish them at $t = 0$ and do not need to update their prior belief on the firms' profitability at $t = 1$. In the first type of equilibrium, both firms set positive hedge ratios, and the good firm sets a higher hedge ratio than the bad firm, i.e. $h_g^* > h_b^*$. In the second type of equilibrium, the good firm chooses a lower hedge ratio than the bad firm, i.e. $h_g^* < h_b^*$.

First of all, by intuition, we can rule out the first type of equilibrium in which the good firm sets a higher hedge ratio than the bad firm. As aforementioned, we only consider the cases in which $c \leq \bar{c}(\theta_b)$, and thus we always have $0 < h_g^0 < h_b^0$ if the

[8]This is empirically supported. See, for example, the survey paper by Beyer, Cohen, Lys, and Walther (2010) for a review of the literature on financial reporting.

[9]Recall that, as shown by equation (2.8) and Figure 2.4, the firm's hedge ratio is decreasing in θ.

[10]As shown in Figure 2.3, $\bar{c}$ is weakly increasing in θ.

firms were in the complete–information scenario. If, with asymmetric information, the good firm sets a hedge ratio $h' \geq h_b^0$, its equity will be under–priced at $t = 1$. In addition, as h' is greater than h_g^0, the transaction cost of hedging $ch' > ch_g^0$. The good firm's insider, thus, would find it better to choose a hedge ratio lower than h'. As a result, the story would end up with either another type of separating equilibrium or the pooling equilibrium. Therefore, the first type of equilibrium never sustains.

In the second type of separating equilibrium, the bad firm lowers its hedge ratio to h_g^0 to mimic because doing so makes its equity over–priced. While this is profitable for the bad firm, the good firm's equity will be under–priced. In response, the good firm could decrease its hedge ratio to $h_g^* < h_g^0$, below which the bad firm is unable to mimic, thus that outsiders can separate the two firms and correctly price the securities issued by them. Hence, for the separating equilibrium where $h_g^* < h_b^* = h_b^0$ to be sustained, we must ensure that $v_{g,0}(h_g^*) > v_{g,0}(h_g^0)$ and $v_{b,0}(h_g^*) < v_{b,0}(h_b^0)$, where $v_{i,0}$ represents the objective function of the firm i, for $i \in \{g, b\}$. Specifically, we have the incentive compatibility condition for the good firm as:

$$
\begin{aligned}
w_0 - ch_g^* + k(\theta_g - 1) - \frac{a}{\theta_g} \int_{w^l(h_g^*)}^{k} (k - w_1(h_g^*)) \cdot f(w_1; h_g^*) dw_1 \\
> w_0 - ch_g^0 + k(\theta_g - 1) - \frac{a}{\hat{\theta}} \int_{w^l(h_g^0)}^{k} (k - w_1(h_g^0)) \cdot f(w_1; h_g^0) dw_1, \quad (2.10)
\end{aligned}
$$

and the condition for the bad firm:

$$
\begin{aligned}
w_0 - ch_g^* + k(\theta_b - 1) - \frac{a}{\hat{\theta}} \int_{w^l(h_g^*)}^{k} (k - w_1(h_g^*)) \cdot f(w_1; h_g^*) dw_1 \\
< w_0 - ch_b^0 + k(\theta_b - 1) - \frac{a}{\theta_b} \int_{w^l(h_b^0)}^{k} (k - w_1(h_b^0)) \cdot f(w_1; h_b^0) dw_1, \quad (2.11)
\end{aligned}
$$

where $\hat{\theta} = \theta_g b(\theta_g) + \theta_b b(\theta_b) = (\theta_g + \theta_b)/2$. Note that, if the two firms' insiders set the same hedge ratio, outsiders cannot distinguish the true qualities and thus set a belief $\hat{\theta}$ for both firms. In words, condition (2.10) ensures that the good firm's insider prefers being separated to being pooled, and condition (2.11) ensures that the bad firm's insider does not mimic the counterpart, as setting $h_b^* = h_g^*$ would cost more than the potential profit from equity over–valuation. Otherwise, if either condition (2.10) or (2.11) is violated, a separating PBE cannot sustain.

Lemma 2.2. *Given $0 < h_g^0 < h_b^0$, a separating PBE where $h_g^* < h_b^*$ can never sustain.*

The proof of Lemma 2.2 is in Appendix 2.6.1. We thus show that neither of the two types of separating PBE can sustain, given $h_b^0 > h_g^0 > 0$. As a result, in our model, hedge ratio cannot be a reliable signal of a firm's quality at $t = 0$.

Now we investigate an intuitive pooling equilibrium in which the insiders of the two firms set identical hedge ratio at $t = 0$. In that case, outsiders would believe that hedge ratio contains no information on the firm's quality. In turn, they would expect the two firms have the same quality, $\hat{\theta}$, which is the average of θ_g and θ_b. Similarly to Lemma 2.1, we can show that, in the incomplete–information case, the optimal hedge ratio of the good firm's insider is

$$h_g^* = 1 - \sqrt{\frac{a(k - w_0 + c)}{a(w_0 - c)^2 - 4\hat{\theta} w_0 c}}. \tag{2.12}$$

Note that, with h_g^*, as the NPV of investment is positive at $t = 1$, the good firm's insider still has incentive to invest in the growth project, although the firm's equity security would be under–priced. However, for the pooling equilibrium to be sustained, we must also ensure $v_{b,0}(h_g^*) > v_{b,0}(h_b^0)$ thus that the bad firm's insider would always mimic the counterpart by setting $h_b^* = h_g^*$. The condition for the pooling equilibrium sustainable can be written as

$$\begin{aligned} w_0 - ch_g^* + k(\theta_b - 1) - \frac{a}{\hat{\theta}} \int_{w^l(h_g^*)}^{k} (k - w_1(h_g^*)) \cdot f(w_1; h_g^0) dw_1 \\ > w_0 - ch_b^0 + k(\theta_b - 1) - \frac{a}{\theta_b} \int_{w^l(h_b^0)}^{k} (k - w_1(h_b^0)) \cdot f(w_1; h_b^0) dw_1. \end{aligned} \tag{2.13}$$

Lemma 2.3. *Given $0 < h_g^0 < h_b^0$, a pooling PBE where both firms set the same hedge ratio h_g^* sustains.*

The proof of Lemma 2.3 is in Appendix 2.6.1. Therefore, we show that only pooling equilibrium sustains, and thus, hedge ratio at $t = 0$ contains no information on the firm's profitability in this two–period model. Outsiders could not infer the firm's true quality based on its hedge ratio at $t = 0$. Based on this intuition, we construct a dynamic model with an infinite time horizon and introduce the learning process for outsiders in Section 2.3. Note that the intuition that hedging is not a signal of the firm's true quality is important for the assumption of outsiders' learning because otherwise, once the firms' qualities can be separated, outsiders do not need to update their belief later on.

2.2.3. External financing cost

Now we discuss the effect of hedging on the external financing cost and compare it in the complete– and incomplete–information cases. With complete–information, as the dollar cost of external financing, $\Lambda(h)$, at $t = 1$ is given as in equation (2.2), the expected external financing cost at $t = 0$ can be written as

$$\mathbb{E}_0\left[\Lambda(h)\right] = \frac{a}{\theta}\int_{max\left\{\underline{w},w^l(h)\right\}}^{min\{k,w^u(h)\}}(k - w_1(h)) \cdot f(w_1; h)dw_1.$$

With incomplete information, as outsiders' belief on the firm's profitability is set as $\hat{\theta}$, we have

$$\mathbb{E}_0\left[\Lambda(h);\hat{\theta}\right] = \frac{a}{\hat{\theta}}\int_{max\left\{\underline{w},w^l(h)\right\}}^{min\{k,w^u(h)\}}(k - w_1(h)) \cdot f(w_1; h)dw_1.$$

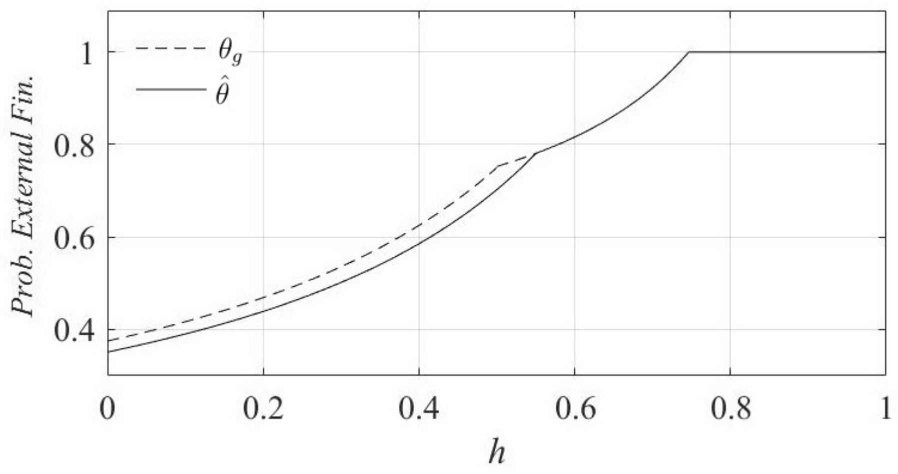

Figure 2.5: **Probability of external financing (Static)**

Notes: The figure depicts the probability of using external financing of the firm with θ_g against h. The dashed line assumes the complete–information case, the solid line assumes the incomplete–information case. The baseline parameterization is: (i) $\theta_g = 1.2$, (ii) $\hat{\theta} = 1.18$, (ii) $w_0 = 2$, (iii) $c = 0.01$, (iv) $k = 2.5$, and (v) $a = 0.4$.

Figure 2.5 provides examples of the contribution of hedging on the likelihood that the good firm's insider raises external funds to invest in the growth project. It shows that hedging increases the likelihood of external financing regardless of whether there is information asymmetry or not, which is opposite to the prediction by Froot, Scharfstein, and Stein (1993) that hedging reduces the likelihood of costly external financing. In fact, this is a result of our model feature. Note that the probability that the firm needs external funds is $\mathbb{E}_0[\chi_{\{\underline{w} \leq w_{g,1}(h) < k\}}] = \int_{\underline{w}}^{k} f(w_1; h) dw_1$, where h lowers the variance of w_1 and so it makes the left tail of the distribution thinner. The intuition behind this result is that raising external funds of $k - w_1(h)$ to invest always delivers a positive NPV for the firm's insider. In turn, when increasing the hedge ratio, the likelihood of investing the growth project increases, while the chance of obtaining $w_1 \geq k$ becomes lower, implying that the likelihood of tapping external capital is higher. As h increases, when $w^l(h) \geq \underline{w}$ and $w^u(h) < k$, insider would raise external capital to finance the project for sure, and thus, the probability of external financing becomes one.

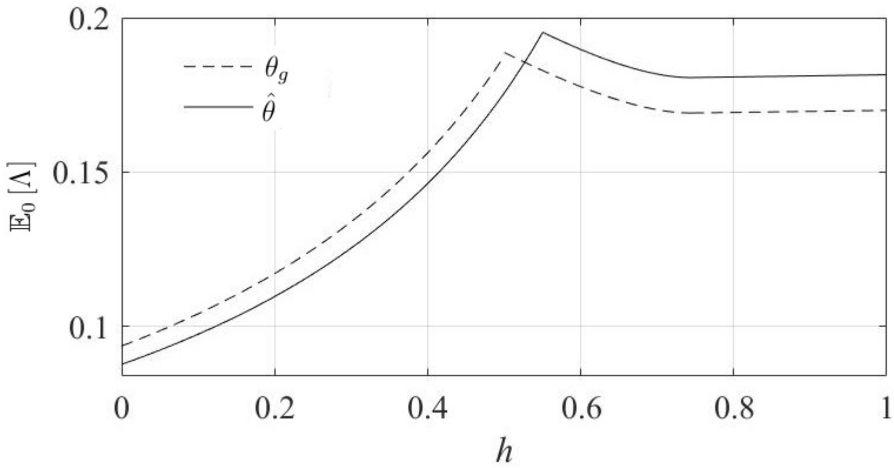

Figure 2.6: **External financing cost (Static)**

Notes: The figure depicts the expected dollar cost of external financing of the firm with θ_g, $\mathbb{E}_0[\Lambda]$, against h. The dashed line assumes the complete–information case, the solid line assumes the incomplete–information case where outsiders set belief $\hat{\theta}$. The baseline parameterization is: (i)$\theta_g = 1.2$, (ii) $\hat{\theta} = 1.18$, (ii) $w_0 = 2$, (iii) $c = 0.01$, (iv) $k = 2.5$, and (v) $a = 0.4$.

Figure 2.6 provides examples of the contribution of hedging on the expected external financing cost for the firm with θ_g. The function with incomplete–information (the solid line) is based on the best–response of the counterpart. For example, if the good firm chooses $h_g = 0.6$, the solid line is such that the bad firm mimics, i.e. $h_b = 0.6$, and outsiders set belief $\hat{\theta}$, which is consistent with our equilibrium analysis. Note that the external financing cost at $t = 1$ is determined by two components: the likelihood of tapping external capital and the total amount of external funds, both controlled by h. As h increases from zero, firstly, the likelihood of external financing monotonically increases and dominates the second component. And as h grows larger, the contribution of h on $k - w_1(h)$ becomes dominating. As a result, one may see a non–monotonic relation between $\mathbb{E}_0[\Lambda(h)]$ and h. More importantly, this lends an interior optimal hedge ratio, which is a key feature that differs our model from prior theories.

2.3. The dynamic model

We now model investment, financing, and hedging decisions in an infinite–horizon discrete–time dynamic and stochastic framework. We generalize the cash flow $w_t(h_t)$, for $t = 1, 2, ..., \infty$, with the following specifications. First, we assume that the capital stock is fully depreciated over a period and that, to recreate the production capacity, the firm receives an investment opportunity k_t in each period. As in the two–period model, at time t, the firm's insider would decide whether to make the investment and the level of hedge ratio. We assume that the amount of exogenous risk received by the firm is proportional to the scale of the investment at t. Therefore, given the investment decision, the net worth at t is

$$w_t \equiv w(\theta_t, k_t, \varphi_t, h_t) = \theta_t k_t + (1 - h_t)\varphi_t k_t, \tag{2.14}$$

where k_t is financed by the internal reserves if $k_t \leq w_{t-1} - ch_t$; otherwise, insider could raise external funds to bridge the financing gap if $k_t + ch_t > w_{t-1}$. Note that, in our model, k_t can be a measure of firm size.

We assume that the latent profitability shock, θ_t, follows an AR(1) process, given as

$$\theta_t = (1 - \rho)\bar{\theta} + \rho\theta_{t-1} + \varepsilon_t, \ \varepsilon_t \sim iid\, \mathcal{N}(0, \sigma_\varepsilon^2), \tag{2.15}$$

where $\bar{\theta}$ is the firm's long–run mean, $0 \leq \rho < 1$ is the persistence parameter, $\mathcal{N}$ denotes the normal distribution, and σ_ε is the conditional standard deviation of the error term ε_t. We assume that the long–run average of profitability shocks, $\bar{\theta}$, is publicly known. The firm's insider observes θ_t at t and always keeps an informational advantage on θ_t, because outsiders can only update their perception of θ_t after they observe w_t at the end of each period. We assume that outsiders' prior belief about θ_t at $t = 0$ has distribution $\mathcal{N}(\mu_0, \eta_0^2)$.

The latent exogenous risk, φ_t, are independent and identically distributed variates with distribution $\mathcal{N}(0, \sigma^2)$, where σ is a constant. We assume that $\{\theta_t\}$ and $\{\varphi_t\}$ are mutually independent processes, that is, $\mathbb{E}\left[\varepsilon_t \varphi_t\right] = 0$. Hence, by observing a large w_t at t, outsiders cannot disentangle whether it is because of a high profitability θ_t or a favorable realization of φ_t.

In our dynamic model, we assume and formulate that in each period, outsiders can update their belief on θ_t by observing w_t and k_t. Specifically, the outsiders' noisy information on θ_t received at t is

$$\frac{w_t}{k_t} = \theta_t + (1 - h_t)\varphi_t, \tag{2.16}$$

where h_t controls the noise term $(1 - h_t)\varphi_t$. That is, h_t reduces the volatility of w_t and makes w_t more informative about θ_t. Hence, by observing the sequence $\{w_t\}$, outsiders can learn and update their belief on θ_t. In our model, the learning process is proposed as the well–known Kalman filter problem.[11] The following lemma defines and describes the learning process. The proof is in Appendix 2.6.1.

Lemma 2.4. *Given the initialization $\mu_0 \equiv \mathbb{E}_0[\theta_1]$ and $\eta_0^2 \equiv \mathbb{E}_0[(\theta_1 - \mu_0)^2]$ at $t = 0$, the posterior distribution of $\{\theta_t\}$, for $t > 0$ is normal with mean*

$$\mu_t \equiv \mu(h_t) = b_t w_t k_t^{-1} + (1 - b_t)(\rho\mu_{t-1} + (1 - \rho)\bar{\theta}), \tag{2.17}$$

and variance

$$\eta_t^2 \equiv \eta(h_t)^2 = (1 - h_t)^2\sigma^2 b_t, \tag{2.18}$$

where b_t corresponds to the Kalman gain, given by the following expression:

$$b_t \equiv b(h_t, w_t) = \frac{\rho^2\eta_{t-1}^2 + \sigma_\varepsilon^2}{\rho^2\eta_{t-1}^2 + \sigma_\varepsilon^2 + (1 - h_t)^2\sigma^2}. \tag{2.19}$$

[11] The Kalman filter process was seminally developed in Kalman (1960) and Kalman and Bucy (1961). See textbooks such as Simon (2006).

For $t > 0$, the estimation error of outsiders' posterior belief has zero mean, $\mathbb{E}_t\left[\theta_{t+1} - \mu_t\right] = 0$, *and variance* $\eta_t^2 \equiv \mathbb{E}_t[(\theta_{t+1} - \mu_t)^2]$. *The speed of adjustment of the learning process is measured as* $1 - \rho(1 - b_t)$.

The learning formula (2.17) implies that to obtain the belief μ_t at t, outsiders would put weight b_t on the latest observation of $w_t k_t^{-1}$, and put weight $(1 - b_t)$ on the past belief μ_{t-1} and the long–run mean of profitability shock, $\bar{\theta}$. In equation (2.18), h_t reduces the variance of the estimation error. In addition, since b_t increases with h_t, for any $t \geq 0$, the outsiders' learning speed, $1 - \rho(1 - b_t)$, increases with h_t. Altogether, the learning process at t is more efficient as h_t increases. Figure 2.7 shows the effect of h_t on the Kalman gain and the learning speed, respectively. As can be seen, as h increases, outsiders' information gain increases because w_t becomes more informative. As a result, outsiders' learning speed also accelerates with h.

Now we formulate the external financing cost function in relation to outsiders' belief on the firm's profitability, based on the derivations from Section 2.2.3. However, in the dynamic model, we are not endogenizing the financing cost, but instead, we use the reduced–form of the flotation cost as in (2.20), based on what we learned from the two-period model. We assume that a flotation cost is incurred when the firm raises funds from outsiders by issuing equity. Equity issuance is equivalent to distribute a negative cash flow to the owner of the firm. Therefore, denoted by $\lambda_t \equiv \lambda(\mu_t)$ the flotation cost for per–unit of equity issuance, we formulate a reduced–form of the external financing cost by assuming that $\lambda'(\mu_t) < 0$.[12] Specifically, we formulate λ_t as follows:

$$\lambda_t \equiv \lambda(\mu_t) = \frac{a}{\mu_t^2}, \tag{2.20}$$

where a is a constant parameter.

[12]Note that, in the two–period example, when the firm needs to issue equity to raise funds, the fraction of equity sold is as expression (2.3). It is then equivalent to distribute $w_1 - k_2 - \theta k_2 \hat{\alpha} = (w_1 - k_2)(1 + \theta/\hat{\theta})$ amount of cash to the firm's owner at $t = 1$. Thus, the term $\theta/\hat{\theta}$ denotes the flotation cost incurred by equity issuance.

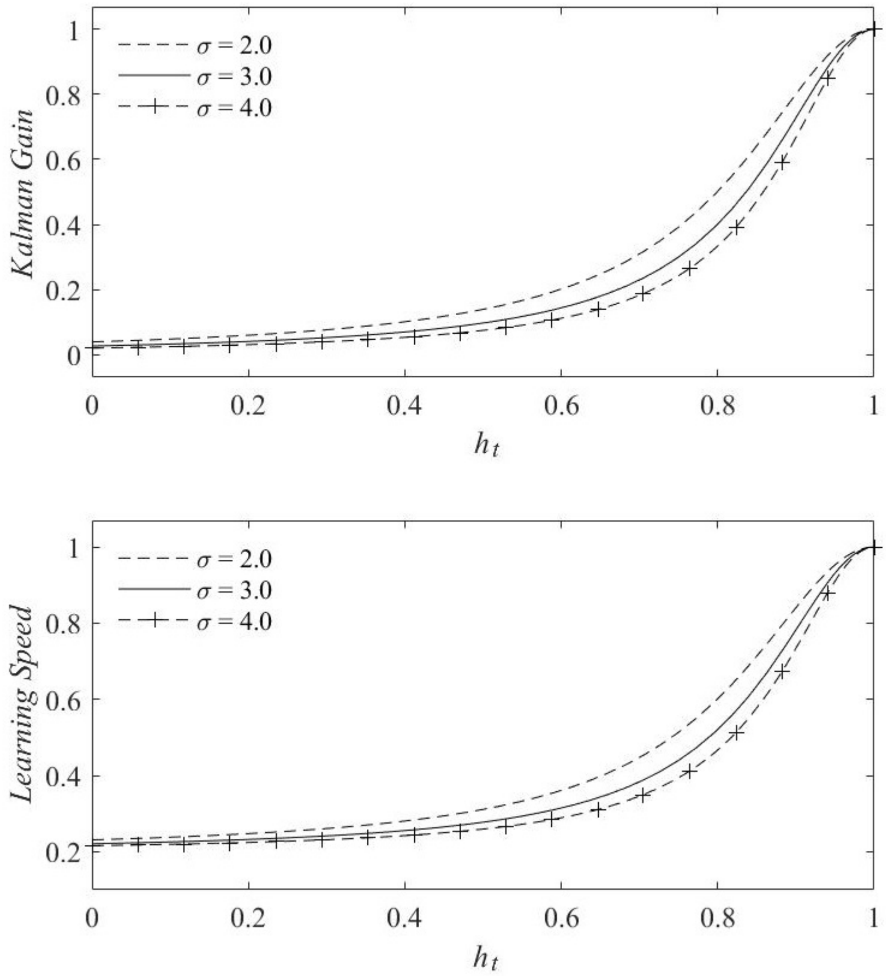

Figure 2.7: **Kalman gain and learning speed (Dynamic)**

Notes: The figure depicts the Kalman gain against h_t in the top panel, and the learning speed against h_t in the bottom panel, respectively. In each panel, lines with different markers correspond to various parameter settings. The baseline parameterization is $\sigma_\varepsilon = 0.15$, $\sigma = 3.0$, and $\eta_0 = 3.0$.

From this specification, if outsiders under–estimate the firm's profitability (i.e., $\mu_t < \theta_t$), then $\lambda(\mu_t)$ is larger than the fair flotation cost $\lambda(\theta_t)$, which is unfavorable to the owner of the firm. Hence, as in the two–period example, hedging increases the accuracy of outsiders' estimation on the firm's profitability and thus reduces the flotation cost. However, unlike the two–period example, as θ_t changes over time, a firm with high quality could be overpriced if $\mu_t > \theta_t$ for any t. In that case, hedging would mitigate the chance for the firm of getting profit from over–valuation, which actually demotivates the firm to hedge. To summarize, the dollar cost of external financing incurred by the firm at time t, based on the decision (k_{t+1}, h_{t+1}), is

$$\Lambda_t \equiv \Lambda(\mu_t) = \lambda_t \cdot \max\left\{k_{t+1} + ch_{t+1} - w_t, 0\right\}. \tag{2.21}$$

To give an intuition of the marginal effect of hedging on the expected external financing cost, we plot $\mathbb{E}_t\left[\mu_{t+1}\right]$ and $\mathbb{E}_t\left[\Lambda_{t+1}\right]$ against h_{t+1} in Figure 2.8.

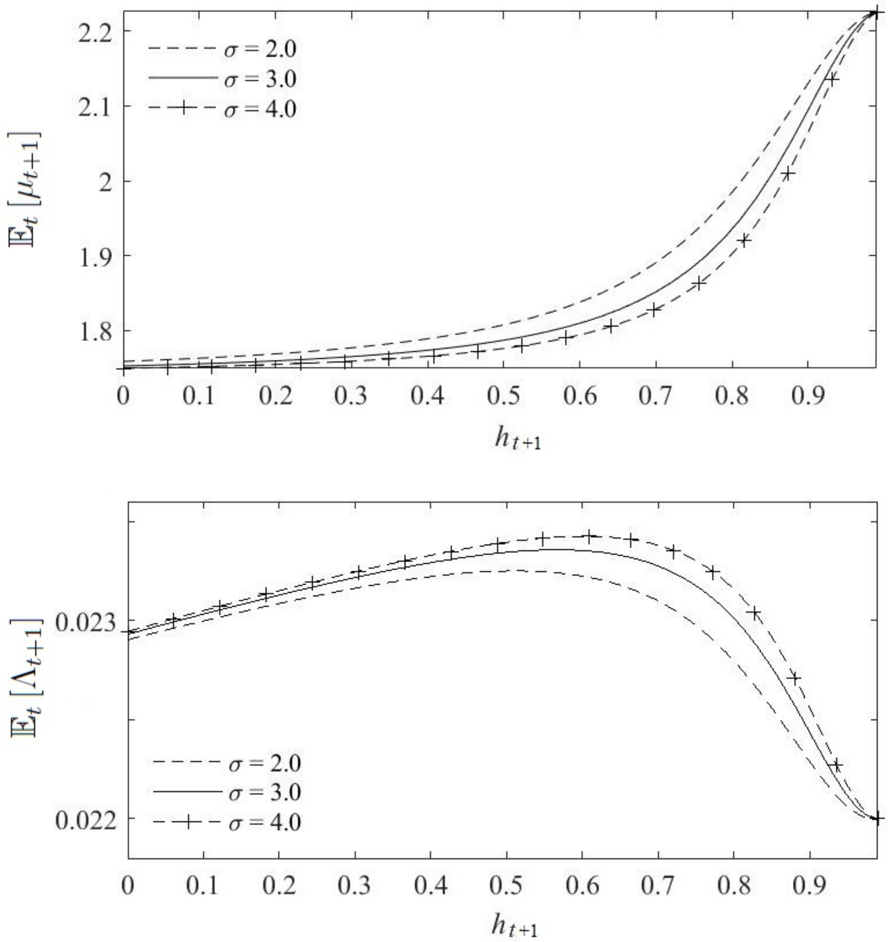

Figure 2.8: **External financing cost (Dynamic)**

Notes: The figure depicts the expected belief od outsiders $\mathbb{E}_t\left[\mu_{t+1}\right]$, the absolute of expected external financing cost factor $\mathbb{E}_t\left[\lambda_{t+1}\right]$, against h_{t+1} in the top panel and the bottom panel, respectively. In each panel, lines with different markers correspond to various parameter settings of σ. The baseline parameterization is $\bar{\theta} = 1.9$, $\rho = 0.8$, $\sigma_\varepsilon = 0.15$, $\eta_t = 0.3$, $k_t = k_{t+1} = 2.2$, $c = 0.01$, $a = 0.2$, $\mu_t = 1.75$, and $w_t = 2$.

Finally, in our model, we assume that the firm's insider does not hold cash when the realized cash flow exceeds the investment, and that she cannot switch the firm's operating status from idle to active; that is, once she decides to terminate the firm's operation, she distributes all the cash reserves at time t, and the firm becomes insolvent.[13] Therefore, at t, the firm's insider maximizes her equity value by choosing the optimal hedging h_{t+1} and investment k_{t+1} as

$$V(w_t, \theta_t, \mu_t) = \max \left\{ 0, \max_{k_{t+1}, h_{t+1}} \{ d_t + \beta \mathbb{E}_t \left[V(w_{t+1}, \theta_{t+1}, \mu_{t+1}) \right] \} \right\}, \tag{2.22}$$

where $k_{t+1} \in \{0, k\}$, $k > 0$ is an exogenously given constant, specifically,

$$k_{t+1} = \begin{cases} k, & \text{if } \beta \mathbb{E}_t[V_{t+1}] \geq k_{t+1} + ch_{t+1} + \Lambda_t, \\ 0, & \text{if } \beta \mathbb{E}_t[V_{t+1}] > k_{t+1} + ch_{t+1} + \Lambda_t, \end{cases}$$

$h_{t+1} \in [0, 1]$, and

$$d_t \equiv d(w_t, \theta_t, \mu_t, k_{t+1}, h_{t+1}) = \begin{cases} w_t - k_{t+1} - ch_{t+1} - \Lambda_t, & \text{if } k_{t+1} = k, \\ w_t, & \text{if } k_{t+1} = 0, \end{cases}$$

denotes the dividend distributed at t, β is the constant discount factor, and $\mathbb{E}_t[V(w_{t+1}, \theta_{t+1}, \mu_{t+1})]$ is the continuation value that results from the policy (h_{t+1}, k_{t+1}). For brevity, we use $\mathbb{E}_t[V_{t+1}]$ to denote the continuation value. At time t, the firm's insider finds it profitable to continue the production and chooses k_{t+1} because the NPV of the continuation value exceeds the total cost paid for producing, hedging, and external financing, i.e. $\beta \mathbb{E}_t[V_{t+1}] \geq k_{t+1} + ch_{t+1} + \Lambda_t$. Note that, if external equity is raised, it is equivalent to distribute a negative dividend which is augmented by the flotation cost, λ_t. However, if the owner finds $\beta \mathbb{E}_t[V_{t+1}] < k_{t+1} + ch_{t+1} + \Lambda_t$, it will be optimal

[13]See Gamba and Triantis (2014) for comparisons among various risk management tools.

for her to distribute all cash, as investments are no longer profitable.

Figure 2.9 shows the timeline of events of the dynamic model. Note that, in the absence of the signalling concern, we assume that outsiders update their belief μ_t and adjust the flotation price λ_t once w_t is realized. The owner of the firm would then decide whether to continue the investment, based on the price λ_t. Hence, the outsiders' belief μ_t can be regarded as a natural state for the firm, and there will be no interaction between the owner of the firm and outsiders during the period.

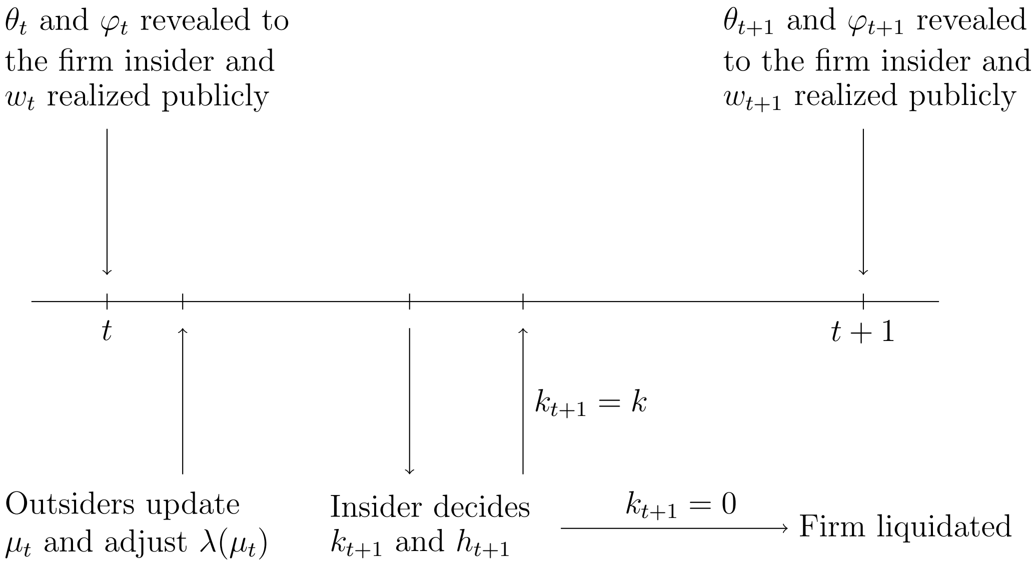

Figure 2.9: **Timeline for the dynamic model**

Notes: At time t, w_t is realized, and the owner of the firm observes θ_t as an informational advantage. Outsiders use the information from w_t to update their belief μ_t on θ_{t+1} and adjust the price of issuance. The owner of the firm then decides whether to continue the business by setting $k_{t+1} = k$ or to liquidate the firm by choosing $k_{t+1} = 0$ and distribute all cash to shareholders, conditional on the cash balance. If $k_{t+1} = k$ is chosen, the owner of the firm maximizes the equity value by optimizing h_{t+1}. If the equity value is negative, the owner defaults.

2.4. Numerical analysis of the dynamic model

The solution of the dynamic model is based on a numerical approximation of the infinite horizon dynamic programming problem in (2.22) by a discrete state space and successive approximation method, following Terry and Knotek II (2011). The dynamics of the logarithmic AR(1) in equation (2.15) is approximated by the quadrature method of Tauchen (1986), where the discrete grids of the Markov chain and the risk-neutral transition probabilities are found by a Gauss-–Hermite quadrature rule. Details of the numerical procedure are provided in Appendix 2.6.2. Table 2.1 reports the baseline parameters which are determined based on the prevailing literature.[14]

$\bar{\theta}$	Long-term mean of productivity shock	1.6
ρ	Persistence of productivity shock	0.8
σ_ε	Annual volatility of productivity shock	0.3
σ	Annual volatility of exogenous shock	3.0
η_t	Standard deviation of outsiders' belief at t	0.3
w_t	Cash flow obtained at t	1.0
k	Investment scale (constant)	1.8
c	negotiation cost of financial derivatives	1%
r	Annual risk-free interest rate	5%
a	Flotation cost factor for equity issuance	0.2

Table 2.1: **Baseline Parameter Values of the Dynamic Model**

2.4.1. Model solution with complete information

We begin by examining the effect of the firm characteristics on the optimal hedging decision in the complete–information case where no asymmetric information exists between the insider of the firm and the outsiders, thus that the flotation cost function λ_t in equation (2.20) becomes $a\theta_t^{-2}$, where θ_t has already been observed.

[14]See Yang (2013) and Gamba and Triantis (2014) for details.

Figure 2.10 depicts the optimal hedge ratio with complete information, h^0_{t+1}, against the profitability shock θ_t. To better isolate the effects of other factors, we plot the policy function for various level of $\bar{\theta}$ and k. We summarize the following two noteworthy findings.

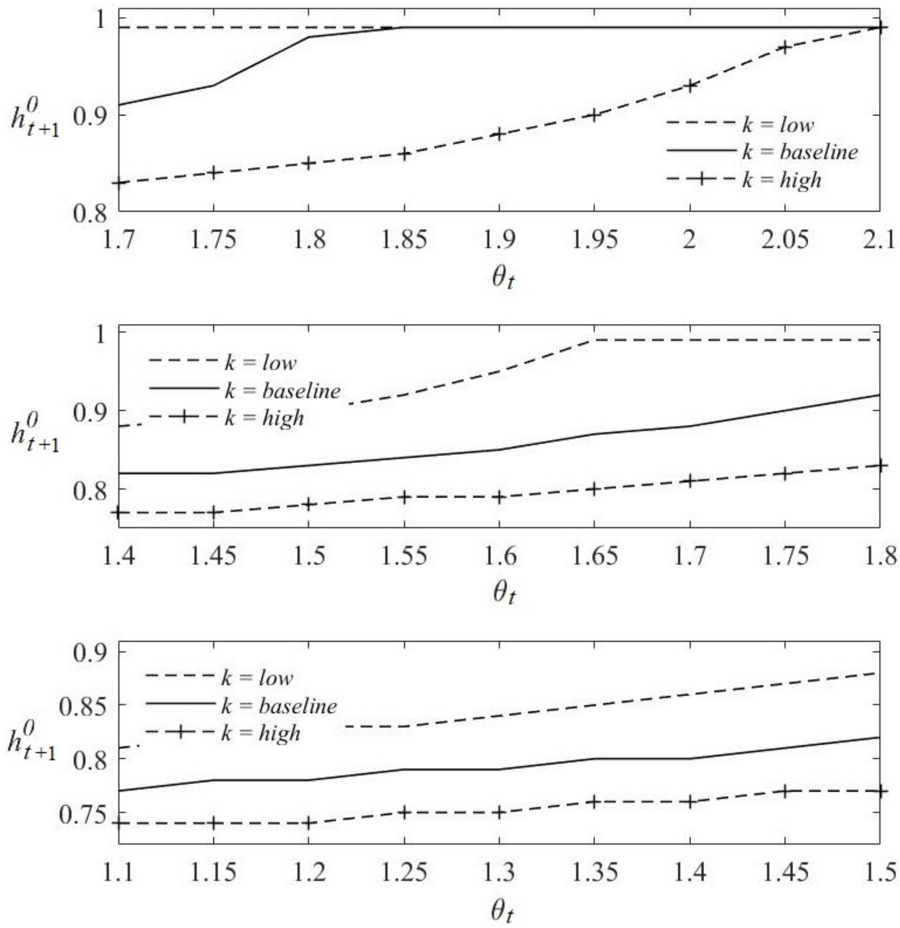

Figure 2.10: **Optimal hedging (Dynamic with complete information)**

Notes: The three panels depict the optimal hedge ratio against θ_t with complete information. The top panel assumes $\bar{\theta} = 1.3$, the middle panel assumes $\bar{\theta} = 1.6$, and the bottom panel assumes $\bar{\theta} = 1.9$, respectively. In this case, the flotation cost, λ_t, becomes $a\theta_t^{-2}$. In each panel, lines with different markers correspond to various k. The baseline parameterization corresponds to the values in Table 2.1.

First, as expected, the relation between h^0_{t+1} and θ_t is weakly increasing. Furthermore, looking among the three panels, we find that, ceteris paribus, the firm with higher $\bar{\theta}$ would hedge more than the firm with lower $\bar{\theta}$. These are consistent with the results obtained in the two–period model in Figure 2.4. The intuition behind such results revolves around that, as discussed in Section 2.2.1, wealthier firms would hedge more, as hedging is relatively cheaper for them and thus h^0_{t+1} would increase with θ_t and $\bar{\theta}$. Rampini, Sufi, and Viswanathan (2014) empirically test such prediction and find a positive relation between hedging and the firm's net worth.

Second, in line with the two–period model, overall h^0_{t+1} has a negative relation with k. As k increases, h^0_t decreases for three reasons. First, as the potential external financing needs become larger, the owner of the firm would prefer to leave part of the cash flow unhedged in order to bet on the high realizations of φ, as discussed in Section 2.2.1. Second, in the dynamic model, a larger k *per se* implies a higher continuation value for the firm and thus a higher likelihood of making investment in the next period. As a result, the incentive for reducing the left tail of the distribution of φ would be weaker. Third, as k can be referred to as a measure of firm size, a small firm would be more likely to reduce the variation of φ_t since it is more vulnerable to exogenous risks. This is counterfactual, though.

2.4.2. Model solution with asymmetric information

We now analyze the firm's optimal hedge ratio, denoted by h^*_{t+1}, in the case where asymmetric information exists between the owner of the firm and outsiders. We numerically solve h^*_{t+1} by using similar methods in Yang (2013) and Gamba and Triantis (2014). Figure 2.11 depicts h^*_{t+1} as a function of θ_t, and Figure 2.12 depicts h^*_{t+1} against μ_t, respectively. Three important features of h^*_{t+1} that may have testable empirical implications stand out in these two figures.

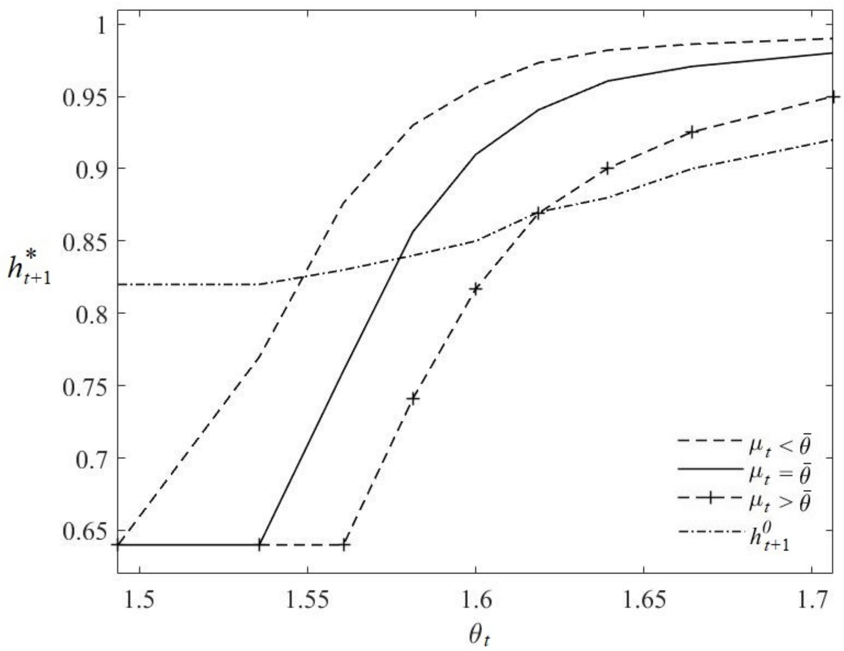

Figure 2.11: **Optimal hedging against profitability shocks (Dynamic with asymmetric information)**

Notes: The figure depicts the optimal hedge ratio against θ_t under the incomplete-information condition. The dashed line corresponds to the case where $\mu_t < \bar{\theta}$, the solid line corresponds to $\mu_t = \bar{\theta}$, the line marked with + corresponds to $\mu_t > \bar{\theta}$, the dash-dot line represents h^0_{t+1} as the optimal hedge ratio in the complete-information case, respectively. The baseline parameterization corresponds to the values in Table 2.1. We also plot the policy function with various parameter settings and obtain very similar patterns with slightly different levels.

First, not surprisingly, with asymmetric information and learning, the belief of outsiders becomes an important determinant of hedging policies. It therefore proves that information asymmetry issue would alter the firm's incentive for hedging. In Figure 2.11, the line with a lower μ_t always lies above the line with a higher μ_t, implying that the firm would hedge more aggressively when outsiders' belief is lower than the long–run profitability of the firm. Further, Figure 2.12 shows that h^*_{t+1} has a monotonic negative relation with μ_t. Intuitively, if μ_t is lower than $\bar{\theta}$, outsiders would be more likely to under–estimate the firm's quality in next period, and thus, the owner of the firm would have more incentive to reveal the true profitability by eliminating the variation of φ. This incentive becomes stronger as θ_t increases thus that h^*_{t+1} has a upward slope. Hence, the first testable prediction would be that firms with an under–estimated profitability would have more incentive for hedging, especially when they obtain favorable profitability shocks, or in the boom market states, and vice versa.

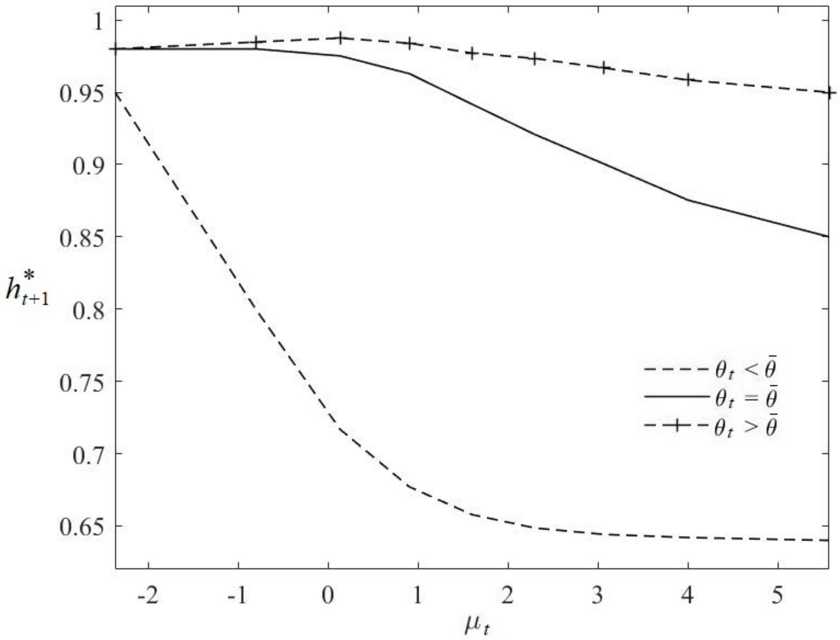

Figure 2.12: **Optimal hedging against the belief of outsiders (Dynamic with asymmetric information)**

Notes: The figure depict the optimal hedge ratio against μ_t under the incomplete-information condition. The dashed line corresponds to the case where $\theta_t < \bar{\theta}$, the solid line corresponds to $\theta_t = \bar{\theta}$, and the line marked with + corresponds to $\theta_t > \bar{\theta}$, respectively. The baseline parameterization corresponds to the values in Table 2.1. We also plot the policy function with various parameter settings and obtain very similar patterns with slightly different levels.

Second, from Figure 2.11, the policy function h^*_{t+1} against θ_t is steeper than the corresponding h^0_{t+1} in Figure 2.10. In particular, for the case in which $\mu_t < \bar{\theta}$, h^*_{t+1} increases more rapidly, which implies that, with asymmetric information, the firm's hedging choice is more sensitive than in the complete–information case. One possible interpretation is inspired by what DeMarzo and Duffie (1995) assert, that by eliminating a source of noise, hedging makes cash flows more informative about the firm's profitability and the public perception of a firm's value more sensitive to its realized cash flows. In turns, if the firm observes $\theta_t < \bar{\theta}$, the owner would prefer $h^*_{t+1} < h^0_{t+1}$ to decelerate outsiders' learning. However, if $\theta_t > \bar{\theta}$, the owner would prefer to set $h^*_{t+1} > h^0_{t+1}$ to accelerate outsiders' learning. Figure 2.12 also shows similar pattern as the line with a smaller θ_t always lies below the one with a larger θ_t. Therefore, in practice, one could expect that, in the presence of asymmetric information, corporate hedging policies are more sensitive to the profitability shocks and market states than the one predicted by complete information models such as Froot, Scharfstein, and Stein (1993) and Bolton, Chen, and Wang (2011).

Third, from Figure 2.12, we find that, with a higher realizations of θ_t, h^*_{t+1} becomes flatter. As aforementioned, the incentive for hedging decrease with μ_t as the firm would wish to enjoy the benefit from equity overvaluation by setting a low hedge ratio. This implication is particularly effective when the realized profitability shock is below the average. In contrast, if the firm realizes $\theta_t > \bar{\theta}$, the owner would be less motivated to blur the learning of outsiders. Therefore, ceteris paribus, one may expect in practice that hedging is more sensitive to the belief of outsiders when the firm realizes an unfavorable profitability shock, or when the market is in recession. This result also provides a possible explanation on the mixed empirical evidence on corporate hedging policies.

2.5. Conclusions

In this chapter, we theoretically analyze the corporate incentive for financial hedging in the presence of external financing frictions and asymmetric information on the profitabilities of firms. We reconcile some seemingly contrasting conventional notions regarding the hedging incentives. Optimal hedging trades off the benefits of less–frequent and less–costly external financing with a better ability to finance investment. When making hedging decisions, firms should consider the perspective on their profitabilities, the severity of information asymmetry, the perspective of the growth opportunity, and all inevitable (opportunity) costs caused by hedging.

Our simple two–period model shows that, without learning process of outsiders, hedging activity cannot be a reliable signal of the firm's quality, and thus, firms could not influence market belief or alter the price of external financing by optimizing their hedge ratios. This is seemingly inconsistent with the conclusion made by incomplete–information models, such as Breeden and Viswanathan (2016), because in our simple model, cash flow is not informative about the firm's true quality with or without hedging activities.

Our dynamic model, which builds on the two–period example, further makes some testable predictions that may have empirical implications. First, firms with an under-estimated profitability would have more incentive for hedging, especially when they obtain favorable profitability shocks, and vice versa. Second, corporate hedging policies are more sensitive to the profitability shocks and market states than the one predicted by the complete information models. Third, hedging is more sensitive to the belief of outsiders when the firm realizes an unfavorable profitability shock, or when the market is in recession. The results of our dynamic model emphasize the importance of information asymmetry to corporate incentives for financial hedging and provide a possible explanation on the mixed empirical evidence on corporate hedging policies.

2.6. Appendix

2.6.1. Proof of Lemmas

Proof of Lemma 2.1. Defining v_0 in equation (2.5) the objective function, firstly, for $\underline{w} \geq w^l(h)$, i.e. for $h \leq h^l$, where h^l is given as in equation (2.6), we have

$$\begin{aligned} v_0(h, w_0, c, \theta, k) =& w_0 - ch + k(\theta - 1) \int_{\underline{w}}^{w^u(h)} f(w_1; h) dw_1 \\ & - \frac{a}{\theta} \int_{\underline{w}}^{k} (k - w_1(h)) f(w_1; h) dw_1. \end{aligned}$$

Thus, differentiating and re-arranging give the first–order derivative of v_0 with respect to $h \in [0, h^l)$ as:

$$v_0'(h) \equiv \frac{\partial v_0}{\partial h} = -c + \frac{2ak(\theta-1)(w_0 - c - \underline{w}) - \theta k^2(\theta-1)^2}{4aw_0(1-h)^2},$$

and the second–order derivative as:

$$v_0''(h) \equiv \frac{\partial^2 v_0}{\partial h^2} = \frac{2ak(\theta-1)(w_0 - c - \underline{w}) - \theta k^2(\theta-1)^2}{2aw_0(1-h)^3}.$$

As shown, when $v_0'(h) = 0$, $v_0''(h)$ must be greater than zero, as $c > 0$, implying that no local maximum point exists for any (w_0, c, θ, k) when $h \in [0, h^l]$.

Secondly, for $w^l(h) \leq \underline{w}$ and $w^u(h) \geq k$, i.e. for $h^l \leq h \leq h^u$, we have

$$v_0(h, w_0, c, \theta, k) = w_0 - ch + k(\theta - 1) - \frac{a}{\theta} \int_{w^l(h)}^{k} (k - w_1(h)) f(w_1; h) dw_1,$$

as in this case, the growth project will be invested for sure. Thus, differentiating and re-arranging give the first–order derivative of v_0 with respect to $h \in [h^l, h^u]$ as:

$$v_0'(h) \equiv \frac{\partial v_0}{\partial h} = -c + \frac{a[(w_0 - c)(2-h) - k][k - h(w_0 - c)]}{4w_0\theta(1-h)^2}.$$

Setting $v_0'(h) = 0$ yields the first–order condition (f.o.c.), and solving the f.o.c. gives h^0 as in equation (2.8). The second–order derivative is then found as

$$v_0''(h) \equiv \frac{\partial^2 v_0}{\partial h^2} = -\frac{a(k - w_0 + c)^2}{2w_0\theta(1-h)^3} < 0,$$

and thus, the local maximum point exists when $h = h^0$. Note that, while $v_0'(h^l) > 0$, we also have

$$\frac{1-h^u}{1-h^0} = \sqrt{\frac{a(w_0 - c)^2 - 4aw_0c\theta}{a(w_0+c)^2}} < 1,$$

which gives $h^0 < h^u$, and thus $h^l < h^0 < h^u$.

Thirdly, for $w^u(h) \leq k$, i.e. for $h \geq h^u$, $w_1(h)$ is always greater than $\underline{w}$ but smaller than k thus that the growth project will be mutually invested by insider and outsiders at $t = 1$ for any realizations of φ. In turn, we have

$$v_0(h; w_0, c, \theta, k) = \theta(w_0 - ch) + k(\theta - 1) - \frac{a}{\theta}(k - w_0 + ch),$$

and its first-order derivative is

$$v_0'(h) \equiv \frac{\partial v_0}{\partial h} = -c(1 + \frac{a}{\theta}),$$

which is a negative constant, implying that v_0 is a straight line with negative slope for $h \geq h^u$. Therefore, the unique peak point of v_0 exists when $h = h^0$.

Finally, we are showing the threshold for c above which $v_0(h^0, w_0, c, \theta, k) < v_0(0, w_0, \theta, k)$. That is, v_0 is maximized by $h = h^0$ only if c is below the threshold, $\bar{c}$, which can be written as in equation (2.9). $\square$

Proof of Lemma 2.2. The condition (2.10) and (2.11) can be simplified as follows:

$$\underbrace{ch_g^* + \frac{a}{4w_0} \cdot \frac{(k - w^l(h_g^*))^2}{\theta_g(1 - h_g^*)}}_{A_1} < \underbrace{ch_g^0 + \frac{a}{4w_0} \cdot \frac{(k - w^l(h_g^0))^2}{\hat{\theta}(1 - h_g^0)}}_{A_2},$$

and

$$\underbrace{ch_g^* + \frac{a}{4w_0} \cdot \frac{(k - w^l(h_g^*))^2}{\hat{\theta}(1 - h_g^*)}}_{A_3} > \underbrace{ch_b^0 + \frac{a}{4w_0} \cdot \frac{(k - w^l(h_b^0))^2}{\theta_b(1 - h_b^0)}}_{A_4},$$

where $\hat{\theta} = (\theta_g + \theta_b)/2$. Note that we have (strictly) $\theta_g > \theta_b$ and $h_g^0 < h_b^0$ thus that $\theta_b < \hat{\theta} < \theta_g$. In addition, to ensure the second type of separating PBE sustainable, we have $h_g^* < h_g^0$. These together yield $A_1 < A_3$, $A_2 < A_4$, and $A_3 < A_2$. However, the condition $A_3 > A_4$ must be violated. Hence, the separating PBE cannot sustain. $\square$

Proof of Lemma 2.3. The condition (2.13) can be simplified as follows:

$$ch_g^* + \frac{a}{4w_0} \cdot \frac{(k - w^l(h_g^*))^2}{\hat{\theta}(1 - h_g^*)} < ch_b^0 + \frac{a}{4w_0} \cdot \frac{(k - w^l(h_b^0))^2}{\theta_b(1 - h_b^0)}.$$

As we have (strictly) $\theta_g > \theta_b$ and thus h_g^* in equation (2.12) must be lower than h_b^0. Thus, condition (2.13) holds for any $\theta_b < \theta_g$, and thus, the bad firm's insider would always mimic the counterpart. Hence, the pooling equilibrium exists and sustains. $\square$

Proof of Lemma 2.4. The Kalman filter is initialized (unconditionally) as follows

$$\mu_0 = \mathbb{E}_0\left[\theta_1\right],$$
$$\text{and } \eta_0^2 = \mathbb{E}_0[(\theta_1 - \mu_0)^2].$$

The Kalman learning process is then given by the following equations, which are computed iteratively for each period $t > 0$. Assume that at $t = 0$, before observe $w_t k_t^{-1}$, outsiders have the following two *prioiri* estimates:

$$\mu_t^- = \mathbb{E}_t\left[\theta_{t+1}|w_1k_1^{-1}, w_2k_2^{-1}, ..., w_{t-1}k_{t-1}^{-1}\right]$$
$$= \rho\mu_{t-1} + (1-\rho)\tilde{\theta},$$

and

$$P_t^- = \mathbb{E}_t[(\theta_{t+1} - \mu_t^-)^2]$$
$$= \rho^2\eta_{t-1}^2 + \sigma_\varepsilon^2.$$

Thus, at this fictitious stage, outsiders have the Kalman gain as:

$$b_t = \frac{P_t^-}{P_t^- + (1-h_t)^2\sigma^2}$$
$$= \frac{\rho^2\eta_{t-1}^2 + \sigma_\varepsilon^2}{\rho^2\eta_{t-1}^2 + \sigma_\varepsilon^2 + (1-h_t)^2\sigma^2}.$$

Finally, after observe $w_tk_t^{-1}$, outsiders update their *posteriori* estimates as

$$\mu_t = \mathbb{E}_t\left[\theta_{t+1}|w_1k_1^{-1}, w_2k_2^{-1}, ..., w_{t-1}k_{t-1}^{-1}, w_tk_t^{-1}\right]$$
$$= \mu_t^- + b_t(w_1k_1^{-1} - \mu_t^-)$$
$$= (1-b_t)(\rho\mu_{t-1} + (1-\rho)\tilde{\theta}) + b_tw_1k_1^{-1},$$

and

$$\eta_t^2 = \mathbb{E}_t[(\theta_{t+1} - \mu_t)^2]$$
$$= (1-b_t)P_t^-$$
$$= (1-h_t)^2\sigma^2 b_t.$$

By definition, this learning process has the speed of adjustment as $1 - \rho(1-b_t)$. $\square$

2.6.2. Numerical Methods

The numerical solution of the dynamic model is obtained through a dynamic programming iteration. We use discretization to approximate the continuous state variables, following Terry and Knotek II (2011) and Tauchen (1986). In particular, we let θ_t, w_t, and μ_t take values from intervals whose centers are the corresponding long-run means of the variables. In each range, 9 points are equally distributed. The value functions are represented as functions on the grid points, and a piecewise linear interpolation is used when function values on the non–grid points are needed.

The expectation is computed using the Gauss–Hermite quadrature method with $n = 11$ sample points. In the quadrature method, the Gaussian integral is approximated by

$$\int_{-\infty}^{\infty} e^{-x^2} f(x)dx \approx \sum_{i=1}^{n} \omega_i f(x_i),$$

where x_i are the roots of the Hermite polynomial $H_n(x)$ and the associated weights are given by

$$\omega_i = \frac{2^n n! \sqrt{\pi}}{n^2 \left[H_{n-1}(x_i)^2\right]}.$$

In the numerical solution of the dynamic model, the optimal hedge ratios are computed through the backward deduction using the recursive formulas in Section 2.3. Note that, with complete information, there will be no discretization for μ_t, as μ_t is a known state in this case. Stationary solutions are found by iterating the recursive procedure until the errors of the value functions between adjacent iterations are less than 10^{-5}. The procedures normally converge within 400 iterations.

Chapter 3

Theory and Evidence on Corporate Financial Risk Management with Growth Opportunities

3.1. Introduction

What determines the extent to which non–financial firms engage in financial risk management? This chapter aims to reconciling some seemingly contrasting notions regarding the hedging incentives. I re–examine the conventional theories of corporate hedging in the presence of external financing needs due to investments and market frictions such as informational asymmetry on firm's profitability. I argue that existing theory models and empirical evidence are mixed in two aspects. First, the prevailing literature, such as Froot, Scharfstein, and Stein (1993), shows that hedging can help a firm avoid costly external financing by making cash flows less volatile.[1] Hence, a firm can ultimately increase its value by hedging because it can thus finance its investment opportunities using less costly internal resources. The value effect of hedging has been

[1] The same argument extends to financial institutions, as demonstrated by Froot and Stein (1998).

examined empirically (e.g., MacKay and Moeller, 2007 and Pérez-González and Yun, 2013), but results are mixed. At the very best, the value effect of financial derivatives is modest, as evidenced by Guay and Kothari (2003), among others. While these inconclusive results may be due to empirical challenges, it is also the case that hedging may not being value–increasing. For instance, Babenko and Tserlukevich (2017) show that if a firm's growth opportunities are positively correlated with the cash flows and the prospects are good, hedging actually jeopardizes the potential of expansion by eliminating the chance of high cash flows. In this case, hedging reduces the value of the growth options and of the firm. More generally, firms using financial derivatives normally incur various endogenous costs (such as transaction costs, negotiation costs, etc.) related to hedging, which offset its benefit (see for instance, Gamba and Triantis, 2014). Hence, there is a case for a more thorough re–examination of hedging as a way to create value.

Second, hedging can have a direct effect on external financing costs by alleviating adverse selection issues. A consequence of informational asymmetry is that outside investors require a premium upon new securities issuance when firms raise external funds, as argued by Myers and Majluf (1984). In this respect, firms can hedge to make their business more transparent, ultimately reducing the underpricing cost of informationally sensitive securities, like equity. More precisely, by reducing the amount of noise, hedging increases the informativeness of cash flow realizations for outside investors, who can thereby make a more accurate inference on the value of the firm. Hence, adverse selection costs for seasoned equity issuance will be lowered when the firm taps financial markets. However, also in this respect hedging may have a drawback. As illustrated by DeMarzo and Duffie (1995), by eliminating a source of noise, hedging makes cash flows more informative and the public perception of a firm's value more sensitive to its performance. Holding fixed the variability of cash flows, this implies that financing costs may become more variable. As they are typically convex, this increases their present value, negatively affecting the value of the firm.

Overall, this result in a negative incentive to hedging. In addition, as suggested by Breeden and Viswanathan (2016), firms with bad news or low–quality projects might prefer to increase risk exposure and hope for a lucky draw. In that case, revealing the true quality makes low-quality firms worse–off. In sum, asymmetric information does not create an obvious incentive to hedge.

I develop a two–period model in which a firm with a growth option can hedge its exogenous risk by using financial instruments. As Babenko and Tserlukevich (2017), the growth option is exercised subject to financing constraints. If the reserved cash is insufficient to finance the investment, the firm must raise external capital to cover the funding gap. If the exogenous risk is unhedged, outside investors cannot directly observe the profitability and deduce the true profitability of the firm because the exogenous risk factor makes the firm's cash flow noisy. It is exactly when the profitability is high (and investment likely), that the firm will be most exposed to the undervaluation costs triggered by security issuance. Leaving the risk unhedged, the firm will face an adverse selection cost when external funds are needed. Hence, it is key that a high–profitability firm makes sure that its profitability is correctly understood by the market, and that the exposure to the exogenous risk is managed. The hedging instrument used by the firm is inherently costly because it insists on the same resources used to finance the investment, in line with Rampini and Viswanathan (2010). In this aspect, the opportunity cost of hedging is higher for a high–quality firm. In addition, in some states, hedging would lower the value of the growth option as described above, which in turn has a negative impact on the hedging incentive. Unlike a full information setting, my model thus provides a rationale for why and when firms will undertake hedging activities in an imperfect capital market. In this respect, the model is closely related to Breeden and Viswanathan (2016), although differently from them I do not need to discuss the firm's reputation concerns.

The model shows that, when making hedging decisions, the firm should consider the severity of informational asymmetry issue, the perspective of its growth opportunity, and all inevitable (opportunity) costs caused by hedging. Optimal hedging trades off the benefits of less-frequent and less-costly external financing with a better ability to finance investment. Consequently, while it can be achieved, perfect hedging of the exogenous risk is usually not optimal, especially when the firm profitability is low, in line with Fehle and Tsyplakov (2005). The model generates results consistent with existing empirical observations, and the predictions of the model provide the basis of further empirical analysis.

I perform in the last part of the chapter using a sample of hand–collected data comprising 62 oil and gas (OG) firms in the United States from 2009 through 2018. The data sample contains 557 firm–year observations. I use the nominal amount of hedging in my definition of a continuous dependent hedging variable. Specifically, I hand collect information on the volume of crude oil and equivalence products hedged by financial derivatives, and scale the hedged volume by the firm's production volume in the same year to construct hedge ratio. I supplement the financial hedging data with accounting information from Compustat and CRSP databases. The panel structure of the data allows me to exploit both cross–sectional and within–firm variation to assess the relationship between financial hedging and the focused variables. Many previous studies use only cross–sectional data and hardly exploit within–firm variation because they largely rely on dummy variables for financial hedging activities that have only limited within–firm variation.

My theoretical model belongs to the growing literature on corporate risk management and real investment. The received theory shows that financing and hedging are intrinsically intertwined, which creates conflicting incentives for hedging, as suggested by Stulz (1996). Positive effects of hedging on corporate financing include (i) reduction in costly external financing, as in Froot, Scharfstein, and Stein (1993); (ii) mitigation of cash flows noise, as in DeMarzo and Duffie (1991) and DeMarzo and

Duffie (1995); (iii) reduction in expected (convex) taxation and bankruptcy costs, as in Smith and Stulz (1985); (iv) reduction of borrowing costs, as in Leland (1998); (v) reduction in expected distress costs, as in Purnanandam (2008); and (vi) reduction in contracting costs (with creditors, suppliers, and customers), as in Bessembinder (1991). the chapter focus on the first two motives for hedging, although other motives could be easily accommodated by extending the model. Differently from the other models, I account for two negative economic forces that may reduce the hedging incentive. First, hedging is suboptimal when cash flow is positively correlated with lumpy profitable investment, as in Babenko and Tserlukevich (2017). Second, in the spirit of DeMarzo and Duffie (1995) and Breeden and Viswanathan (2016), a firm (and its executives) may not always intend to eliminate the informational asymmetry with outside financiers.

The empirical findings support the predictions of the model. First, *ceteris paribus*, firms with stronger ability to generate income should more likely engage in financial hedging. Indeed, I find a strong and positive relation between a firm's profitability and hedging decision. Second, the hedging incentive should be positively related to the severity of informational asymmetry, and I evidence a positive, although decreasing, marginal effect of informational asymmetry on the likelihood of hedging. Third, the potential external financing needs of a firm, resulting from the perspective of exercising the growth opportunities, should increase the hedging incentive in the presence of adverse selection costs. The empirical analysis confirms this prediction, although the effect is economically modest. Fourth, as hedging is inherently costly, it is less preferred by those firms whose capital resource constraint is tighter. By using various proxies of hedging costs, I find evidence in support of a negative relation between firms' inability to accessing financial derivatives and their hedging incentives.

The empirical findings contribute to the empirical risk management literature by analyzing corporate financial hedging activities of a comprehensive sample of OG firms. Since the reliability of disclosures on firms' derivatives fair values for the purpose of hedging remains doubtful, I investigate only the sample firms' disclosure on physical hedge ratio or nominal volume of commodity hedged, following a sizable prior empirical literature, such as Rampini, Sufi, and Viswanathan (2014) and Rampini, Viswanathan, and Vuillemey (2017). Some empirical studies use yes-no decision of hedging as the dependent variable. For example, Geczy, Minton, and Schrand (1997) use a 372 firms sample with 154 hedgers. Similarly, Graham and Rogers (2002) use 446 firms with 158 hedgers. Mian (1996), Purnanandam (2008), and Bartram, Brown, and Fehle (2009) use large samples of categorical data on the hedging decision. Tufano (1996) provide evidence from the gold mining industry. Haushalter (2000) and Pérez-González and Yun (2013) focus on utility firms. Purnanandam (2007) analyzes the effects of bank characteristics and macroeconomic shocks on the usage of interest rate derivatives. In addition, Brown (2001) provides a clinical study to show why and how a typical manufacturing firm engages in foreign exchange risk management. Differing from the prior research, the results of my study emphasize the importance of growth potential and information asymmetry on corporate incentives for financial hedging

This chapter is organized as follows. Section 3.2 introduces the model, by illustrating the time line of events, the outsiders' inferences on the firm's profitability, and the equilibrium hedging strategies that solves the firm's value–maximization problem and satisfies outsiders' learning process. In Section 3.3, I numerically analyze the optimal hedging policies of the firm and study how hedging decisions depends on the parameters of the model. To close the section, I provide a self–contained summary of theoretical predictions for my empirical estimations. Then, I empirically examine the theoretical model by testing regression models in Section 3.4. Finally, Section 3.5 concludes the chapter.

3.2. The model

To illustrate the main arguments, I introduce a simple two-period model featuring key assumptions that relate to my research interest. In an economy with three dates, $t = 0, 1, 2$, I assume a firm featuring real investments, financing frictions, and informational asymmetry between existing shareholders (hereinafter *insiders*), and public investors in the capital market (hereinafter *outsiders*). I assume that borrowing is excluded and that all financing needs can only be met by using internal reserves and, when they are exhausted, by issuing equity to outsiders.[2] By endogenizing the external financing cost and outsiders' inference on latent information, I determine the equilibrium exercize of the growth option and the optimal hedging policy. I also abstract from managerial agency issues, which are inessential to my argument.

3.2.1. Complete information case

I assume a firm (hereinafter *the firm*) having access to a production technology with constant returns to scale. I denote k_t the amount invested this technology in period t. At $t = 0$, the firm is endowed with w_0 units of capital input. A non–hedgeable profitability shock, denoted $\theta_t > 0$, affects the output in period t, which is therefore $\theta_t k_t$, for $t = 1, 2$. I assume that the profitability shock remains constant over the last two dates, $\theta_1 = \theta_2 = \theta$, so that the information about profitability is revealed at $t = 1$.[3] In order to rule out the signalling concern, I assume that at $t = 0$, the owner and outsiders of the firm share the same expectation on θ_t. Thus, there would

[2]This assumption is equivalent to a case where the firm could abscond with all cash flows and would be excluded from future lending, see Rampini and Viswanathan (2010).

[3]Throughout this chapter, I focus on steady–state θ for the purpose of model simplicity. Nevertheless, intuitively, the technological quality of a firm could be time-varying due to changing market conditions, such as preferences of consumers, competition of goods market, and launch of new innovations, etc.

be no information asymmetry issue regarding to the quality of the firm; that is, the firm would not mimic any other type of firms at $t = 0$. In addition to production shocks, each firm is also exposed to an idiosyncratic exogenous shock with symmetric distribution, which yields a cash flow φ_t at the end of each period and has average $\varphi_m \leq 0$. Thus, the firm's asset returns a total cash flow $\theta_t k_t + \varphi_t$, for $t = 1, 2$.

The exogenous shock can be hedged by purchasing one–period ahead Arrow–Debreu securities. For instance, the firm may take at $t-1$ a long position in a one–period futures contract with price φ_m, in exchange of the obligation to deliver φ_t at t.[4] Empirically, the ability of the firm to hedge its risk exposure using financial derivatives is quite low.[5] In the model this is rationalized by interpreting φ as any hedgeable risks, and θ_t as whatever remaining non-hedgeable risks the firm is exposed to.

At the beginning of each period, the firm makes a hedging decisions, summarized by the hedge ratio $h_t \in [0, 1]$, for $t = 1, 2$. Trading Arrow-Debreu securities entails a cost ch_t, proportional to the notional amount h_t, for a constant $c \geq 0$.[6] The firm must pay in advance the Arrow-Debreu securities, and the maximal amount of cash that can be put on hedging is k_t, implying a budget constraint on hedging instruments, $ch_t \leq k_t$.[7]

Given the state $(k_t, \theta_t, \varphi_t)$ and the firm's decision h_t, the cash flow at the end of period t is $w_t \equiv w_t(h_t, k_t, \theta_t, \varphi_t) = \theta_t(k_t - ch_t) + \varphi_t + h_t(\varphi_m - \varphi_t)$, for t = 1, 2. Without loss of generality, I assume: (i) $\varphi_m = 0$, (ii) zero discount rate; (iii) full depreciation of productive capital; (iv) the capital input at $t = 0$ is $w_0 = k_1 = 1$.

[4] In the airline industry, as illustrated by Rampini, Sufi, and Viswanathan (2014), this corresponds to locking in the jet-fuel cost.

[5] See empirical papers such as Graham and Rogers (2002), Carter, Rogers, and Simkins (2006), Bartram, Brown, and Minton (2010), Campello, Lin, Ma, and Zou (2011), and among others.

[6] One may interpret c as the negotiation costs or the interest loss in margin account, but I do not need to endogenize this cost to derive the results.

[7] Bolton and Oehmke (2015) study the seniority for financial derivatives in bankruptcy. But this chapter has no interest in bankruptcy, and thus I assume the hedging instrument in my model as default-free.

Hence,

$$w_t = \theta_t(k_t - ch_t) + \varphi_t(1 - h_t) \quad \text{for } t = 1, 2. \tag{3.1}$$

The firm has the option to expand the productive asset at $t = 1$. That is, at $t = 1$, $\theta_1 = \theta$ is realized and the firm decides whether to invest k_2 in the growth option. The expected payoff from the investment is $\mathbb{E}_1[w_2] = \theta(k_2 - ch_2)$ as $\mathbb{E}_1[\varphi_2] = 0$ and $\mathbb{E}_1[\theta_2] = \theta$, where $\mathbb{E}_t[\cdot]$ is the expectation operator conditional on information at t. Clearly, the incentive it to choose k_2 so that $\mathbb{E}_1[w_2]$ is as large as possible. On the other hand, because there is no financing need at $t = 2$, $\partial\mathbb{E}_1[w_2]/\partial h_2 = -c\theta < 0$, so that the firm has no incentive to hedge at $t = 1$. Hence, the payoff can be simplified into $\mathbb{E}_1[w_2] = \theta k_2$, as $h_2 = 0$.

The financing needs in $t = 1$ are motivated by investment. If the net worth is greater than the investment cost, $w_1 \geq k_2$, the firm uses the cash reserve w_1 to exercise the option and distribute the remaining cash, $w_1 - k_2$, to insiders. Because internal financing is cheaper than external financing, it is easy to show that it is optimal to use up all cash reserves before tapping the financial market. Hence, if $w_1 < k_2$, to finance the shortfall the firm will raise $k_2 - w_1$ from outsiders, incurs the financing cost which is proportional to the scale of issuance. Specifically, we denote the dollar cost of external equity financing as

$$\Lambda(h_1) \equiv \Lambda(w_1, \theta, k_2, h_1) = \frac{\alpha}{\theta} \cdot \max\{k_2 - w_1(h_1), 0\}, \tag{3.2}$$

where $\alpha = 1/k_2$ is a positive constant. To make the problem non–trivial, I assume that the firm's cost for accessing to debt is higher than Λ for any h_1 thus that debt is always a sub–optimal financing tool, comparing with equity. The firm forgoes the investment opportunity if $w_1(h_1) + \Lambda(h) > \theta k_2$, whereby investment and financing costs exceed the expected payoff to insiders. Taking a deeper insight on how hedging marginally affects the external financing cost, I differentiate $\Lambda(h_1)$ as

$$\frac{\partial \Lambda}{\partial h_1} = \frac{c\theta + \varphi_1}{\theta k_2}.$$

Hence, φ_1 determines whether h_1 enhances or reduces the cost of external financing. Specifically, when φ_1 is greater (smaller) than $-c\theta$, Λ is positively (negatively) affected by h_1. This is non–trivial in the sense that hedging drives external financing more (less) costly when the realized exogenous shock is favorable (adverse). However, from the perspective at $t = 0$, for $\mathbb{E}_0[\varphi_1] = 0$, the marginal effect of h_1 on $\mathbb{E}_0[\Lambda]$ is always non–negative.

Thus, the value of the growth option at $t = 1$ is

$$g_1 \equiv g_1(w_1, \theta, k_2) = \max\left\{0, -k_2 + \theta k_2 - \Lambda(h_1)\chi_{\{k_2 > w_1\}}\right\},$$

where $\chi_{\{\mathcal{E}\}}$ is the indicator function of event $\mathcal{E}$. The insiders' value at $t = 1$, is

$$V_1 \equiv V_1(w_1, \theta, k_2, h_1) = w_1 + \begin{cases} -k_2 + \theta k_2, & \text{if } k_2 \leq w_1, \\ -k_2 - \Lambda(h_1) + \theta k_2, & \text{if } \underline{w} \leq w_1 < k_2, \\ 0, & \text{if } w_1 < \underline{w}, \end{cases}$$

where $\underline{w}$ is the threshold for w_1, above which the growth option is exercised. The first and the second row of the above expression is the equity value when the option is exercised, whereas the third row is the equity value when the option is forgone. By equating the second and the third row of the above expression gives $\underline{w} = (2 - \theta)k_2$. Note that, if the realized profitability shock $\theta < 1$, exercizing the growth option always generates a loss to insiders as $\theta k_2 < k_2$, implying a negative-NPV project, and thus the firm never exercizes the growth option. In fact, $\theta < 1$ gives a counterfactual condition that the lower bound of exercizing the growth option exceeds the investment cost, i.e. $\underline{w} > k_2$. Intuitively, if a firm's *ex post* profitability is very low, its best choice is abandoning the investment project and distributing all cash in-hand to insiders.

Restricting the consideration in $\theta \geq 1$, the expression of $\underline{w}$ entails three salient points. First, for any $k_2 > 0$, a firm with superior profitability has lower investment constraint, $\underline{w}$, and a higher probability of exercising the growth option. Second, $\underline{w}$ increases in k_2 for $\theta < 2$, whereas $\underline{w}$ decreases in k_2 if $\theta > 2$. It implies that the effect of k_2 on the chance for investing at $t = 1$ depends on the firm's *ex post* profitability. Third, to investigate how h_1 determines the likelihood of exercising the option, I re-write $\underline{w}$ in the form of equation (3.1) and replace φ_1 by $\underline{\varphi}_1$, where $\underline{\varphi}_1$ denotes the realization of φ_1 that gives $\underline{w}$. By equating the new form of $\underline{w}$ and $(2-\theta)k_2$ and re-arranging, one may get

$$\underline{\varphi}_1(h_1) = \frac{(2-\theta)k_2 + (ch_1 - 1)\theta}{1 - h_1}.$$

It is straightforward that a larger $\underline{\varphi}_1$ begets higher threshold $\underline{w}$ and thus lower possibility for exercising the growth option. Clearly, the sign of $\partial\underline{\varphi}_1/\partial h_1$ is decided by the association between θ and k_2. Specifically, $\partial\underline{\varphi}_1/\partial h_1 > 0$ only if $k_2 > (1-c)\theta/(2-\theta)$, which is easy to derive, and I do not show the details in the chapter.

The firm is, therefore, maximizing the insiders' value as the expected first-period cash flow *plus* the value of growth option at $t = 0$ by optimally choosing hedging policy, h_1^*. That is,

$$V_0(\theta, k_1, k_2) = \max\left\{0, \max_{h_1} \mathbb{E}_0[V_1]\right\}.$$

A numerical solution of the optimal hedging policy with complete information will be shown in Section 3.3.

3.2.2. Incomplete information with investors' inferences

I now consider an alternative scenario, in which the firm's profitability and the idiosyncratic shock are concealed to outsiders. More precisely, while the distributions of θ and φ are publicly known, the realizations of θ and φ cannot be observed by outside investors. I assume that firms disclose the hedging strategy, h_1, but do not truthfully convey the net payoff from the hedging contract.[8] However, outsiders can infer the actual realization of θ from the cash flows, on which basis they can price the firm's securities. Figure 3.1 depicts the timeline of the model.

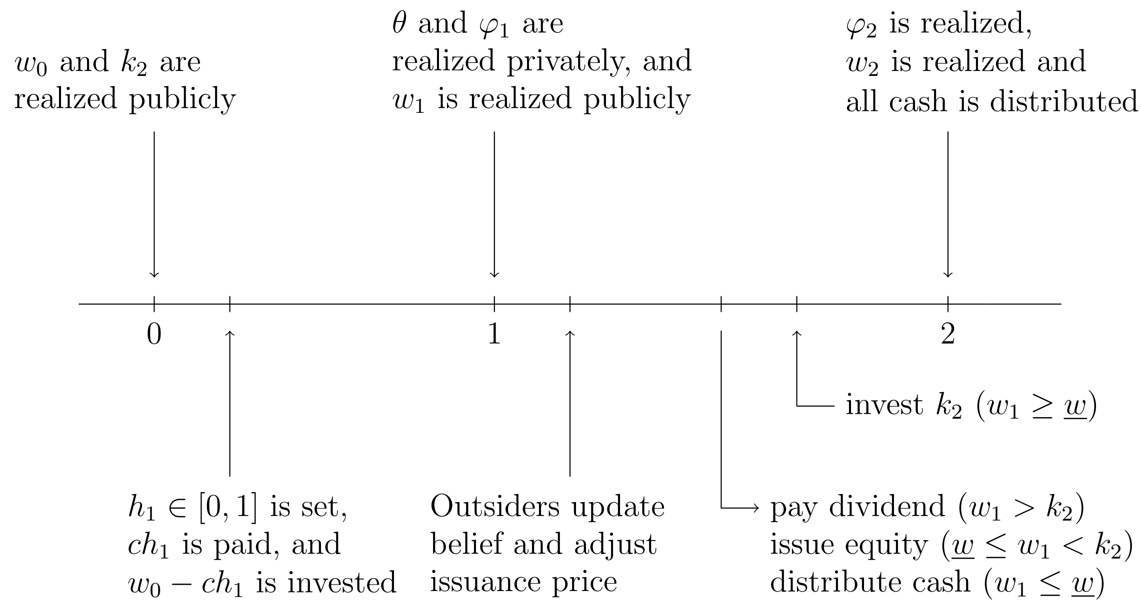

Figure 3.1: **Timeline for the model**

Notes: At $t = 0$, the firm makes hedging decision h, based on the endowment w_0 and the growth option k_2 that can be exercised at $t = 1$. At $t = 1$, the firm observes θ and φ_1, and thus obtains w_1; the investment decision depends on w_1 and k_2; the hedging decision is zero. At $t = 2$, if the investment k_2 is made at $t = 1$, the firm observes φ_2 and obtains w_2. All cash will be distributed to shareholders.

At $t = 1$, outsiders receive the following information: (i) the initial capital input $k_1 = 1$; (ii) the realized net worth, w_1; (iii) the hedge ratio, h_1. Outsiders infer

[8] See, for example, the survey paper by Beyer, Cohen, Lys, and Walther (2010) for a review of the literature on financial reporting.

θ from w_1. However, the presence of φ_1 blurs the link between θ and w_1, and investors can only estimate θ with an error. I denote x the information on θ drawn from w_1:

$$x = \frac{w_1}{1 - ch_1} = \theta + \xi\varphi_1, \qquad \text{where } \xi \equiv \frac{1 - h_1}{1 - ch_1}. \tag{3.3}$$

Because $\varphi_m = 0$, the average of x is θ and the estimation error is unbiased. The random variable x can be interpreted as a noisy signal about θ, whose distribution is publicly known.[9]

The assumed informational asymmetry becomes relevant if the firm needs external financing to exercise the growth option, at $t = 1$. In exchange for investment, outsiders require a fraction of equity stake, which is regarded as a financing cost by the insiders. In the extreme case of $h_1 = 0$, the estimate is as inaccurate as it can be, because outsiders cannot tell if a high (low) realization of w_1 is due to a high (low) profitability, θ, or a small (large) payoff of the exogenous shock, φ_1. In the other extreme case, if a firm fully hedges ($h_1 = 1$), the exogenous shock is eliminated, as $\xi = 0$. Hence, investors can perfectly tell the profitability of the firm from the net worth, and price its issuance accordingly. The resulting financing cost, based on the firm's actual profitability, is identical to the issuance cost in the complete-information scenario in the previous section.

For $0 < h_1 < 1$, outsiders can observe relatively smooth w_1 but cannot derive the true θ. The following lemma states sufficient conditions for the accuracy of the estimate of θ to depend on the hedge ratio.[10]

Lemma 3.1. *Assume outsiders infer the firm's profitability, θ, based on the realizations of net worth w_1. Suppose θ is drawn from a truncated normal distribution $\mathcal{N}(\mu, \eta^2; 0)$ with open support $(0, \infty)$, and φ has normal distribution $\mathcal{N}(0, \sigma^2)$, where*

[9] One may think of x as corresponding to, for example, analysts' estimate of the firm's cash flow.

[10] The proof is in Appendix 3.6.1. Some derivations rely on special knowledge on pure mathematics theories, such as Barr and Sherrill (1999) and Jawitz (2004).

$\sigma = 1$. *Then, for* $h \in [0, 1)$, *the inference, or the posterior belief, on* θ *drawn by outside investors has mean of*

$$\hat{\theta} \equiv \mathbb{E}_1[\theta | w_1, h_1] = \frac{x\eta^2 + \mu\xi^2}{\eta^2 + \xi^2} + \frac{\eta^2\xi^2}{\eta^2 + \xi^2} \frac{\phi(a)}{\Phi(-a)}, \tag{3.4}$$

where

$$a \equiv -\frac{x\eta^2 + \mu\xi^2}{\eta^2\xi^2},$$

and $\phi(\cdot)$ *and* $\Phi(\cdot)$ *are respectively the density and the cumulative probability functions of standard normal distribution. If the firm adopts a hedge ratio approaching to one,* $h_1 \uparrow 1$, *then the signal revealed from realized cash flows is less noisy,* $x \to \theta$, *and (thus) the posterior mean approaches a perfect inference, i.e.* $\hat{\theta} \to \theta$.

The essence of drawing inferences on θ is a Bayesian approach to specify the posterior distribution of θ with mean $\hat{\theta}$, known as the outsiders' learning process. Notably, I define $\mu \equiv \mathbb{E}_0[\theta]$ the *ex ante* profitability, which is the unconditional mean of θ at $t = 0$ known by both insiders and outsiders. Moreover, without loss of generality, I assume that the volatility of the exogenous risk factor is $\sigma = k_1 = 1$, which reflects the scale of the firm's exposure to φ. In the limiting case of a firm that fully hedges, the noise around x becomes zero, which results in a perfect inference on θ, as $\hat{\theta}$ equals $x = \theta$. In general, the higher the hedge ratio the better the inference on the profitability of the firm that the outsiders will make. Investors then price the equity issued by the firm and require a fraction of equity stake based on their inference on θ. Therefore, the dollar cost of flotation charged by the outsiders is

$$\Lambda(h_1) \equiv \Lambda(w_1, \hat{\theta}, k_2, h_1) = \frac{\alpha}{\hat{\theta}} \cdot \max\{k_2 - w_1(h_1), 0\}. \tag{3.5}$$

Equation (3.5) reflects the outsiders' informational gain from their learning. By comparing equation (3.2) in the complete–information scenario to equation (3.5), one may see that an additional risk of being undervalued exists when the firm raises external funds. Such risk can also be referred to as an adverse selection problem in capital market. Financial hedging reduces cash–flow noise and thus alleviates the severity of the potential adverse selection problem. Hence, once the informational asymmetry concern is taken into consideration, the additional incentives for hedging comes from the transparency-enhancing potential of hedging. Consequently, the value of the growth option at $t = 1$ becomes

$$g_1(h_1, \theta, \hat{\theta}, k_2) = \max\left\{0, -k_2 + \theta k_2 - \frac{\theta}{\hat{\theta}}\,(k_2 - w_1)\,\chi_{\{k_2 > w_1\}}\right\}.$$

The last term in the above equation is the subsidy from insiders to outsiders. Clearly, as a result of informational asymmetry, when the firm raises external funds by issuing equity, it is undervalued by outsiders, if the *ex post* profitability shock is superior $\theta > \hat{\theta}$, and overvalued if $\theta < \hat{\theta}$.

In my model, in line with Wilson (1980), investors are assumed to be risk-neutral with respect to the firm's profitability. Outsiders price the equity based on the inferred profitability of the firm. Therefore, by actively choosing the hedge ratio, the firm can potentially bias the outsiders' inference process and thus indirectly controls the external financing cost. Of course, in equilibrium this will not happen, because the investors in market will know what to expect and adjust the expectation, which is noisy though, accordingly.

To summarize, because the firm maximizes the value of insiders, the valuation equation at $t = 0$ is

$$\begin{aligned} V_0(\theta, k_2) = \max\Bigg\{0, \max_{h_1}\Bigg(\mathbb{E}_0\Bigg[&\theta(1 - ch_1) + (1 - h_1)\varphi_1 \\ &+ \max\left\{0, -k_2 + \theta k_2 - \frac{\theta}{\hat{\theta}}(k_2 - w_1)\cdot\chi_{\{k_2 > w_1\}}\right\}\Bigg]\Bigg)\Bigg\}. \end{aligned} \tag{3.6}$$

The first line of (3.6) reflects (i) the limited liability of insiders, (ii) the expected payoff from hedging activity, and (iii) the expected net worth at $t = 1$. The second line is the expected value of the growth option, as well as the cost of external financing if the new investment exceeds the contemporaneous net worth.

The optimal hedge ratio $h_1^*(\hat{\theta})$ solves the program in (3.6) and satisfies outsiders' inference process in (3.4). Any deviation $h_1' \neq h_1^*$ is suboptimal for insiders because it yields a lower value. Moreover, the firm manipulates the outsiders' learning process by altering the hedge ratio, which is a key feature of my model.

Equation (3.6) enable us to show the fundamental forces that determine the firm's risk management decision. First, on the one hand, hedging helps the firm avoid the costly external finance in the state where a negative φ lowers the operating cash flows, but on the other, hedging may result in a lower valuation of the firm's growth option because it mitigates the possibility of high cash–flow realizations. This would suggest executives to reduce hedging. Second, the financial instrument itself is of non–zero costs so that the firm hedges only if the benefit of doing so dominates the costs. If the firm expects a high profitability shock occurring in the future, the opportunity cost of hedging becomes higher, which lowers the *ex ante* incentive for hedging. Third, the transparency–enhancing potential of hedging favors the firm. However, hedging makes it less possible that the firm would enjoy a benefit from the outsiders' overvaluation. To that extent, in line with DeMarzo and Duffie (1995), when the realized cash flow is a more informative signal of its profitability, outsiders' perception of the firm's profitability is more sensitive to its performance. As a consequence, hedging makes the firm entirely exposed to the profitability shock that cannot be hedged. Such effect in fact reduces the incentive to hedge.

3.3. Numerical implementations

To help the model intuition, I solve a calibrated model to explore the impact of hedging and examine the policy function, h_1^*, because the numerical results are more revealing in my model. I analyze the marginal benefit of hedging and exhibit the association between firm characteristics and optimal hedging policy. The parameters for the base case environment are μ =1.3, η =1.0, k_2 =1.9, and c =4%. In my analysis, I also investigate the effects of varying these parameters other than their base case values. Notably, the unconditional volatility, η, can be regarded as a measure of the severity of informational asymmetry. A firm with large η faces severe informational asymmetry problem because large variance in profitability shock implies large likelihood of being misvalued when it issues equity to outsiders. The numerical procedure can be found in Appendix 3.6.2.

3.3.1. Value contributions of hedging

To gain an appreciation of the relative contributions of hedging to value creation in different states, I begin by studying the marginal effect of hedge ratio on the firm's equity value and growth option value, respectively. Figure 3.2 demonstrates the complete-information and the incomplete–information value functions against all possible hedge levels, h_1. The left column of panels contains the firm's equity values, and the right column contains the growth option values. The first row of panels corresponds to the base case valuation, and apart from that, I plot four interesting scenarios with different firm characteristics: (i) The firm has low *ex ante* profitability so that its growth option is very unlikely to be exercised; (ii) the firm has a severe informational asymmetry concern as its profitability shock is highly volatile; (iii) the firm's next-period investment project is of small scale so that its external financing need is potentially small; and (iv) the firm's access to financial derivatives market is very costly. In each row, the optimal hedge ratio that maximizes insiders' value corresponds to the peak of the firm equity value curves.

Overall, model results plotted in Figure 3.2 are consistent with the conjectures. Firstly, looking across the graphs, the optimal hedge ratio exists as insiders' equity value is concave in h_1, showing that the firm trades off the benefits and costs associated with hedging. As expected, hedging alleviates the information asymmetry problem, which is shown by the decreasing difference between the complete–information and the incomplete-information equity values as h_1 increases. When $h_1 = 1$ (i.e. fully hedging), the two models are fully aligned. It is noteworthy that, although a high hedge ratio is normally favorable to the growth option value, such a high hedge level does not always optimize equity value.

Secondly, apparently the dash–dotted line dominates the solid line, and the two function curves are of different shapes, indicating that informational asymmetry structurally reduces equity value and alters the marginal contribution of hedging. It implies that informativeness concern plays an essential role in corporate risk management policies, which is in contrast to traditional full information models that whether firms hedge or not is irrelevant.[11] In fact, the complete-information model is another manifestation of the model proposed by Babenko and Tserlukevich (2017) in which information is symmetric. With certain parameter combinations, the results are fairly in line with their argument that hedging is not favorable to firm value when the growth option is taken into account. However, when information is asymmetric, the firm would hedge more aggressively than in the complete-information environment.

Thirdly, the marginal value of hedging appears to be quite state specific, reflecting a variety of factors. Looking at the second row of panels, it can be clearly

[11]For example, by proposing a full information model, Culp and Miller (1995) assert that "most value maximizing firms do not, in fact, hedge."

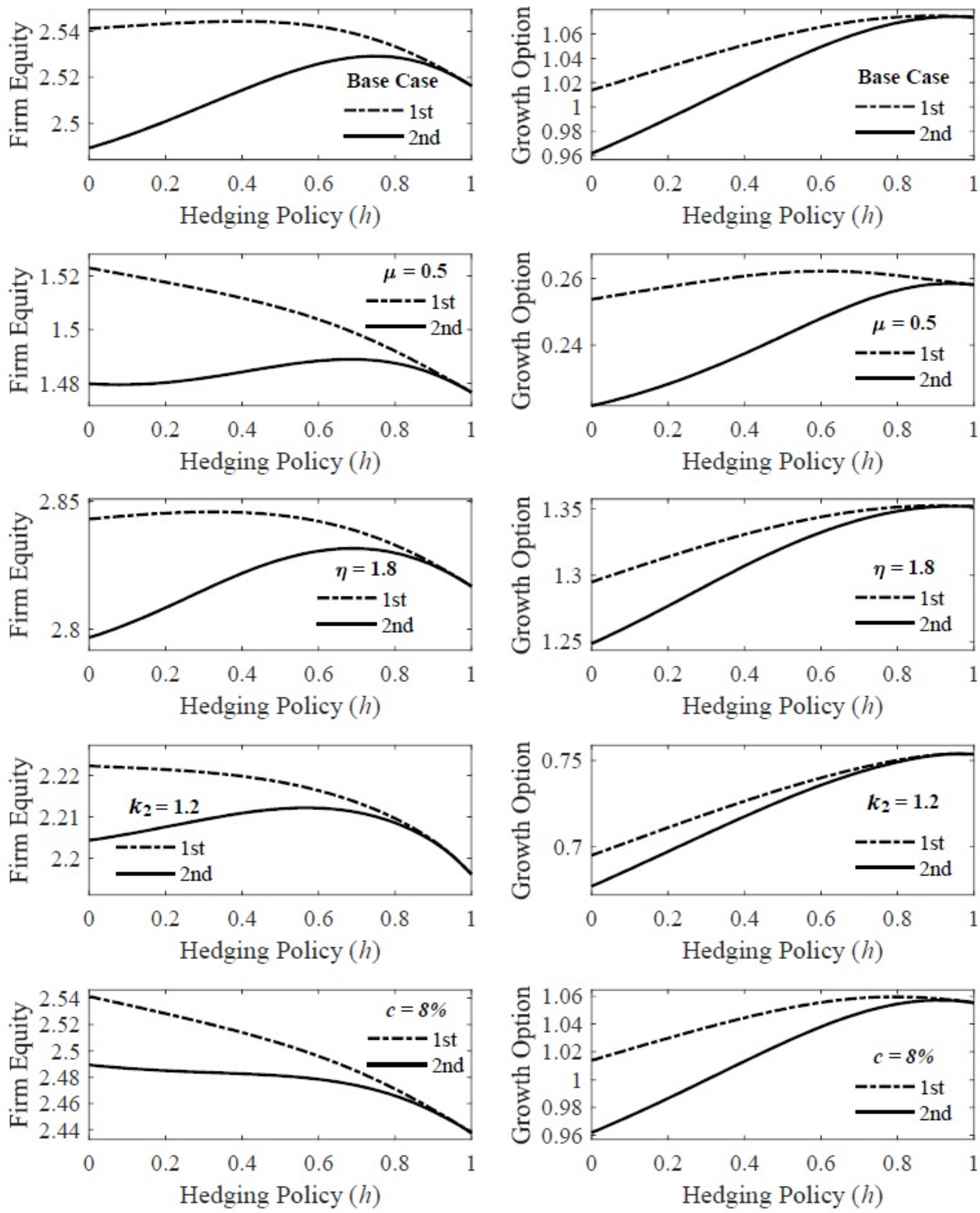

Figure 3.2: **Marginal value of hedging**

Notes: The figure depicts the values of equity and growth option against hedging policy at $t = 0$. The panels on the left plot the equity values, and the panels on the right plot the growth option values. The dash–dotted lines represent the value functions in the complete–information scenario, and the solid lines are the value functions in the incomplete-information scenario. The base–case parameterization is: (i) $\mu = 1.3$, (ii) $\eta = 1.0$, (iii) $k_2 = 1.9$, and (iv) $c = 4\%$.

seen that the firm hedges less aggressively when μ is very low. This is consistent with Breeden and Viswanathan (2016) that firms, or executives, with low qualities do not hedge. The third row shows that both firm equity and growth option values are lower than the baseline model, given η is higher than its base-case setting, but the marginal contribution of hedging is not significantly different from the base case. The fourth row illustrates a scenario in which the next-period investment costs less capital than in the base case so that the firm is more likely to finance the investment by internal reserves. Not surprisingly, the firm does not hedge if information is symmetric, but hedges if information is asymmetric, showing that the transparency-enhancing effect of hedging is overwhelming. In the bottom row, the hedging cost is much higher than its base-case setting, and as expected, hedging is suboptimal because it imposes higher opportunity cost, making capital input scarcer.

3.3.2. Policy functions

In this section, I examine the hedging policy function, h_1^*. Figure 3.3 sketches the optimal hedge ratio on the vertical axis to a particular parameter on the horizontal axis. The baseline parameterization is identical to that used to construct Figure 3.2. We let each of the estimated parameters take values in a range whose center is roughly its baseline setting: $\mu \in [0.5, 2.1]$, $\eta \in [0.2, 1.8]$, $k_2 \in [1.2, 2.6]$, and $c \in [0, 0.08]$.

Five remarks are in order. First, looking across the four panels, despite it can be achieved, perfect immunization against the exogenous risk is usually not optimal. In a sense, this is akin to some standard theories that firms maximize the values of their assets by leaving, at least part of, their profits unhedged. For example, the closed-form optimal hedging ratios in Bolton, Chen, and Wang (2011) and Bolton, Chen, and Wang (2013) imply that partial hedging strategies could be de facto optimal.

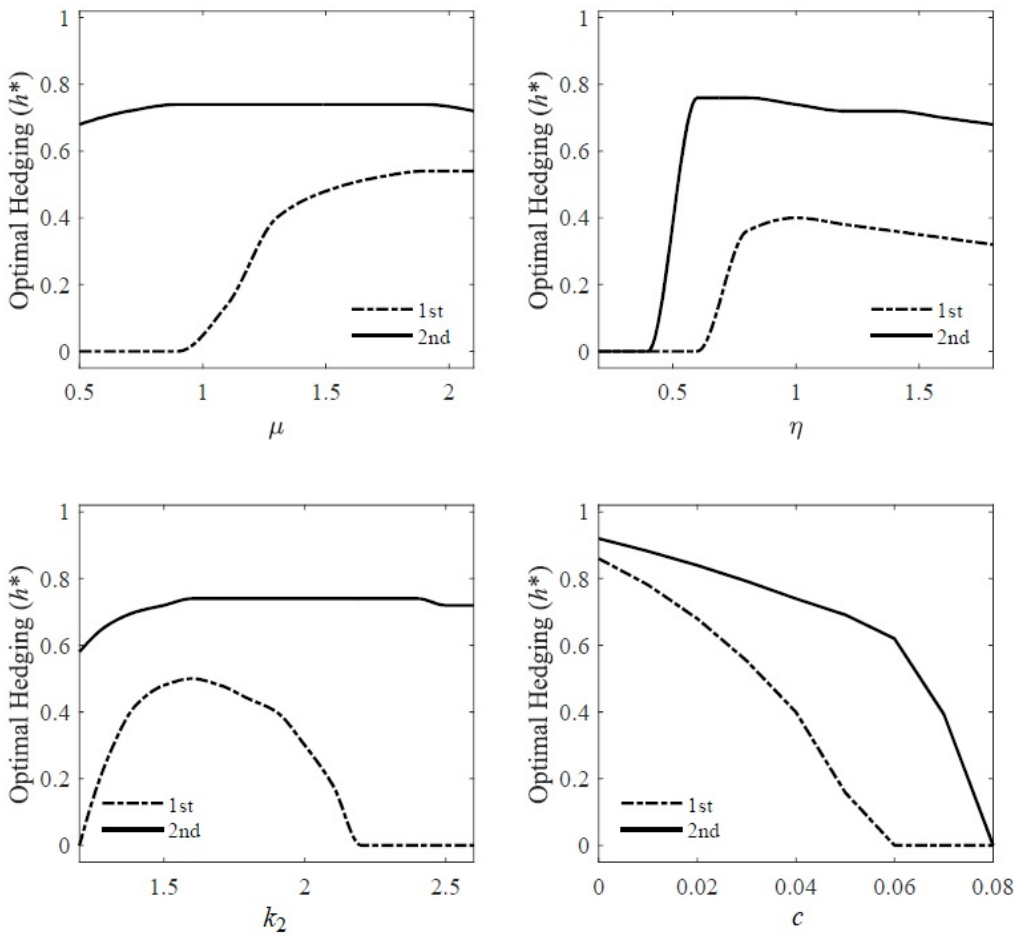

Figure 3.3: **Hedging policy functions**

Notes: The figure depicts the optimal policy of hedge ratio, h_1^*, in response to the *ex–ante* profitability of the firm μ, the unconditional volatility of profitability η, the scale of new project k_2, the hedging cost factor c, respectively. The dash–dotted lines are optimal hedging policies for the complete–information model, while the solid lines are optimal hedging policies for the incomplete–information model. The base–case parameterization is: (i) $\mu = 1.3$, (ii) $\eta = 1.0$, (iii) $k_2 = 1.9$, and (iv) $c = 4\%$.

Second, in the complete–information model, the hedging incentive increases with the *ex–ante* profitability. Intuitively, a high-expected-net-worth firm has large μ and sufficient financing for the new project in most, but not all, cases. Hedging is thus desirable for such a firm because it increases the cash flow in bad states, in which investment would otherwise be less possible, and meanwhile preserves the level of internal funds in good states. In contrast, smaller μ implies lower expected net worth at $t = 1$ for the firm, and hedging effectively moves cash away from good to bad states. As a consequence, hedging is actually value-destroying, and higher risk exposure is optimal at low net worth as suggested by Rampini and Viswanathan (2010) and Rampini and Viswanathan (2013). This result is also consistent with empirical observations in Rampini, Sufi, and Viswanathan (2014), without relying on the potential financing needs and the costs of risk management.[12] The positive relation between μ and h_1^* is less obvious for the incomplete–information model, showing that informativeness concern dominates in this case.

Third, it is interesting that hedge ratio responds sharply to small η but then decreases gradually with large η. The intuition behind the results revolves around the main idea that hedging policy depends critically on the uncertainty of profitability shock which is also a measurement of the severity of informational asymmetry. Overall, the complete–information function shows that firms with safe assets (very small η) choose to hedge more aggressively than firms with risky assets (large η), which coincides with Babenko and Tserlukevich (2017). The incomplete-information function, however, is more informative. Intuitively, as η rises, the firm is more likely to observe an extreme realization of the profitability shock and thus more likely to be misvalued. In turn, the firm is more motivated to reveal its true profitability if there is a server concern that its issued equity is undervalued. On the other hand, when effective hedging eliminates the noise from the firm's cash flow, outsiders' perceptions

[12]In fact, Rampini, Viswanathan, and Vuillemey (2017) empirically study the financial hedging activities in financial industry and draw a conclusion that less constrained institutions hedge more, which is reversing from the evidence found by Rampini and Viswanathan (2013).

of θ are more sensitive to the firm's realized performance at $t = 1$, as DeMarzo and Duffie (1995) assert. In other words, by effectively hedging, the firm eventually exposes more on the unhedgable profitability shock, which is to the detriment of the firm, especially when η is large. As a consequence, large η destroys the incentive for effective hedging.

Fourth, I consider the parameter k_2 that governs the scale of the next-period investment opportunity. In the complete–information case, the firm's optimal hedging policy is of a bell shape rather than a monotonic relation as in Rampini and Viswanathan (2010). This is because in my model, the strike price of investment is exogenously given as k_2, while the up–front investment is endogenously determined in Rampini–Viswanathan model. In other words, the key decision at $t = 1$ made by the firm in my case is on whether or not to invest, whereas the key decision made by the firm in Rampini–Viswanathan case at $t = 1$ is on how much to invest. However, in the incomplete-information scenario, overall, the optimal hedging ratio for each firm is monotonically increasing with k_2. Intuitively, it suggests that financing needs override hedging costs and subsequent concerns. That is, when the firm may only be able to seize expansion opportunity by external financing as a result of (relatively) low net worth, the optimal action could be taken by the firm is minimizing external financing cost, which can be achieved by hedging to reduce the cash-flow noise. Therefore, I expect that companies holding large-scale investment options but having severe informational asymmetry problem would hedge more aggressively.

Finally, the right–bottom panel in Figure 3.3 indicates a negative relationship between the firm's hedging incentive and the hedging cost. Not surprisingly, when hedging actions are too costly, the firm's incentive for hedging is completely eliminated. The complete–information policy function responds more sharply to c than the incomplete-information model. Intuitively, this is because the firm has incentive for using hedging instruments to alleviate the informational asymmetry problem in the incomplete–information case, whereas the problem and the consequent hedging incentive never occur in the symmetric-information case.

3.3.3. Summary of model predictions

According to the stylized model, corporate incentive for hedging or risk management is a trade–off between the risk–shifting and the risk–avoidance effects, which is consistent with Purnanandam (2008).[13] However, Purnanandam mainly focuses on the risk management caused by the presence of financial distress costs, whereas the model suggests that firms' hedging motivations are essentially provided by potential financing needs and the subsequent costs of hedging. As a consequence, the predictions of my model have some empirical implications that differs from Purnanandam (2008). I highlight four important predictions as follows.

First, ceteris paribus, firms with stronger abilities to generate incomes engage in financial hedging more aggressively because they are less likely to be financially constrained. As a result, the model predicts a positive relation between the firm's hedging decision and its profitability, or ability to generate incomes.

Second, corporate incentives for hedging are positively related to the severity of informational asymmetry problem, or the severity of potential adverse selection, facing the firm.[14] However, the model predict a decreasing marginal effect of the severity of informational asymmetry on hedging incentives, since the firm would enjoy potential over–valuation in extreme cases.

Third, the firm's potential financing needs positively affects its hedging in-

[13]See risk-shifting models such as Jensen and Meckling (1976) and Babenko and Tserlukevich (2017), and risk-avoidance models such as Smith and Stulz (1985) and Froot, Scharfstein, and Stein (1993).

[14]Fauver and Naranjo (2010) empirically examine the association between firms value and derivative usage when firms have monitoring concerns. Unlike their work that focuses on how hedging affects firms value, the interest is mainly on how likely firms hedges.

centive. Firms with financial needs would incur issuance costs (including adverse selection costs) when they raise funds externally.[15] In turn, firms with more expansion opportunities and severe informational asymmetry concerns are expected to be of higher incentives for hedging. This prediction is due to two reasons: (i) hedging can help them avoid costly external financing; and (ii) hedging increases their financial transparency and so reduces the adverse selection costs when they issue securities.

Fourth, the inevitable costs imposed on the firm by hedging activities reduces the firm's hedging incentive. A related empirical paper discussing hedging costs and associated incentives is by Acharya, Lochstoer, and Ramadorai (2013). However, their insight is on the commodity market and commodity futures market, which falls outside this research scope.

3.4. Empirical evidence and discussions

This section begin with discussing the sample construction and data collection procedure, and empirical results follow these discussions. I test the key predictions of my theory by examining commodity price hedging activities in the oil and gas (OG) industry. The data sample is based on hand–collected information from the United States OG firms' 10–K Securities and Exchange Commission (SEC) filing. The OG industry offers an excellent laboratory for the following reasons. First, as in my model, the commodity (i.e. crude oil and natural gas) price volatility represents a major source of cash flow risk for OG firms. Second, more detailed data on the extent of financial hedging are available from OG firms' 10–K SEC filings than from those for other firms. In particular, the time–series dimension of my panel data on the extent of financial hedging, as opposed to only data on whether or not firms hedge, allows me to study the within–firm relation between hedging activity and focused

[15]Normally, external financing is expensive to firms, see Hennessy and Whited (2007).

quantities. Third, OG firms are required to disclose their annual production volume as well as total proved underground reserves of crude oil and natural gas, which provides an ideal proxy of the firm's growth potentials. Fourth, focusing on one industry holds constant characteristics of the economic environment that vary across industries. In particular, this sample selection limits my analysis to only those firms that have well–defined exposures to oil and natural gas prices risk.

3.4.1. Sample selection and hedging data

I draw my data sample based on the U.S. companies in the intersection of Compustat and CRSP. An OG firm is defined as any company that has reported a Standard Industrial Classification (SIC) code of 1311 or 1382 on a 10–K filing from 2009 through 2018. The sample period is chosen because, from 2009, most OG firms adopted a revision to ASC 815 "Derivatives and Hedging" which requires more detailed information about hedging transactions including the location and effect on the primary consolidated financial statements. Since I rule out the bankruptcy effect in my theoretical model, I only choose firms that are solvent during the period 2009–2018.

Next, I collect the accounting information of all the selected OG firms from Compustat's Fundamentals Annual File and CRSP's Monthly Stock File. I exclude the firm-year observations whose annual sales amount below \$7.5 million.[16] Dolde (1993) and Nance, Smith Jr, and Smithson (1993) suggest that such small firms are very unlikely to use financial derivatives for hedging purposes due to the lack of economies of scale, which falls out of the scope of this chapter. Furthermore, I remove all observations with missing values for total assets, the gross capital stock value, market value, total sales, and stocks monthly closing prices.

[16] In the United States, the Small Business Administration generally specifies a small business as having less than \$7.5 million in annual revenues. See details on https://www.sba.gov/.

For the remaining firms, the information on their annual production volume, nominal hedging volume, and total proved reserves are hand-collected from the 10–K report archived in SEC's EDGAR database. OG firms are required to disclose their production and proved reserves each year, measured at barrels of oil equivalence (*boe*) or thousand cubic feet of natural gas equivalence (*mfce*), in the beginning section of 10–K reports.[17] I obtain the financial hedging data by by searching the entire 10–K filings for the following text strings: "hedg", "derivative", "instrument", "nominal", and "commodity price risk". If a reference is made to any of these key words, I read the surrounding text to obtain the nominal volume data on commodity derivatives. If the firm's hedge ratio is available in the context, the ratio will be used directly. If the firm only discloses the nominal volume hedged, its hedge ratio is then computed as the nominal volume scaled by its production volume. If the firm claims that its hedging activity is ineffective, the firm-year observation will be classified as a non-hedger with zero hedge ratio. Examples of OG firms' disclosures about various mechanisms for commodity price hedging are shown in the Appendix 3.6.3. If there are no references to the key words, the firm-year observation will be removed. My methodology of collecting the data is similar to Carter, Rogers, and Simkins (2006) and Purnanandam (2008).

Finally, I drop off firms having hedging data for less than five years, as I study only firms that remain in the sample for a sufficiently long period. This restriction allows me focus on within–firm variation. Observations with over 100% hedge ratios are removed in order to rule out speculation incentives. After the above screens, the data sample I use in the analysis covers 62 OG firms for a total sample of 557 firm–year observations.

[17] In computing *boe*, natural gas is converted to equivalent barrels of oil using a ratio of six thousand cubic feet to one barrel of oil, i.e. 1 *boe* = 6 *mfce*.

				Percentiles				
	N	Mean	Std.Dev.	Min.	25th	50th	75th	Max.
Hedge Ratio	557	0.396	0.307	0.000	0.101	0.396	0.621	1.000
Volume hedged (mmboe)	557	19.72	35.46	0.000	0.720	5.277	20.54	248.3
Production (mmboe)	557	69.17	121.9	0.106	4.270	17.63	74.00	883.0
Proved reserves (mmboe)	557	772.2	1301	2.040	52.85	221.7	997.0	8921
Total assets ($b)	557	10.79	19.89	0.031	0.590	2.758	11.39	156.3
Sales revenue ($b)	557	4.515	15.40	0.008	0.155	0.703	2.680	67.11
EBIT ($b)	557	0.199	2.632	−19.10	−0.087	0.027	0.337	18.56
Market value ($b)	557	8.521	15.42	0.002	0.350	2.002	9.447	97.44
Book value ($b)	557	4.894	9.170	−0.872	0.206	1.197	4.669	65.22
Bid-ask spread	557	0.075	0.511	0.005	0.010	0.013	0.021	5.007
Leverage	557	0.399	0.386	−0.536	0.248	0.357	0.497	2.032

Table 3.1: **Summary Statistics**

Notes: The table presents the summary statistics at the firm-year level for the 62 oil & gas companies in the sample. *Hedge ratio* is collected directly from 10–K SEC filings, or computed by nominal volume hedged divided by total production volume of the year. *Volume hedged* stands for the nominal volume of crude oil equivalence hedged via financial derivatives, collected directly from 10–K SEC filings. *Production* represents the annual production volume of oil equivalence, collected directly from 10–K SEC filings. *Proved reserves* represents the volume of the proved reserves of oil equivalence, collected directly from 10–K SEC filings. The unit *mmboe* stands for millions of barrels of oil equivalence. *Total assets* is in billion dollars, measured by Compustat item AT divided by 1000. *Sales revenue* is in billion dollars, measured by Compustat item SALE divided by 1000. *EBIT* is the earnings before interests and taxes in billion dollars, measured by Compustat item EBIT divided by 1000. *Market value* is in billion dollars, measured by Compustat item MKVALT divided by 1000. *Book value* is in billion dollars, measured by Compustat item SEQ divided by 1000. *Bid–ask spread* is the mean of monthly bid–ask spread of the year, based on CRSP's Monthly Stock File. *Leverage* is the leverage ratio, measured by total liabilities and total assets net of cash.

Table 3.1 presents the summary statistics as well as the definitions of Compustat-based variables. Across 557 observations, the average fraction of each year's production hedged is 39.62%, which is exactly the median of the distribution. The nominal volume of oil equivalence hedged is 19.72 million *boe* on average. The average production volume is 69.17 million *boe* and the average proved reserves is 772.21 million *boe* each year, implying that the crude oil equivalence reserves is approximately 11 times as much as production, for the OG companies in the sample.

3.4.2. Explanatory variables

I consider empirical proxies for the explanatory variables on the right-hand side of my regression, motivated by prior literature. First, I measure a firm's profitability by using the earnings before interests and taxes (Compustat item: EBIT) to lagged market value (Compustat item: MKVALT) ratio, i.e. *ROE*. As documented by Foster, Haltiwanger, and Syverson (2008), such revenue–based output measures are ubiquitous and standard in micro-data.[18] Indeed, the firm's profitability θ in the theoretical model, conceptually, refers to as the traditional revenue–based profitability combining both technological efficiency of the firm's plants or labour and the impact of market demands or prices. Prior literature, Asplund and Nocke (2006) for example, suggest that businesses with higher revenue, and thus with higher revenue–based profitability, are more likely to survive in the market. I, hence, employ this revenue–based measure of profitability as a measure of a firm's ability to generate revenues.

Second, I employ a firm's market liquidity, i.e. the percentage bid–ask spreads of individual equity securities traded in capital markets, as a proxy for informational asymmetry. Prior empirical studies use (percentage) bid–ask spreads to mea-

[18]Foster, Haltiwanger, and Syverson (2008) precisely compare revenue–based profitability measures with measures of physical efficiency, which is beyond the scope of my study.

sure firms' informational asymmetry and suggest that accounting disclosure positively links to (percentage) bid-ask spreads as well as their informational asymmetry problems.[19] Similar to prior studies, I define the annual percentage spread as

$$persprd = \frac{1}{12}\sum_{t=1}^{12}\frac{ask\ price_t - bid\ price_t}{(ask\ price_t + bid\ price_t)/2} \times 100, \tag{3.7}$$

which considers the closing ask price and the closing bid price of each month of a firm's calendar year, respectively. Unlike other accounting information, the data of market liquidity are obtained from CRSP Monthly Stock File.

Third, I use the proved reserves to production ratio (*growth*) as a proxy for a firm's growth potential each year. It measures how many years remaining underground reserves can be exhausted if the company keeps the current drifting speed without discovering new fields. Earlier studies including Purnanandam (2008) use market-to-book ratio (*mtb*) as a control variable for a firm's growth opportunities. I use the Compustat items (CSHO×PRCC_C) scaled by the Compustat item SEQ to construct the market-to-book ratio for the firms in the sample. However, market-to-book ratio is also taken as a measure of firm value in several corporate finance studies, and firm value may itself depend on hedging decision in my case. Hence, I rather use market-to-book ratio as an alternative control variable for measuring the scarcity of the firm's capital input.

Fourth, I use net worth (Compustat item: SEQ) to total assets (Compustat item: AT) ratio as an inverse proxy for the cost of hedging. Rampini and Viswanathan (2010) show that purchasing hedging instruments is more costly for firms with low net worth due to their collateral scarcity, which is empirically supported by Rampini, Sufi, and Viswanathan (2014) using airline companies' hedging data. In my model, scarce capital implies costly hedging activities, in line with Rampini and Viswanathan's

[19]See Venkatesh and Chiang (1986), Welker (1995), Affleck-Graves, Callahan, and Chipalkatti (2002), Kanagaretnam, Lobo, and Whalen (2005), and among others.

model setting. Thus, following Rampini, Sufi, and Viswanathan (2014), I expect that the net worth to assets ratio has a positive relation with hedging incentives.

Moreover, I use the ratio between total liabilities and total assets net of cash to proxy the firm's leverage. Purnanandam (2008) shows that leverage is an important positive effect on commodity hedging activities. Also, I use the natural log value of the firm's sales revenues (Compustat item: SALE) to capture the pursuit of economies of scale, as in Dolde (1993) and Purnanandam (2008). Prior literature, Dolde (1993) for instance, suggests that large firms are the majority of derivatives users (exclusive of financial firms). In addition, I use Whited-Wu (WW) index as a control variable measuring the firm's financial constraint. As in Whited and Wu (2006), the WW index is computed as

$$\begin{aligned} WW_{i,t} = & -0.091 CF_{i,t} - 0.062 DIVPOS_{i,t} + 0.021 TLTD_{i,t} \\ & - 0.044 LNTA_{i,t} + 0.102 ISG_t - 0.035 SG_{i,t}, \end{aligned} \tag{3.8}$$

where $CF_{i,t}$ is the ratio of cash flow to total assets, $DIVPOS_{i,t}$ is an indicator that takes the value of one if the firm pays positive dividends, $LTLD_{i,t}$ is the ratio of the long-term debt to total assets, $LNTA_{i,t}$ is the natural log of total assets, ISG_t the OG industry sales growth, and $SG_{i,t}$ is the firm's sales growth.[20] As a financially constrained firm is conjectured to have lower ability to access financial market, the WW index is expected to have a negative effect on hedging.

[20]In this chapter, $CF = (IB+DP)/AT$ is the income before extraordinary items plus depreciation to total assets. $DIVPOS$ equals one if the total dividends $DVT > 0$. $TLTA = DLTT/AT$ is the long-term debt to total assets. $LNTA = log(AT)$. ISG is computed based on the sum of sales of all the firms with 3-digit SIC code 131. $SG_{i,t} = SALE_{i,t}/SALE_{i,t-1} - 1$ is the firm's current sales divided by the lagged sales minus one.

3.4.3. Univariate tests

Table 3.2 provides the descriptive statistics for the explanatory variables across hedgers and non–hedgers. To prevent outliers from affecting my empirical analysis, all explanatory variables are winsorized at 1% from both tails. In Panel A, I report the number of sample firms that use financial derivatives for hedging purposes and the number of sample firms that do not hedge. In Panel B, I present the mean characteristics, with the standard errors in parentheses, for hedger and non–hedger groups as well as the entire sample. In the last column I provide *p*–values for differences in variables between hedger and non–hedger groups. I explore these effects more carefully in the multivariate regression models.

Through the univariate tests, I find that the hedgers have significantly different characteristics from the non–hedgers. First, the hedgers are overall more profitable than the non–hedgers. Second, the hedgers are significantly larger, maturer firms, as expected. In particular, firms using financial hedging instruments have significantly higher total sales (*sale*) and smaller market-to-book ratios (*mtb*). Third, the hedger firms have higher net worth ratio (*nwbv*), consistent with the findings of Rampini, Sufi, and Viswanathan (2014). Fourth, the hedgers have higher leverages, in line with Purnanandam (2008). Fifth, the WW index (*WW*) shows that hedgers are overall less financially constrained as compared with the non-hedgers. Sixth, surprisingly, hedgers have lower average percentage bid–ask spread (*persprd*) and lower growth potential (*growth*). However, the standard deviations of non–hedgers' *persprd* and *growth* are much larger than that of hedgers. Thus, I include variables capturing the marginal effects of *persprd* and *growth* in the main regression model.

	Non-hedgers	Hedgers	All	p-value
Panel A: Identifications				
Number of observations	98	459	557	–
Panel B: Characteristics				
ROE	$-.0312$	0.0106	0.0032	0.0088
	(0.0204)	(0.0068)	(0.0067)	–
persprd	0.7142	0.2305	0.3156	<0.01
	(0.1056)	(0.0269)	(0.0299)	–
growth	32.62	14.08	17.34	<0.01
	(5.388)	(0.3174)	(1.024)	–
nwbv	0.4180	0.4902	0.4307	0.0208
	(0.0126)	(0.0485)	(0.0135)	–
sale	-1.673	$-.0783$	$-.3591$	<0.01
	(0.2052)	(0.0873)	(0.0845)	–
mtb	2.252	2.037	2.074	0.2696
	(0.3978)	(0.1378)	(0.1332)	–
lev	0.2437	0.4276	0.3952	0.0387
	(0.0565)	(0.0132)	(0.0150)	–
WW	$-.3001$	$-.3930$	$-.3767$	<0.01
	(0.0132)	(0.0053)	(0.0052)	–

Table 3.2: **Descriptive Statistics**

Notes: The table presents the descriptive statistics at firm-year level for the 62 oil & gas companies in the sample. The sample is constructed based on Compustat Fundamental Annual File and CRSP Monthly Stock File. Panel A provides the number of sample firms that use financial derivatives for hedging purposes between 2009 to 2018. Panel B exhibits the mean characteristics, with the standard errors in parentheses, for hedger and non-hedger groups as well as the entire sample. The last column reports p-values for differences in variables between hedger and non-hedger groups. In the first column of Panel B, *ROE* stands for the EBIT to lagged market value, EBIT/MKVALT(lagged); *persprd* stands for the annual percentage bid-ask spread of the firm's equity securities traded in capital markets, computed as in equation (3.7); *growth* represents the proved reserves to production ratio of the firm; *nwbv* is the net worth to total asset ratio, SEQ/AT; *sale* represents the log of total sales in billion U.S. Dollar, log(SALE/1000); *mtb* stands for the market-to-book ratio, (CSHO$\times$PRCC_C)/SEQ; *lev* stands for the leverage, (DLTT+LCT$-$CH)/(AT$-$CH); *WW* represents the Whited-Wu index, defined as in equation (3.8).

3.4.4. Regression analysis

To keep the empirical estimation as tightly linked to the theoretical model as possible, I estimate the following regression to test my theory:

$$\begin{aligned} HR_{i,t} &= \beta_0 + \beta_1 ROE_{i,t} + \beta_2 persprd_{i,t} + \beta_3 persprd_{i,t}^2 \\ &\quad + \beta_4 growth_{i,t} + \beta_5 growth_{i,t}^2 + \beta_6 nwbv_{i,t} + \sum \gamma X_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{3.9}$$

where $HR_{i,t}$ denotes the hedge ratio of firm i at year t, definitions and constructions of focused explanatory variables refer to Section 3.4.2, and X contains relevant control variables. On the left–hand side, HR is the fraction of production hedged by financial derivatives. Our theory predicts a positive relation between a firm's ability to generate incomes (ROE)), information asymmetry (*persprd*), potential of expansion (*growth*), and hedging decision. Therefore, I expect a positive sign of β_1, β_2, and β_4. A large net worth to assets ratio stands for less costly hedging, and thus I expect a positive sign of β_6. Hence, I develop the following four key hypotheses that link the model predictions and empirical setting.

Hypothesis 1: $\beta_1 > 0$ *vs.* $\beta_1 = 0$, i.e. positive effect of *ROE*.

Hypothesis 2: $\beta_2 > 0$ *vs.* $\beta_2 = 0$, i.e. positive effect of *persprd*.

Hypothesis 3: $\beta_4 > 0$ *vs.* $\beta_4 = 0$, i.e. positive effect of *growth*.

Hypothesis 4: $\beta_6 > 0$ *vs.* $\beta_6 = 0$, i.e. positive effect of *nwbv*.

In addition, to capture and investigate the effect of extreme information asymmetry and growth potential on hedging decision, I include $persprd^2$ and $growth^2$ as an additional explanatory variable in the base regression model. As predicted by my theoretical results, I expect negative coefficients for $persprd^2$ and $growth^2$.

	(I)		(II)		(III)		(IV)	
	Est.	t-Stats.	Est.	t-Stats.	Est.	t-Stats.	Est.	t-Stats.
ROE	0.0429***	(2.79)	0.0545***	(3.41)	0.0642***	(3.64)	0.0732***	(3.70)
$persprd$	0.0554	(0.84)	0.0743	(1.12)	0.0093	(0.13)	0.0883	(0.42)
$persprd^2$	−.0109	(−.72)	−.0147	(−0.96)	−.0104	(−.68)	−0.0125	(−.78)
$growth$	0.0051**	(2.53)	0.0043**	(2.09)	0.0061***	(2.86)	0.0046**	(2.39)
$growth^2$	−3.7e−5***	(−3.39)	−3.2e−5***	(−2.91)	−3.0e−5***	(−2.68)	−7.4e−5	(3.04)
$nwbv$	0.4792***	(4.82)	0.4591**	(4.59)	0.4673**	(2.51)	0.4589***	(4.49)
mtb	−.0085**	(−1.97)	−.0078	(−1.77)	−.0065	(−1.48)	−0.0038**	(−1.04)
lev	0.5458***	(6.56)	0.5378***	(6.42)	0.5521***	(6.55)	0.5233***	(5.08)
$sale$	0.0039	(0.31)	0.0106	(0.78)	0.0061	(1.36)	0.0052	(0.80)
WW	0.0142	(0.08)	0.0786	(0.39)	0.0864	(0.43)	0.0899	(0.79)
$persprd \times ROE$					0.1522**	(2.33)		
$persprd \times growth$					−.0030***	(−3.25)		
Year–fixed Effects	No		Yes		Yes		Yes	
Size–fixed Effects	No		No		No		Yes	
R^2	0.1438		0.1613		0.1778		0.1853	
N	557		557		557		557	

Table 3.3: **Firm–level Hedging Policies**

Notes: The table presents the results of regression (3.9) for firms' hedging via financial derivatives. The dependent variable is firms' hedge ratio. The first column states definitions of explanatory variables: ROE stands for the EBIT to lagged market value, EBIT/MKVALT(lagged); *persprd* stands for the annual percentage bid-ask spread of the firm's equity securities traded in capital markets, computed as in equation (3.7); *growth* represents the proved reserves to production ratio of the firm; *nwbv* is the net worth to total asset ratio, SEQ/AT; *sale* represents the log of total sales in billion U.S. Dollar, log(SALE/1000); *mtb* stands for the market-to-book ratio, (CSHO×PRCC_C)/SEQ; *lev* stands for the leverage, (DLTT+LCT−CH)/(AT−CH); WW represents the Whited-Wu index, defined as in equation (3.8). The marginal effect of explanatory variables on hedging along with associated t−statistics are presented. R^2 for OLS regression and the number of observations are provided at the end of the table. Coefficients that are statistically different from zero at the 1%, 5%, and 10% significance level are denoted by ***, **, and *, respectively.

Overall, the regression results are in line with the theoretical arguments. I present the regression results in Table 3.3. In Table 3.3, the first regression, labeled as model (I), is the basic model with random effects for examining my theory. The second regression, labeled as model (II), accommodates year–fixed effects. All observations are clustered into groups based on years. Fixing time effect is important for a sample from oil and gas industry because it isolates the effects of any industry–wide shocks, such as the Gulf of Mexico Oil Spill in 2010 and the Paris Climate Accord in 2016. The third regression, labeled as model (III), further accommodates additional control variables examining the interactions between *ROE*, *growth* and *persprd*. The fourth regression, labeled as model (IV), further accommodates size–fixed effects. Specifically, firms are clustered into three groups based on their total assets, in order to better isolate the effect of economical scale.[21]

First of all, in each regression model, the positive and significant estimated coefficient on *ROE* evidently verifies my first theoretical prediction that a firm's hedging is positively affected by its profitability. This is consistent with the finding of Rampini, Sufi, and Viswanathan (2014) who use operating incomes to lagged assets as an income-based measure and find a positive relation between hedging and firm's income. In regression model (III), I find the coefficient on the interaction of ROE with percentage spread to be positive and significant at 2% level. Notably, including the interaction term does not reduce the significance of β_1. These results support the prediction that information asymmetry would positively interact with profitability effect on hedging.

As expected, the proxy of informational asymmetry, *persprd*, is positive and $persprd^2$ is negative. However, the coefficients are not statistically significant. Purnanandam (2008) uses institutional shareholdings as an inverse proxy of informational asymmetry between firm insiders and outsiders, and finds positive relation between

[21]While within–firm clustering is usually used for regressions with firm fixed–effects, for a sample of firms all from oil and gas industry, cross–firm clustering would be a rather reasonable assumption.

institutional ownership and hedging. In contrast, my finding is consistent with informational asymmetry-based theories, such as Breeden and Viswanathan (2016), that firms with severer informational asymmetry would be more aggressive to hedge. However, the negative sign on $persprd^2$ represents a decreasing marginal effect of annual percentage spread on hedging decision, pointing toward a concave relation between informational asymmetry and hedging of a firm, consistent with the second prediction given by the model.

The third theoretical prediction tells a positive effect of growth options on the likelihood of hedging. From the regressions, I find a positive, but modest, relation between hedging decision and firm's growth opportunities whose coefficient is positive and significant in the first three regression models. This is also consistent with the theory of Froot, Scharfstein, and Stein (1993) and the empirical findings of Geczy, Minton, and Schrand (1997). The negative coefficient on $growth^2$ shows that the hedging incentive decreases with extremely large growth potentials, which is partly in line with the theory of Babenko and Tserlukevich (2017) that growth options could reduce hedging. However, the coefficients on *growth* and $growth^2$ lack of economical significance, which implies a probably more complicated relation *per se* between growth potentials and hedging incentives.

Full information models discussing hedging and growth opportunities, including Froot, Scharfstein, and Stein (1993) and Babenko and Tserlukevich (2017), do not integrate informational asymmetry in the analysis, while incomplete information models of hedging such as Breeden and Viswanathan (2016) rarely coordinate the influence of real growth options. However, the interaction of firm's growth option and informational asymmetry is apparently important for hedging decision. Regression (III) includes the interaction of percentage bid-ask spread and growth potentials. Surprisingly, I find a negative coefficient on the interaction of *persprd* with *growth*. Introduction of this interaction variable does not lower the significance of growth potential. This finding does not support my theoretical prediction that informational asymmetry induces firms with more hedging incentives.

Consistent with Rampini, Sufi, and Viswanathan (2014), I find a positive relation between the net worth to total assets ratio and hedging. This positive relation is both statistically and economically significant. As *nwbv* is an inverse proxy for hedging cost, it is in line with the fourth theoretical prediction that firms with higher hedging costs would be less likely to hedge. Additionally, as the alternative proxies of hedging cost, market-to-book ratio and WW index are negatively related to hedging, although their coefficients lack of statistical significance. Notably, smaller market-to-book also implies mature, fewer growth opportunities. Thus, the negative coefficient on *mtb* holds for the empirical evidence that mature firms with fewer growth options tend to hedge more aggressively, as in Mian (1996), Tufano (1996), Bartram, Brown, and Fehle (2009), and among others.

Following Rampini, Sufi, and Viswanathan (2014), I run regression (IV) in order to isolate within-firm variation in characteristics using firm-fixed effects regressions. Comparing with model (I) and model (II), model (IV) shows that the firm-fixed effects estimates are less significant for most measures, despite of the similarity of the sign and magnitude of the coefficients. It thus suggests that some unobservable firm characteristics might play a role in the significance of the coefficients but are not responsible for the observed relations between firms profitability, information asymmetry, growth potential, hedging cost, and hedge ratio.

3.5. Conclusions

This chapter delves deeper into the reasons for corporate hedging and documents the important explanatory roles played by firm's profitability, growth opportunity, and informational asymmetry. I develop a theory of corporate optimal hedging policy in the presence of external financing frictions and asymmetric information on firm's profitability. The firm's growth option offers future investment opportunity but creates potential external financing needs. Due to information asymmetry between existing shareholders and outside investors of the firm, issuing new equity imposes costs to the firm. The issuance cost of equity financing is endogenously derived based on outside investors' inference process which is crucially influenced by the firm's hedging strategy. The firm's optimal hedging policy, therefore, strategically balances the benefits of less-frequent and less–costly external financing with better ability to finance investment. I show that the attractiveness of hedging to a firm is determined by both the value-enhancing and the transparency-enhancing potential of hedging. My theoretical model provides the basis for my empirical analysis.

My empirical study then examines the key model predictions by using hand–collected panel data on 62 the U.S. oil & gas firms' derivative usage for hedging commodity price risk. I find evidence in support of the theoretical model. First, I find a positive relation between a firm's profitability and hedging activity. Second, a firm's hedging incentive increases with the severity of informational asymmetry but this relation becomes negative for extremely high–level informational asymmetry. In addition, I find that informational asymmetry positively interacts with firms profitability. Third, the relation between growth potential and hedging decision is positive but modest in economical significance, and the marginal effect is negative, implying that extremely large growth opportunity would reduce the firm's hedging incentive. Finally, consistent with the theory and intuition, I show that a firm with less ability to access derivatives market is less likely to hedge by using an inverse proxy of hedging cost.

3.6. Appendix

3.6.1. Proof of Lemma

Proof of Lemma 3.1. Insiders and outsiders share the same prior belief for θ with truncated normal distribution $\mathcal{N}(\mu, \eta^2; 0)$. Hence, the probability density function of θ is

$$f(\theta) = \frac{1}{\sqrt{2\pi}\eta\Phi(\mu)} \exp\left\{-\frac{(\theta-\mu)^2}{2\eta^2}\right\},$$

where $\Phi(\cdot)$ is the cumulative probability of the standard normal distribution. Given that equation 3.3 is publicly observable, the variation of w_1 is entirely due to φ, the volatility of x equals the volatility of $\xi\varphi$. As assumed, $\sigma = 1$, and thus $x|\theta \sim \mathcal{N}(\theta, \xi^2)$, we have

$$l(x|\theta, h_1) = \frac{1}{\sqrt{2\pi}\xi} \exp\left\{-\frac{(x-\theta)^2}{2\xi^2}\right\}.$$

Applying Bayes' Theorem to draw an inference on θ gives

$$\begin{aligned} f(\theta|x, h_1) \propto f(\theta) l(x|\theta, h_1) \exp\left\{-\frac{(\theta-\mu)^2}{2\eta^2} - \frac{(x-\theta)^2}{2\xi^2}\right\} \cdot \chi_{\{\theta>0\}} \\ \propto \exp\left\{-\frac{\eta^2+\xi^2}{2\eta^2\xi^2}\left(\theta - \frac{x\eta^2+\mu\xi^2}{\eta^2+\xi^2}\right)^2\right\} \cdot \chi_{\{\theta>0\}}, \end{aligned}$$

that is

$$\theta|w_1, h_1 = \theta|x, h_1 \sim \mathcal{N}\left(\frac{x\eta^2+\mu\xi^2}{\eta^2+\xi^2}, \frac{\eta^2\xi^2}{\eta^2+\xi^2}; 0\right),$$

which implies that the posterior distribution and the prior distribution share identical parametic form. Hence, refer to Barr and Sherrill (1999) and Jawitz (2004), conditional on the observed information w_1 and h_1, the posterior belief on θ is given as in (3.4), which yields $\lim_{h_1 \uparrow 1} \mathbb{E}[\theta|w_1, h_1] = \lim_{h_1 \uparrow 1} \mathbb{E}[\theta|x, h_1] = \theta$. $\square$

3.6.2. Numerical Methods

In the numerical solution of the two–period model, I use discretization to approximate the continuous state variables, θ and φ. In particular, I let θ and φ take values from intervals whose centers are μ and zero, respectively. For the range of θ, 11 points are equally distributed. For the range of φ, 26 points are equally distributed. The value functions are represented as functions on the grid points, and a piecewise linear interpolation is used when function values on the non–grid points are needed.

The expectation is computed using the Gauss–Hermite quadrature method with $n = 11$ sample points. In the quadrature method, the Gaussian integral is approximated by

$$\int_{-\infty}^{\infty} e^{-y^2} f(y)dy \approx \sum_{i=1}^{n} \omega_i f(y_i),$$

where y_i are the roots of the Hermite polynomial $H_n(y)$ and the associated weights are given by

$$\omega_i = \frac{2^n n! \sqrt{\pi}}{n^2 \left[H_{n-1}(y_i)^2\right]}.$$

In the numerical solution of the model, the optimal hedge ratio is computed through a two–period backward deduction using the optimization functions in Section 3.2 for the complete information case and incomplete information case.

3.6.3. Example Disclosures of Hedging

This appendix provides examples of commodity price hedging disclosures for the U.S. oil and gas companies that use financial derivatives to hedge (see Panel A), use financial derivatives to ineffectively hedge (see Panel B), and do not hedge (see Panel C). The information is collected from the 10–K SEC filings of oil and natural gas producers and illustrates how hedging activities varies by firm based on the firm's hedging mechanisms.

Panel A. Example disclosures from companies that effectively hedge future commodity prices:

- From Consol Energy Inc. 2010's report: "As of December 31, 2010, the total notional amount of the Company's outstanding natural gas swap contracts was 78.2 billion cubic feet. These swap contracts are forecasted to settle through December 31, 2014 and meet the criteria for cash flow hedge accounting."
- From Penn Virginia Corporation 2011's report: "For 2012, we have hedged approximately 47% of our estimated oil production at average floor/swap and ceiling prices of $97.08 and $99.61 per barrel. In addition, we have hedged approximately 32% of our estimated natural gas production at a weighted-average floor/swap price of $5.43 per MMBtu and ceiling price of $6.05 per MMBtu."
- From Unit Corporation 2011's report: "Our qualifying cash flow hedges used in the ceiling test determination at December 31, 2011, consisted of swaps covering 5.0 MMBoe in 2012 and 0.7 MMBoe in 2013. The effect of those hedges on the December 31, 2011 ceiling test was a $22.1 million pre-tax increase in the discounted net cash flows of our oil and natural gas properties."

- From Unit Corporation 2016's report: "For 2017, we have derivative contracts covering approximately 3,750 Bbls per day of oil production. For the first quarter, second and third quarters, we have hedged approximately 105,000 MMBtu per day of natural gas production, and for the fourth quarter, we have hedged approximately 92,000 MMBtu per day of natural gas production. For the first quarter of 2018, we have hedged approximately 60,000 MMBtu per day of natural gas production. For the remainder of 2018, we have to date hedged approximately 20,000 MMBtu per day of natural gas production."

Panel B. Example disclosures from companies that ineffectively hedge future commodity prices:

- From Continental Resources, Inc. 2015's report: "We do not designate any of our derivative instruments as hedges for accounting purposes and we record all derivatives on our balance sheet at fair value. Changes in the fair value of our derivatives are recognized in current period earnings. Accordingly, our earnings may fluctuate significantly as a result of changes in crude oil and natural gas prices and resulting changes in the fair value of our derivatives. ...Our crude oil sales for future periods are currently unhedged and directly exposed to continued volatility in crude oil market prices, whether favorable or unfavorable."
- From Exco Resources, Inc. 2012's report: "We do not designate our derivative financial instruments as hedges and accordingly, do not include the impact of derivative financial instruments when computing the Standardized Measure."
- From Goodrich Petroleum Corporation 2014's report: "We offset the fair value of our asset and liability positions with the same counterparty for each commodity type. ...We have not designated any of our derivative contracts as hedges; accordingly, changes in fair value are reflected in earnings."

- From Marathon Oil Corporation 2011's report: "The fair value of commodity derivatives outstanding at December 31, 2011 was less than $1 million. For these derivatives, hypothetical 10 percent and 25 percent increases and decreases in commodity prices would not significantly impact income from operations ("IFO")."

Panel C. Example disclosures from companies that do not hedge commodity prices:

- From Barwell Industries, Inc, INC. 2017's report: "In fiscal 2017, over 90% of Barnwell's oil and natural gas revenues were from products sold at spot prices. Barnwell does not use derivative instruments to manage price risk."
- From Contango Oil & Gas Company 2010's report: "The Company did not enter into any derivative instruments or hedging activities for the fiscal years ended June 30, 2010, 2009 or 2008, nor did we have any open commodity derivative contracts at June 30, 2010."
- From Murphy Oil Corporation 2016's report: "Except in limited cases, the Company typically does not seek to hedge any significant portion of its exposure to the effects of changing prices of crude oil, natural gas and refined products."
- From Ring Energy, Inc. 2016's report: "In order to reduce commodity price uncertainty and increase cash flow predictability relating to the marketing of our crude oil and natural gas, we may enter into crude oil and natural gas price hedging arrangements with respect to a portion of our expected production. ... As of December 31, 2015, we have not entered into any hedging arrangements with respect to our expected production."

Chapter 4

The Role of Managerial Compensation in Corporate Financial Risk Management

4.1. Introduction

Corporate use of financial derivatives increased exponentially over the last few decades. Firms can use various types of derivatives to hedge the market risk exposures or to speculate on the underlying assets. Current accounting standards require fair value accounting for derivatives in a dedicated account. To some extent, these requirements meet the increasing public demand for information on firms' use of derivative. With separate accounts of hedging activity, the transparency of firm operations is improved, and the knowledge of firm hedge transactions is enriched. However, fair value-based accounting standards for derivatives can also induce managers to engage in hedging strategies that are non–optimal for shareholders, if they could be potentially beneficial from doing so. That is, if shareholders use derivative disclosure to reveal information linked to managers' benefit, it may lead to principal–agent conflict.

Once the fair value of derivatives is observed from managers' disclosure, the performance of derivatives tends to be taken into account when outside investors assess the financial skills and insights of managers. Such evaluation would only depend on the payoff of derivatives rather than the aggregated performance of firm operation. Firm executives compensation (managerial rent) can be then associated with gains and losses from using derivatives. Managers are hence incentivized to take actions in financial market to maximize their compensations rather than firm value.

Recent empirical researches find material effect of derivative gains on managerial rent. For example, Dechow, Myers, and Shakespeare (2010) use data from the SEC, and examine the sensitivity of top executives compensation to securitization gains. Their results show that managements are rewarded for the gains they report, although gains on securitization are uncertain and not fully realized until future periods. It implies that firm managers are rewarded for gains on derivatives based on fair values rather than realized payoff. The authors also suggest that the board of directors of a firm treats derivative gains similar to operational earnings components. Livne, Markarian, and Milne (2011) show that the phenomenon of rewarding managers for derivative performance also exists in financial industry. However, neither Dechow, Myers, and Shakespeare (2010) or Livne, Markarian, and Milne (2011) investigate the effect of derivative loss on executives compensation. This question is supplemented by Manchiraju, Hamlen, Kross, and Suk (2016) who further show evidence that executives cash compensation is significantly sensitive to gains from both hedging and non-hedging derivatives by using a data sample from utility industry. The authors also suggest an asymmetric bonus scheme for derivatives usage, which implies a positive compensation for profitable derivatives but no penalty for any losses on derivatives. Because the data samples in the above two papers are both collected directly from the separate hedging accounts of corporations financial reports, their findings suggest that the information from the hedging account is currently treated as a measurement of top executives' financial performance.

In this chapter, I theoretically explore how managerial rent influences corporate hedging policy under current fair–value based accounting standards for derivatives and how a compensation scheme for gains from derivatives impacts contracting efficiency. The contracting efficiency is defined as the alignment of the interests of manager and shareholders. I also discuss circumstances in which full disclosure could affect severity of the agency issue in different ways. To do so, I propose managerial rent into a dynamic, open-horizon model. In my model, a firm offers a long–term contract to an infinitely lived manager whose wealth can be rarely diversified through outside financial resources. The managerial compensation package comprises equity–based rent and cash–based remuneration. The equity–based rent is in the form of a certain level of access to the firm capital, whilst the cash compensation is an amount of cash bonus rewarded for gains from corporate use of derivatives. The manager is maximizing the present value of his compensation package. It is noteworthy that I do not derive the form of an optimal incentive contract but instead approximate a contract that actually exists in practice and that may or may not be optimal.

The rationale of such an assumption of managerial rent scheme is as follows. Firstly, sharing power of public corporations with managers is quite normal nowadays in order to align the interests of outside equity holders and inside managers. Evidently, agency problems created by the separation of ownership and control can be mitigated by such a mechanism. For example, Tufano (1996) shows that managers tend to substantially hedge firm value if managers own a substantial fraction of equity because the volatility of their wealth is significantly related to the volatility of the equity price. Therefore, it is reasonable in the model to give the manager the right to claim a certain level of the firm's cash flow as an equity holder. Secondly, empirical researches provide an abundance of evidence of the reward mechanism for successful speculation. For example, Géczy, Minton, and Schrand (2007) demonstrate that CFOs in those frequently–speculating firms get a significantly greater amount of bonus than those of CFOs of those firms that less frequently speculate. Manchiraju, Hamlen, Kross, and Suk (2016) find that CEOs' cash compensation is significantly sensitive to gains from non–hedging derivatives. Hence, in the model of this chapter, the manager will get an amount of cash bonus conditional on gains from financial derivatives, which is also reasonable in practice.

The motivation of this work is from the association between reward scheme for profitable derivatives and agency conflict. The aim of my research is mainly to analyze the effect of the managerial compensation mechanism on hedging policy and on any stakeholder's interests. Previous researches using dynamic models mainly focus on the rationale of managing risk and optimal hedging strategy,[1] but a few of them have analysed the managerial incentive to deviate from the optimal hedging ratio for shareholders. Researches discussing agency problems, like DeMarzo and Duffie (1995) compare different levels of transparency of information, but do not well fit current compensation scheme used by most firms. The authors propose a model with a perfect separation of ownership and control, in which manager acts like a normal employee. In practice, however, top managers can usually act both as an executive and a member of the board of directors, which means managerial rent generally comprises both cash–based and equity–based compensations.

The basic idea of this chapter is related to DeMarzo and Duffie (1995) that firm managers may take hedge positions for their own benefits which is possibly not in line with shareholders stake. My model differs from their model especially in terms of the type of contract and managerial compensation scheme. Firstly, in my model, long–term contract is available, which is not in DeMarzo and Duffie's paper. Such a long–term incentive scheme mitigates the importance of reputational considerations for managers. Secondly, I assume the manager holds a certain fraction of access to corporate capital, which is not the case in those two authors' model. This makes my model more practical by allowing the manager to hold both equity–based and

[1] See Bolton, Chen, and Wang (2011), Gamba and Triantis (2014), Rampini and Viswanathan (2010), and Rampini, Sufi, and Viswanathan (2014), for example.

cash–based compensation. Moreover, in my model the cash–based compensation to the manager depends on the performance of financial derivatives solely instead of the firm's aggregated net income.

This chapter builds on the empirical evidence provided by empirical studies that firms reward their managers for profitable derivatives, such as Dechow, Myers, and Shakespeare (2010), Livne, Markarian, and Milne (2011), and Manchiraju, Hamlen, Kross, and Suk (2016). In their studies, the performance of derivatives is directly observed from the separate account of hedging activity required by the current fair–value based accounting standards. Some of my results are in line with the conclusion of Manchiraju, Hamlen, Kross, and Suk (2016) that reward for gains from derivatives can reduce contracting efficiency. My research differs from their work in respect to methodology and baseline model. More specifically, Manchiraju *et al* focus on examining the sensitivity of managers' compensation to derivative gains. This chapter, however, uses a dynamic model to theoretically analyse the association between managerial compensation and risk management policy.

This essay makes at least three contributions to the literature. First, my research extends the work DeMarzo and Duffie (1995) by proposing a more practical managerial incentive scheme. The career contract between the firm and manager includes both equity–based and cash–based compensation, which makes the objective of the firm manager differs from the objective of shareholders in respect of the choice of hedging policy. This has not been previously analyzed. Second, my research provides theoretical support for empirical works depicting managerial incentive for profitable derivatives. I capture the conflict between firm manager and shareholders by using a dynamic model that relieves the manager from the reputational considerations. Thus, my results are believed to be persistent. Third, I explore the association between the cash compensation for fair value based-accounting earnings and contracting efficiency in different situations respectively. To my best knowledge, my research is the first that shows that the degree of the conflict varies among different situations.

The structure of this chapter is as follow. Section 4.2 reviews the prevailing literature that is related to this study. Section 4.3 proposes the theoretical model settings and assumptions. In Section 4.4, the numerical results will be shown, and the conflict between firm managers and outside shareholders will be analyzed. Finally, conclusions and some implications will be summarized in Section 4.5.

4.2. Prior literature

Theoretical researches suggest various managerial incentives for firm managers to use financial derivatives as a hedging tool under fair value based accounting concepts. First is to mitigate the contracting costs caused by agency conflicts.[2] Mayers and Smith Jr (1982) and Mayers and Smith Jr (1987) indicate that thereof contracting costs provides the basis for the demand for insurance of corporations. Managers tend to use financial hedging tools in order to avoid financing restriction. Stulz (1984) further shows that risk–averse managers are more willing to hedge firm value.

Second is to reduce external costs facing firms, and thus, to potentially increase the present value of future cash flows. For example, Smith and Stulz (1985) suggest that firms will generally be beneficial from hedge if taxation is a convex function of earnings. Moreover, Froot, Scharfstein, and Stein (1993) analyze the circumstance in which external resources are more costly than internal funds, and suggest a typical benefit to hedging because it helps firms keep sufficient internal funds when attractive investment opportunities occur. In this way, hedge can reflect the willingness of managers to reduce cash flow volatility, and thus reflects the alignment of the interests of managers and shareholders.

[2] Agency problems in public corporations are mainly created by the separation between ownership and control. See seminal works by Jensen and Meckling (1976) and Fama (1980)

Empirical researches also find results supportive of the fact that fair value based hedge is desirable. For instance, Mian (1996) finds financial derivatives lowers contracting costs and risk associated with equity return. Adam and Fernando (2006) use data from gold mining industry and indirectly demonstrate that firms' derivatives transactions translate into increase in shareholder value. More recently, Bartram, Brown, and Conrad (2011) use data from non–financial firms to examine the effect of derivative use on firms' risk and market values and show a strong and consistent evidence of lower cash flow risk, equity price risk, and systematic risk. Pérez-González and Yun (2013) demonstrate that active risk management leads to a statistically significant increase in firm value by using utility firms as a data sample.

However, researches list above have a basic postulate that interests of managers and shareholders are well aligned. In other words, the firm-wide governance mechanisms are assumed to be perfectly effective. Managers use financial derivatives to hedge firm value just for the purpose of maximizing firm values. In practice, nevertheless, this is not always the truth. Géczy, Minton, and Schrand (2007) demonstrate that frequent speculation of firms is associated with weak firm-wide governance mechanisms. Bartram (2017) finds evidence consistent with that firms use derivatives for both hedging purpose and speculative component.

In fact, on the one hand, researches show that hedge under fair value based accounting provides managers with opportunities for reducing cash flow volatility, and hence reduces contracting costs. On the other hand, reward scheme for gains from derivatives based on fair value accounting gives managers incentives that are not mainly to bring extra benefits for shareholders but for managers' personal interests. For example, DeMarzo and Duffie (1995) propose a model that managers undertake hedging positions and achieve greater risk reduction in order to show their own ability to labour market. Breeden and Viswanathan (2016) also argue that managers are incentivized to hedge firm value to increase their ability to signal their managerial quality. Furthermore, Tufano (1996) empirically shows that new financial managers would have less developed reputation and thus seek to signal their management quality through hedging.

As for the difference in value–adding effect between derivatives designated as hedge and non–hedge, Gamba and Triantis (2014) show that derivatives with effectively large correlation always create greater firm value than derivatives with ineffective correlation do. Consistently, Brown, Crabb, and Haushalter (2006) find evidence that potential economic benefit created by firm selective hedging is negligible. Géczy, Minton, and Schrand (2007) find that firm size of speculators is insignificantly larger than the size of those firms that never speculate. Hence, in a way, it is believed that hedge–designated derivatives increase firm value, while speculation–designated derivatives can rarely do that.[3]

4.3. Model setup

The model in this chapter continues a line of Gamba and Triantis (2014). I consider an unlevered firm (*the firm*) in absence of taxation with the separation of ownership and control in my model. I use a discrete–time, infinite–horizon framework to model the operating process, hedging decisions, and payout policy of a firm. Any cash flows of the firm are obtained at the end of each period when the state is observed. I assume that shareholders hire an expert to manage the firm, since she has better skills in production and financial knowledge. The firm's manager (*the manager*) holds a fixed fraction, $0 < \alpha < 1$, of claim on the firm's cash flow. In practice, a firm may be able to design in a higher α in order to strengthen the manager's incentives or a lower α to increase access to capital. Please note that I do not derive any form of an optimal

[3] Appendix 3.6.3 provides example disclosures from 10–K SEC filings of oil and natural gas companies that effectively and ineffectively hedge risks via financial derivatives. The disclosures meet the requirements of the fair–value hedge accounting criteria.

career contract, but instead, approximate a contract that practitioners use and that may or may not be optimal. Hence, I do not consider any information asymmetry and signaling problems in my model.

4.3.1. Production technology

The market price of one unit of the firm's products is regarded as stochastic, denoted by θ_1. Assuming risk neutrality in this model, the log of this price variable, $x_1 = \log\theta_1$, has the following process:

$$x_{1,t} - x_{1,t-1} = (1-\kappa_1)(\mu_1 - x_{1,t-1}) + \sigma_1\varepsilon_{1,t}, \tag{4.1}$$

where $0 \leq \kappa_1 \leq 1$ is the persistence parameter; $\mu_1 = \log\bar{\theta}_1$ denotes the long–term mean of the log price; $\sigma_1 > 0$ is the conditional standard deviation; and ε_1 denotes the shocks to the log price of products, which are independent and identically distributed standard normal variates. We can think of the risk ε_1 as corresponding to fluctuations in commodity prices, or social demands; and σ_1 is the level of exposure of the firm to ε_1.

Suppose the firm produces one unit of products from its operation in each period for sure. The net cash income from operations in the current period, denoted as $g_t(\theta_1) = g_t$,[4] is thus equal to the revenue θ_1 less the fixed production cost, $f > 0$. That is,

$$g_t = \theta_{1,t} - f. \tag{4.2}$$

Hence, the entire business risk facing the firm's operational income is the fluctuation in its product price. The firm is able to hedge this risk exposure to some

[4]The notation $g_t(\cdot)$ indicates that the value of g at the time t depends on the information $(\cdot)$ available at time t. This will be consistent in all my notations hereafter.

extent by using financial instruments. In addition, the fixed production cost, f, can be regarded as a measure of financial constraints. A higher level of fixed cost rate represents a situation in which the firm is more financially constrained. It is implicitly assumed that a firm could be financially constrained due to various reasons including limitation of productivity, debt outstanding, labour wages, etc. The impact of different levels of financial constraints on the alignment of the interests of the manager and shareholders will be discussed in detail in Section 4.4.2.

4.3.2. Hedging

In financial market, a derivative contract is available to hedge the firm's business risk to some extent. The hedging decision of the firm is made by the manager. The firm can take a certain position in a swap agreement issued by a bank. The underlying asset of the contract has the market price, θ_2, and its log price, $x_2 = \log \theta_2$, follows the stochastic process

$$x_{2,t} - x_{2,t-1} = (1 - \kappa_2)(\mu_2 - x_{2,t-1}) + \sigma_2 \varepsilon_{2,t}, \tag{4.3}$$

where $0 \leq \kappa_2 \leq 1$, $\mu_2 = \log \bar{\theta}_2$, $\sigma_2 > 0$, and ε_2 denotes the independent and identically distributed standard normal variables, in line with the notations of x_1. Here θ_2 is regarded as corresponding to, for example, a market index; and thus ε_2 is corresponding to the fluctuation of price in this index. I denote $\Theta = (\theta_1, \theta_2)'$ as the vector of the exogenous state variables. Thus, each firm in the economy has a certain correlation between its business risk and the fluctuation in this underlying asset price, i.e. $\mathbb{E}_t[\varepsilon_{1,t}\varepsilon_{2,t}] = \rho$, almost surely.[5] This correlation coefficient determines the direction of hedging position. If $\rho > 0$, the firm will only take a long position in the swap contract; whereas if $\rho < 0$, the firm will only take a short position. It is convenient

[5]Note for any $t \neq t'$, $\mathbb{E}_t[\varepsilon_{1,t}\varepsilon_{2,t'}] = 0$.

and without loss of generality to only consider the case in which $\rho > 0$ in my model. Generally, a perfect hedging tool without basis risk (i.e. $\rho = 1$) can rarely be found in practice. Hence, I restrict my analysis to the case in which $0 < \rho < 1$ in order to capture basis risk.

If the firm takes a long position in a swap contract for a notional capital of one dollar, then at the end of period t, the firm will be required to deliver $\theta_{2,t}$ in exchange to receive s, where $s = \bar{\theta}_2$ is a given constant. That is, with a notional physical amount $h_t \in [0, 1]$, the total payoff from the contract at the end of each subsequent date t is $h_t(s - \theta_{2,t})$. Therefore, the par value of the swap for each unit of notional amount excluding counterparty risk and put provision at time t is

$$SP_t(\theta_2, t) = \sum_{i=1}^{\infty} \frac{s - F_i(\theta_2, t)}{(1 + r_f)^i} < \infty, \tag{4.4}$$

where $F_i(\theta_2, t) = \mathbb{E}_t[\theta_2, t + i]$ denotes the price at any time t of delivery the asset at time $t + i$; $\mathbb{E}_t[\cdot]$ is the expectation under the risk-neutral probability, conditional on the information at time t, and r_f is the risk–free rate. The forward price is calculated as follows:

$$F_i(\theta_2, t) = exp\{\mathbb{E}_t[x_{2,t+i}] + \frac{1}{2} var_t[x_{2,t+i}]\} = \theta_{2,t}^{\kappa_2^i} \mu_2^{1-\kappa_2^i} e^{\frac{\sigma_2^2}{2}\frac{1-\kappa_2^{2i}}{1-\kappa_2^2}}.$$

At time $t + 1$, the firm can default on the swap and choose to change the notional amount, for $h_{t+1} \neq h_t$, where $h_{t+1} \in [0, 1]$. Then the firm needs to redeem the current contract at the *par value* and enter into a new position at *fair values.* In the absence of arbitrage opportunity, the fair value of the swap contract, SF_t, must involve both counterparty risk and the option to close the position in the future. For simplicity, I assume that the bank selling the swap is not subject to default risk, and thus the only credit charge is related to the default possibility of the firm. Hence, the fair value of the swap at time t is

$$SF_t = \mathbb{E}_t\left[\sum_{i=1}^{\min\{T_d,T_p\}} \frac{s-\theta_{2,t+i}}{(1+r_f)^i}\right] + \mathbb{E}_t\left[\chi_{\{T_d \geq T_p\}}\frac{SP_t(\theta_2,T_p)}{(1+r_f)^{T_p}} + \chi_{\{T_d<T_p\}}\frac{RS_t(\Theta,t+T_d)}{(1+r_f)^{T_d}}\right], \quad (4.5)$$

where T_d denotes the default date of the firm, and T_p denotes the date the swap position is closed, both stopping times with respect to the process Θ_t. The term $\chi_{\{T_d \geq T_p\}}$ is the indicator function of the event that default happens after the position is closed, and $\chi_{\{T_d<T_p\}}$ denotes the case in which the opposite happens. The bank's recovery value on the swap upon defaults, $RS_t(\cdot)$, depends on the value of the firm at its bankruptcy.

In sum, cash flow rises from any hedging strategy is the sum of the net payoff from the contract and changes in fair value of hedging strategy. Because the cash flow from any derivative transactions is recognized at the end of each period, the realized net cash flow from hedging contract, $w_t(\theta_2, h_t, h_{t+1}, SP_t, SF_t) = w_t$, at time t can be written as

$$w_t = h_t(s-\theta_{2,t}) + \chi_{\{h_{t+1}\neq h_t\}}(h_t SP_t - h_{t+1}SF_t), \quad (4.6)$$

where $\chi_{\{h_{t+1}\neq h_t\}}$ is the indicator function of event $h_{t+1} \neq h_t$.

4.3.3. Cash compensation contract

Under current fair value based accounting standard for hedge, the firm is required to report the net realized payoff and any changes in fair value of the hedging contract to shareholders at the end of each period. Hence, under the accrual accounting concept, the information set disclosed to outside investors at time t is denoted as $\mathcal{I} = \{h_t(s-\theta_{2,t}), h_t SF_t, h_{t-1}SF_{t-1}\}$. Then the observed fair–value gain or loss from the swap contract, $y_t(\theta_2, h_{t-1}, h_t, SF_{t-1}, SF_t) = y_t$, is calculated as

$$y_t = h_t(s - \theta_{2,t}) + h_t SF_t - h_{t-1} SF_{t-1}. \tag{4.7}$$

Manchiraju, Hamlen, Kross, and Suk (2016) show that gains from derivatives (regardless of the hedge designation) are significantly positively related to managers' cash compensation. One explanation is that shareholders treat the performance of derivatives as a signal of the managers' financial skills. Based on this result, it is supposed in my model that the manager will get an amount of cash compensation (or bonus) for the fair–value gains from the hedging contract. This bonus is in the form of an amount of cash conditional on the derivative realized payoff and change in fair value. However, Manchiraju, Hamlen, Kross, and Suk also show that managerial cash compensation is much more sensitive to derivative gains than to derivative losses. Thus, in my model, the manager only get cash bonus from derivative gains but does not incur penalty for derivative loss.

In the base case version of my model, I consider a fixed amount of cash compensation to start with, which is also analogous to the setup in DeMarzo and Duffie (1995). In Section 4.4.4, I will discuss the case in which the cash bonus is linear and concave with respect to the magnitude of derivative gains, respectively. Here, the cash bonus, $z_t(y_t) = z_t$, to the manager for profitable derivatives can be written as

$$z_t = \zeta y_t \chi_{\{y_t > 0\}} \tag{4.8}$$

where ζ denotes a constant fraction of cash bonus accounting for the derivatives' fair–value gain, and $\chi_{\{y_t>0\}}$ is the indicator function of positive profits from derivative tradings at time t. This bonus is classified as one term of employee wages so that it takes priority over any dividends payout and flotation payments. This cash–based compensation scheme can be also regarded as a typical incentive plan consists of zero payment if performance is below a specified threshold, which is consistent with the survey of executive compensation in Murphy (1999). In other words, in my model, the manager only get cash bonus from successful speculation but does not incur penalty from loss on speculation. Recent empirical studies, such as Manchiraju, Hamlen, Kross, and Suk (2016), show supportive evidence that top-executive cash compensation is 70% more sensitive to non–hedge derivative gains than it is to non–hedge derivative losses, which is consistent to my model setup.

4.3.4. Payout policy

The net cash flow to the firm, denoted as $\pi_t(g_t, w_t, z_t) = \pi_t$, in the current period is the sum of net cash flows from operation and hedging contract netting of any cash bonus paid to the manager:

$$\pi_t = g_t + w_t - z_t. \tag{4.9}$$

In this model, π_t can be either positive or negative as a consequence of the profitability and the payoff of hedging contract. Assume the firm has no cash balance, then in the absence of leverage and taxation, shareholders (including the manager who holds α of the firm's equity) receive the net cash inflow at the end of period t, if $\pi_t > 0$. The firm will be in a liquidity crisis if the total net cash flow to the firm is negative, i.e. $\pi_t < 0$. In this case, the firm will raise further equity capital to ensure the operation going forward. In addition to the cash raised for covering the shortfall, shareholders will incur a flotation cost, λ per dollar, of external fund in this case of distress. Therefore, if the net cash flow is negative, shareholders will pay an amount of $(1 + \lambda)\pi_t$ in total. In sum, the net cash flow to equity at the end of period t, denoted as $e_t(\pi_t) = e_t$, is the net cash flow from operation and hedging contract less any managerial monetary compensation:

$$e_t = \max\{\pi_t, 0\} + \min\{\pi_t, 0\}(1 + \lambda). \tag{4.10}$$

Moreover, it is assumed that the manager will always pay her own cash to purchase an equal fraction of the new issued shares in order to avoid a dilution of her power when the firm raises external fund by issuing equity. This would pose an interest conflict between the manager and shareholders because shareholders would actually afford the manager's risky action. For instance, if $g_t + w_t = 0$ but $y_t > 0$, the manager will get a bonus of z_t, resulting in $\pi_t = -z_t$. However, the manager just needs to pay $\alpha(1 + \lambda)z_t$ to prevent the dilution, and shareholders must pay $(1 - \alpha)(1 + \lambda)z_t$, which is actually compensating the manager.

Shareholders have the objective of maximizing the present value of cash flow to equity by choosing an optimal hedging magnitude for next period. If the equity value is negative, shareholders will simply close the firm and leave because of the limited liability. Therefore, the equity value, denoted by $E_t(e_t, h_{t+1}) = E_t$, is

$$E_t = \max\left\{max_{h_{t+1}\in\mathcal{H}}\{e_t + \beta\mathbb{E}_\Theta[E_{t+1}]\}, 0\right\}, \tag{4.11}$$

where $\mathbb{E}_\Theta[\cdot]$ denotes the expectation conditional on the observed current state, Θ_t; and $\mathcal{H}$ denotes the set of all feasible choices of the notional amount of hedging for next period. The outcome of states in next period, Θ_{t+1}, is unknown until the end of period $t + 1$. The discount factor for valuing the equity of the firm is $\beta = 1/(1 + r_f)$, where r_f is the risk–free interest rate in the market. The hedging policy solved from equation (4.11) is regarded as the first–best. Hereafter, the first–best hedging policy will be denoted by h^E for convenience.[6] Note outside shareholders are not able to directly observe or derive h^E unless they can perfectly learn the magnitude of σ_1.

[6]The first–best hedging policy, h^E, can be explained as a hedging policy chosen by an imaginary (ideal) manager who would always perform for the best sake of shareholders, regardless of the type of career contract.

4.3.5. Managerial rent

In line with the previous description, the value of managerial rent is the present value of a combination of the equity–based and the cash–based compensations. As I have already wiped out the reputational concerns by allowing a long–term career contract, the manager would have the objective of managerial value maximization. Hence, the manager tends to choose a hedging magnitude that maximizes the managerial rent. However, as shareholders hold property rights to the assets of the firm, managerial rent will become zero once the operation is shut down by shareholders (i.e. when $E_t = 0$). Hence, the managerial rent, $R_t(e_t, z_t, h_{t+1}) = R_t$, can be written as

$$R_t = \begin{cases} max_{h_{t+1} \in \mathcal{H}} \{\alpha e_t + z_t + \beta \mathbb{E}_\Theta [R_{t+1}]\}, & \text{if } E_t(e_t, h^R) > 0, \\ 0, & \text{if } E_t(e_t, h^R) = 0, \end{cases} \tag{4.12}$$

where β is assumed to be equal to the discount factor for valuing the equity. The term $E_t(e_t, h^R)$ is found as the fixed point of a Bellman equation similar to (4.11), in which the optimization with respect to h^E is excluded, because we apply the manager's optimal response, h^R, to the entire firm and get $E_t(e_t, h^R) = \max\{e_t(h^R) + \beta \mathbb{E}_\Theta [E_{t+1}(e_{t+1}, h^R)], 0\}$. Hence, the equity value is not the one calculated by using the first–best policy for shareholders but the optimal response of the manager. It is expected that the equity value is reduced due to the deviation from equity maximization. Because shareholders hold the property right of the firm, they are always able to close the firm when the value of their equity goes below to zero due to applying the hedging policy h^R.

The owner–manager case ($\alpha = 1$) coincides with a special case of the more general case of separation between ownership and control. Setting $\alpha = 1$ not only perfectly aligns the interests of the manager and shareholders, but it also reduces the cash–based compensation to zero. The proof of the case in which $E_t(h^R) = 0$ can be easily seen as $R_t = 0$. The proof of the case in which $E_t(h^R) > 0$ is as follows:

$$\begin{aligned} R_t &= max_{h_{t+1}\in\mathcal{H}}\{\alpha e_t + z_t + \beta\mathbb{E}_\Theta[R_{t+1}]\} \\ &= max_{h_{t+1}\in\mathcal{H}}\{(g_t + w_t - z_t) + z_t + \beta\mathbb{E}_\Theta[R_{t+1}]\} \\ &= max_{h_{t+1}\in\mathcal{H}}\{g_t + w_t + \beta\mathbb{E}_\Theta[R_{t+1}]\}, \end{aligned}$$

whose solution h^R is equal to the first–best hedging ratio h^E. This makes this special case equivalent to the owner-manager case, in which any agency problem is ruled out.

The expression of R_t in equation (4.12) demonstrates the incentive scheme in my model, comprising two parts. First, αE_t presents a natural alignment of the interests of the manager and shareholders. By giving the manager the ability to capture cash flow, her wealth is directly related to the aggregated performance of the firm. Second, z_t presents an encouragement of keeping a positive value in financial derivatives. This cash–based compensation fits the empirical evidence that shareholders are rewarding managers who have high financial ability and insight.

Meanwhile, equation (4.12) also shows that the manager distorts the first-best hedging decision. A difference between h^R and h^E implies an agency conflict between the manager and shareholders in respect of the choice of hedging policies, and thus causes a reduction of contracting efficiency, which is the fundamental tension in this research. Essentially, the conflict is caused by the cash bonus for profitable derivatives, as a consequence of treating the derivative performance as a measure of the manager's financial skill. The cash–based reward induces the manager to increase the expected fair value of derivatives by deviating from the first–best hedging ratio. Therefore, I make te following prediction: With a compensation scheme for profitable derivatives, the actual hedging ratio chosen by the manager may differ from what benefits shareholders most.

4.4. Numerical Results

In this section, I will explore and discuss the impact of the incentive scheme on the contracting efficiency. The degree of efficiency is determined by comparing the actual equity value with the first–best equity value, that is, $E_t(e_t; h^R)/E_t(e_t; h^E)$. The agency conflict is observed if there exists a difference between the equity value with h^R adopted by the manager and the equity value with the first–best hedging ratio h^E. The numerical technique is an iterative method for solving a Bellman equation with a bivariate-normal specification for the state transitions, following Tauchen (1986) and Terry and Knotek II (2011). Details of the numerical procedure are provided in Appendix 4.6.1. In this chapter, I present a calibrated model to obtain results that help to explain existing evidence, and to provide further implications.

4.4.1. The misalignment of interests

The baseline parameters for the firm's production and the underlying asset of hedging contract are shown in Table 4.1. The rationale for the parameter choices of business risk and hedgeable risk is in line with Gamba and Triantis (2014), corresponding to some typical values found in existing literature.[7] It is noteworthy that the correlation coefficient, ρ, measures the ability of the firm to hedge its business risk exposure using financial derivatives. The risk exposure to θ_1 is considered as the main motivation for hedging. However, in practice, firms always face many kinds of risk that cannot be fully hedged by a single derivative contract. For example, Bartram, Brown, and Minton (2010) find that, despite financial hedging can significantly reduce foreign exchange exposure for a global sample of manufacturing firms, these firms would still face many other risks that are not as readily hedgeable. Consistently, Guay and

[7]See Gamba and Triantis (2014) for details.

Kothari (2003) suggest that corporate derivative use has very modest effect. The lack of derivative instruments that closely track entire risk exposure is considered as one key reason why the ability of hedge to reduce firm's cash-flow volatility is not economically significant. Here I use a general formulation in my model rather than breaking down various types of risk that can or cannot be hedged, and thus, the correlation between the derivative contract and the hedged item is believed to be quite low.

μ_1	long–term mean of product log price variable	0
μ_2	long–term mean of underlying asset log price variable	0
σ_1	Annual volatility of x_1	15%
σ_2	Annual volatility of x_2	15%
κ_1	Persistence of x_1	0.8
κ_2	Persistence of x_2	0.8
ρ	Correlation Between product price and swap	0.1
f	Fixed production cost	0.97
s	Swap price (fixed rate)	1.0
r_f	Annual risk-free interest rate	5%
λ	Flotation cost rate for equity issuance	5%

Table 4.1: **Baseline Parameter Values**

My analysis starts with a firm whose equity shares are partly held by its manager. The fraction of equity held by the manager, α, represents the level of managerial ownership. Empirical estimations on managerial ownership in real world show that firm managers on average own small fractions of the firm equity. For example, Jensen and Murphy (1990) find managerial compensation has a very weak relation with firm equity value. More recently, in Nikolov and Whited (2014), the estimated result demonstrates that the lower quartile, the median and the top quartile of the fraction of equity shares excluding options are 0.3%, 0.8% and 2.8%, respectively. Therefore, in my estimation, the parameter α ranges from 0.3% to 2.8%. In addition, I consider three other parameters to present my analysis: the cash bonus, ζ, the persistence of prices processes, $\kappa = (\kappa_1, \kappa_2)'$, and the volatility of prices, $\sigma = (\sigma_1, \sigma_2)'$. The amount of cash bonus is set to be reasonably low. The persistence and the volatility of prices processes take values in a range whose center is roughly the estimate from Table 4.1.

Figure 4.1 exhibits an outline of the conflict between the manager and shareholders in respect of hedging policies, when the cash–based bonus scheme, z_t, for profitable derivatives is involved. Each panel corresponds to a different variable that may affect hedging decision, in which the sensitivity of contracting efficiency on the vertical axis to a particular parameter on the horizontal axis. The higher the degree of efficiency, the weaker the agency conflict in respect of hedging decisions. That is, a higher degree of efficiency reflects a circumstance in which the manager choose a hedging policy that deviates far from the first-best one. In all cases, cash flow naturally rises in the state $\theta_1 = 1$ and $\theta_2 = 1$, which are exactly the long–term mean of their processes.

My first result is that contracting efficiency increases with managerial ownership, and decreases with the amount of compensation for profitable derivatives. This result matches our common sense. Intuitively, the larger the fraction of managerial ownership or the smaller the encouragement on profitable derivatives, the more incentive of maximizing firm equity value the manager will have. Hence, based on this numerical result, I can make the following prediction: Once investors interpret the fair values of financial derivatives as a signal of executives' financial insight and skill, firm managers will improperly use financial derivatives to hedge firm production for their own stake, which actually damages shareholders' benefit and contracting efficiency.

Next, I examine the parameters that govern market states. The bottom two panels illustrate how contracting efficiency is affected by persistence and volatility of processes of product price and the underlying asset's price. I find that the manager's behavior, in terms of choosing hedging ratios, depends critically on these two parameters. Firstly, a monotonic and positive relation between the persistence, κ, and contracting efficiency is observed. As κ rises, it is more likely that a profitable production (high θ_1) will continue to be profitable, and vice versa. As a result, with a large κ, equity–based compensation will have a dominating influence on managerial compensation package. The manager then will concern more about their equity–based compensation, and adopt some hedging ratios close to the first–best one. Secondly, the effect of process volatility, σ, on contracting efficiency is also monotonic but negative. An increase in σ implies a larger possibility that the hedging contract is profitable. Therefore, in contrast to the effect of κ, a larger σ yields a higher likelihood for getting cash bonus. In turn, the manager will adopt a hedging ratio that deviates farther from the first–best policy, because she is more likely to gain cash bonus by doing so.

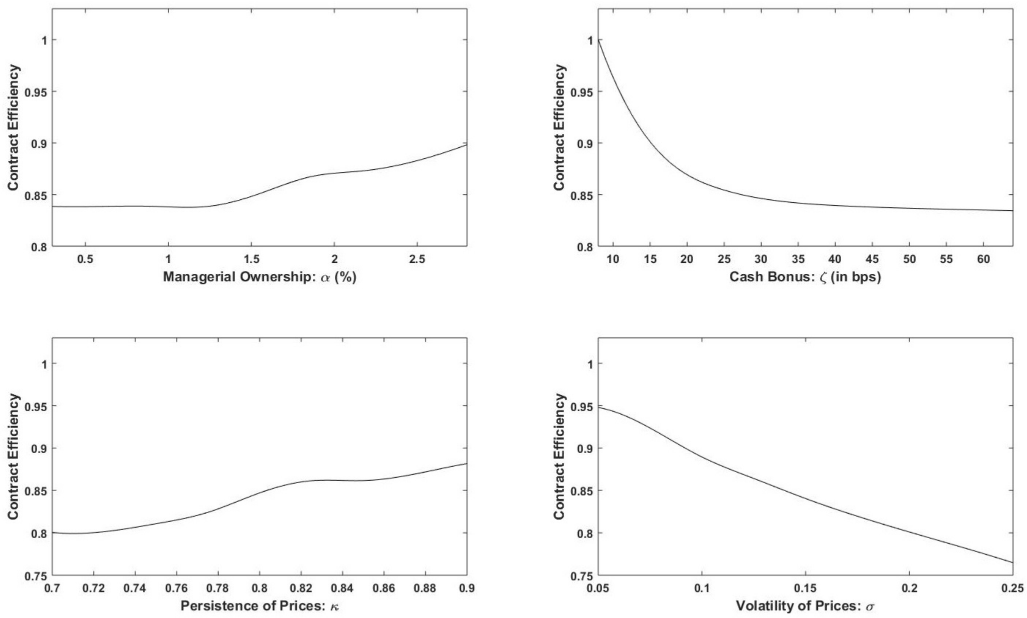

Figure 4.1: **The Conflict between Manager and Shareholders**

Notes: The figure depicts how contracting efficiency is affected by the managerial ownership (α), the magnitude of cash compensation for profitable derivatives (ζ), the persistence at lag one of the prices processes (κ), and the volatility of the prices processes (σ). Note it is assumed that $\kappa_1 = \kappa_2$ and $\sigma_1 = \sigma_2$, so any specific values κ_s and σ_s taken by κ and σ in the graph implies $(\kappa_1, \kappa_2)' = (\kappa_s, \kappa_s)'$ and $(\sigma_1, \sigma_2)' = (\sigma_s, \sigma_s)'$. For example, $\kappa = 0.8$ and $\sigma = 0.15$ in the graph means $(\kappa_1, \kappa_2)' = (0.8, 0.8)'$ and $(\sigma_1, \sigma_2)' = (0.15, 0.15)'$. The contracting efficiency is measured by comparing equity value $E_t(e_t; h^R)$ relative to its first-best level. The baseline parameters used to generate the figure are in line with Table 4.1.

4.4.2. Effect of financial constraint

Observations could be different as a consequence of changing the level of financial constraint when the firm raises external funds. In this model, the financial constraint of the firm is measured by the flotation cost, λ. With the same market price, a more financially constrained firm has lower ability for tapping external capital than a less constrained firm does, which means a more financially constrained firm is more likely to be in distress. In the base case, the flotation cost is set as $\lambda = 5\%$. In the estimation of this section, I will compare how different levels of financial constraint affect the alignment of the interests of the manager and shareholders.

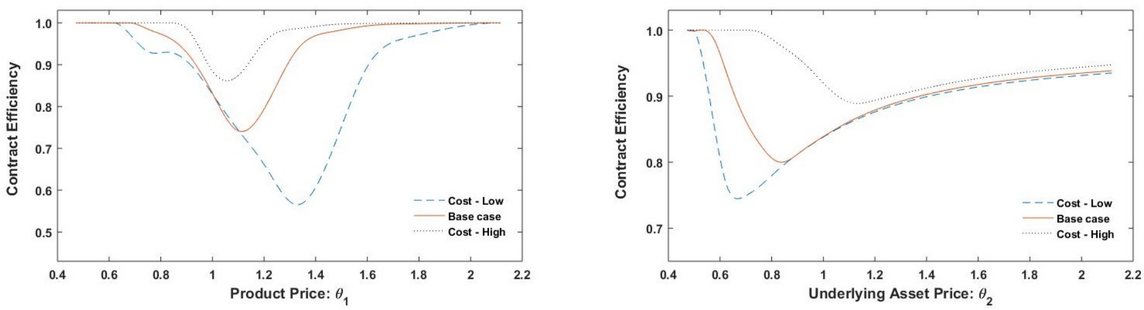

Figure 4.2: **Effect of Financial Constraint**

Notes: This figure is to compare the degree of contracting efficiency among various levels of financial constraints (λ) facing the firm. The left panel plots the efficiency in response to the product price (θ_1), and the right panel plots the efficiency in response to the underlying asset price of the hedging contract (θ_2). In the base case, $\lambda = 5\%$; in the low–cost case, $\lambda = 2\%$; and in the high–cost case, $\lambda = 8\%$. The baseline parameters used to generate the figure are in line with Table 4.1.

Figure 4.2 contains two panels to show the alignment of the interest of the manager and shareholders, when the firm faces different levels of financial constraint (i.e. high–constraint, base, and low–constraint case). Roughly the contracting efficiency shows a "V–shaped" relation with both the change in product price and the change in underlying asset price in all three cases. This result suggests that the agency conflict in hedging decision is considerably apparent when the market states are around its long–term mean, 1.0, and is alleviated when the market states are much below– or above–average. The degree of contracting efficiency approaches 100% when the firm faces either a market collapse (< 0.5) or a great booming market (> 1.5). The intuition behind the V–shape of curves revolves around the importance of managerial ownership to the compensation package. With extreme market conditions, the value of managerial ownership affects the manager's compensation package more than cash compensation for derivatives performance does. In particular, when a market collapse occurs, the manager will be aware that her total compensation is at risk due to a bad performance of equity value; whereas, when the market is booming, the manager will find that she could earn more from equity share than from speculation in financial derivatives. It is thus understandable that the manager is more motivated to optimize firm equity value in extreme market states than in normal market states.

The degree of contracting efficiency of the three cases differ in several ways. The firm with higher financial constraint has a higher degree of contracting efficiency on average, which is directly reflected by the position of each curve. It implies that a higher level of financial constraint lessens the conflict between the manager and shareholders. One possible explanation on this observation could be that if a firm faces a higher financial constraint, the manager's compensation will be dominantly affected by the risk of distress, so that the manager will concern more about equity value. In turn, the interests of outside shareholders and the manager are better aligned in a higher constrained firm. Moreover, the shapes of curves slightly vary among different cases. The curve of a lower constrained firm is more skewed from the long–term mean of prices of firm product and underlying asset. The minimum point of each curve denotes the situation in which the manager has the biggest hope for a cash reward. The manager in the high–constrained firm has the worst behavior in choosing hedging policy when θ_1 and θ_2 takes the value of 1.0, whereas the manager in the low–constrained firm has the lowest contracting efficiency when θ_1 is slightly above 1.0 or θ_2 is below 0.8.

4.4.3. Effect of hedging ability

In my model, the hedging ability of the firm is gouged by the correlation between the hedging contract and the product price as described previously. With different levels of hedging ability, firms could achieve different values. Pérez-González and Yun (2013) find that a launch of new financial instrument enables firms to obtain a better ability to eliminate risk exposure, and thus firms are expected to increase in value. However, a higher hedging ability also implies a smaller possibility of profitable derivatives, which directly influences the manager's expectation on the cash–based compensation. Consequently, the manager's decision in hedging strategies may differ when the hedging ability of the firm varies. Thus, in this section, I will explore the effect of hedging ability on the alignment of the interests of the manager and shareholders.

Panels in Figure 4.3 are organized to show the effect of financial hedging ability on the alignment of managerial interest and shareholders' stake. In each graph, curves respectively correspond to various levels of hedging ability ρ of 0.1 (the base case), 0.5 (medium level), and 0.9 (high level). Similar to the base–case curves, both medium-ρ and high–ρ curves in Figure 4.3 present a "V–shape". This result indicates that the lowest contracting efficiency occurs around $\theta_1 = 1.0$ and $\theta_2 = 1.0$, while the agency conflict is alleviated when θ_1 and θ_2 are extremely low or extremely high.

Looking among three curves in each graph, the effect of hedging ability on contracting efficiency is surely considerable. Surprisingly, the firm with a higher hedging ability has a lower contracting efficiency than the firm with a lower hedging ability does. Roughly, the dotted curves (representing the high–ability firm) is below the dash curve (representing the medium-ability firm), and the dash curve is below the solid curve. In addition, curves representing a higher-ability firm are less skewed from 1.0. One intuition for this result is that higher hedging ability lowers the possibility of cash reward for profitable derivatives, which makes the manager focus more on the cash compensation than on the equity value, especially when the prices of product and underlying asset are around long–term mean. However, a more accurate economic explanation might be needed to supplement this numerical result.

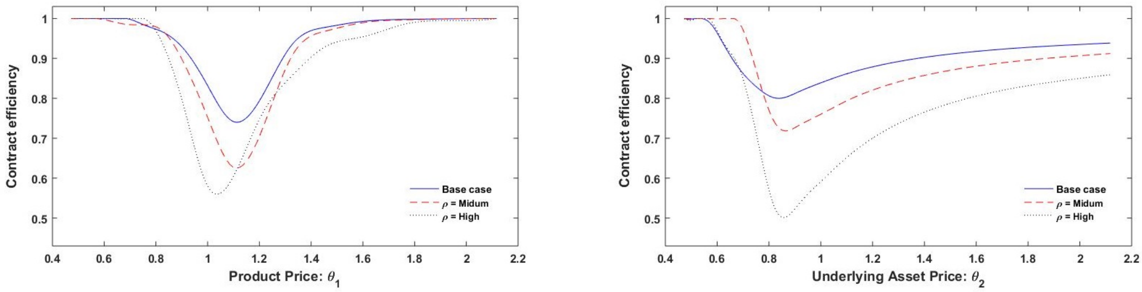

Figure 4.3: **Effect of Hedging Ability**

Notes: This figure is to compare the degree of contracting efficiency among various levels of hedging ability (ρ) of the firm. The left panel plots the efficiency in response to the product price (θ_1), and the right panel plots the efficiency in response to the underlying asset price of the hedging contract (θ_2). In the base case, $\rho = 0.1$, represented by the solid curves; in the medium-ability case, $\rho = 0.5$, represented by the dash curves; and in the high-ability case, $\rho = 0.9$, represented by the dotted curves. The baseline parameters used to generate the figure are in line with Table 4.1.

4.4.4. Effect of cash compensation

The frame of cash compensation can also be an important concern when the manager makes financial decisions. As described previously, shareholders treat the performance of derivatives as a signal of the manager's financial skill and insight, so that the cash compensation for profitable derivatives is involved in managerial compensation package. Murphy (1999) documents that compensation packages typically consist of a fixed wage, a profit share, straight equity and options. In this research, I do not take any exercizable or non–exercizable options into consideration because of its complexity. The equity–based compensation is referred to as the straight equity part in the compensation package. In addition, equation (4.8) is an example in which shareholders encourage positive fair values of derivatives by setting a fixed amount of cash bonus for profitable derivatives, which can be regarded as a fixed wage included in compensation package. However, shareholders are also likely to design in a reward scheme in which the amount of bonus is positively related to the amount of derivative gains, which can be regarded as a profit share. It then raises a question: Will such a scheme improve the alignment of the interests?

In order to explore the effect of different cash compensation schemes, I propose an alternative cash compensation scheme in which the amount of reward is directly related to the payoff of profitable derivatives. The scheme, $z_t^A = z^A(y,t)$, can be written as follow

$$z_t^A = \zeta y_t^\gamma \chi_{\{y_t>0\}}, \tag{4.13}$$

where $0 < \gamma \leq 1$ is a constant. One advantage of this type of scheme is its smooth decline in cash bonus instead of a sudden deduction before the fair value of derivative decreases to zero. When $\gamma = 1$, the scheme is linear to positive payoff of derivatives, and the amount of cash bonus is directly proportional to gains from derivatives. That is exactly the base–case compensation scheme in (4.8). With an open interval $(0 < \gamma < 1)$, it can be seen that the cash bonus is a non–linear function against the payoff of derivatives, when the hedging contract is profitable. A non–linear scheme is encouraging the manager to keep a positive fair value of derivative instrument in the account, but the reward grows slower when the magnitude of profitable derivative goes high.

Figure 4.4 is constructed to show the effect of the concavity of cash compensation on the alignment of the interest of the manager and shareholders. There are three examples with different concavity coefficients in each panel. Other than the base–case curves ($\gamma = 1$), the dotted curves represent a linear bonus scheme for profitable derivatives with $\gamma = 0.5$, and the solid curves represent a concave bonus scheme with $\gamma = 0.01$. In order to keep equity value consistent, for the $\gamma = 0.5$ scheme, the coefficient of cash reward, ζ, is assumed to be 5 times of the baseline parameter; and for the $\gamma = 0.01$ scheme, ζ is set to be 3 times of the baseline parameter. The V–shaped relation holds for the curves representing the two alternative schemes. The agency conflict in choosing hedging policy is most apparent when θ_1 is around 1.1 or when θ_2 is around 0.8, and is alleviated when θ_1 and θ_2 come out other values, according to the graphs in Figure 4.4.

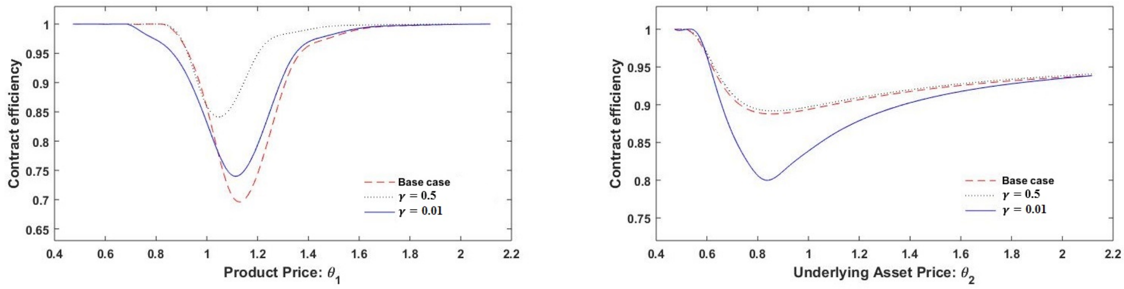

Figure 4.4: **Effect of Concavity of Cash Compensation**

Notes: This figure is to compare the degree of contracting efficiency among various concavity coefficient (γ) of the firm cash compensation scheme. The left panel plots the efficiency in response to the product price (θ_1), and the right panel plots the efficiency in response to the underlying asset price of the hedging contract (θ_2). In the base case, $\gamma = 1$, the cash scheme is a linear–compensation scheme, represented by the dashed curves; in the first non–linear case, $\gamma = 0.5$, represented by the dotted curves; and in the second non–linear case, $\gamma = 0.01$, represented by the solid curves. The baseline parameters used to generate the figure are in line with Table 4.1.

Overall, Figure 4.4 shows that, comparing to the linear–compensation scheme, the non–linear schemes increase contracting efficiency. However, the linear scheme aggravates the agency conflict when $\theta_1 > 1.0$. This result is reflected by the curves position in each panel. In the left panel of Figure 4.4, the dotted curve locates above the solid curve, but the dash curve roughly locates below the solid curve in the range $\theta_1 > 1.0$. Rather, in the right panel of Figure 4.4, the dash curve and the dotted curve both locate above the solid curve. Nevertheless, it can be seen that the non–linear scheme always results in a higher degree of contracting efficiency than the linear scheme does.

My results in this section suggest two implications. First, ceteris paribus, by relating the amount of cash bonus to the amount of profitable derivatives, the interests of the manager and shareholders is overall better aligned. Second, the misalignment of interest is aggravated by the linear scheme when $\theta_1 > 1.0$, as a consequence of higher expectation of a lucky draw in financial market.

4.4.5. Simulations

A structural estimation of my model is limited because of the lack of detailed empirical data on the magnitude of hedging and the amount of executives cash compensation, and would lead to unreliable parameter estimates. Instead, I present a simulation to explain my main results, and to provide empirical implications.

I use Monte Carlo simulation to generate a sample of possible future paths for the state variables. The simulated dynamics of the state variables θ_1 and θ_2 are obtained by applying the recursive formula (4.1) and (4.3) for $t = 0, 1, ..., T-1$, where ε_1 and ε_2 are independent draws from Normal distributions $N(0, \sigma_1)$ and $N(0, \sigma_2)$, respectively. There are Ω_1 possible future paths for θ_1 and Ω_2 for θ_2, each refers to as an economy for the product price and for the underlying asset price, respectively. The optimal policy function for shareholders is from the solution of valuation problem in equation (4.11), while the optimal function for the manager is from the solution of equation (4.12). In my numerical experiments, I generate simulated state samples with $\Omega_1 = 17$ economies and $\Omega_2 = 17$ economies. The firm sample involves 10,000 firms for each combination of economic states, and $T = 150$ years (steps) for each firm.

Table 4.2 summarizes the information of statistics of the sample simulated. Numbers outside bracket are the mean value of each data, while numbers inside

	E_t	R_t	h^E	h^R	Δh	*t-test*
Base case	1.298	0.013	0.328	0.401	0.073	> 99
	(0.773)	(0.006)	(0.164)	(0.095)	—	—
$f = 0.95$	1.605	0.033	0.522	0.655	0.133	> 99
	(0.841)	(0.011)	(0.323)	(0.186)	—	—
$\lambda = 0.08$	1.234	0.033	0.486	0.588	0.103	> 99
	(0.688)	(0.008)	(0.156)	(0.052)	—	—
$\rho = 0.5$	1.235	0.023	0.699	0.766	0.067	> 99
	(0.721)	(0.010)	(0.347)	(0.242)	—	—
$\gamma = 0.5$	1.315	0.011	0.544	0.641	0.097	> 99
	(0.636)	(0.009)	(0.247)	(0.151)	—	—

Table 4.2: **Statistics of the Sample Firms by Simulation**

brackets are the corresponding standard deviations. The second and third column are the value of equity and of managerial rent, respectively. Next, the fourth and fifth column show the the optimal hedging magnitude for shareholders and the optimal hedging magnitude for the manager, respectively. In the second column to the right, $\Delta h = h^R - h^E$ denotes the average difference between h^E derived from equation (4.11) and h^R derived from equation (4.12). The column very close to the right is the t-test value for examining the difference between h^E and h^R. The first row collects statistics for the base case. The second and third row show the cases when $f = 0.95$ and $\lambda = 0.08$, respectively, and other parameters are equal to the base case. Similarly, the fourth row demonstrates statistics of the firm with $\rho = 0.5$, while all the rest of parameters stay consistent with the base case. Finally, the bottom row shows the case in which the firm has a non–linear cash compensation scheme for profitable derivatives.

As Table 4.2 shows, Δh is statistically and economically significant in all cases, indicating an apparent conflict of hedging policy choices between the manager and shareholders. In the base case, the difference between the manager's optimal hedge and shareholders' optimal hedge is estimated at a level of 7.3%, suggesting that the manager is likely to hedge 40.1% of the firm's production on average, which is around 22% more than what shareholders actually want. With lower production cost

($f = 0.95$), the manager will over–hedge around 25% than the optimal hedging ratio of shareholders. With a higher financial constraint where $\lambda = 0.08$, the manager is over–hedging 10.3% of the production, implying that h^R is 21% larger than h^E in this case. These results from simulation support my numerical results and conclusions in Section 4.4.2.

In the industry where firms have a higher hedging ability ($\rho = 0.5$), the interests of the manager and shareholders are better aligned than the base case. When the optimal choice of hedge of the manager h^R is 76.6% of the firm production, which is around 10% higher than the optimal hedge of shareholder $h^E = 69.9\%$. Therefore, through the simulation in this section, my results and conclusions in Section 4.4.4 are directly verified.

Finally, with a non–linear cash compensation scheme for profitable derivatives, the magnitude of the manager's deviation from the optimal hedge of shareholders is around 17.8% of h^E. It suggests that a linear cash–bonus compensation scheme could alleviate the conflict of hedging policy between the manager and shareholders, as it is making the manager less aggressive for taking positions in financial derivatives.

4.5. Conclusions

Ideally, financial hedging strategies set by managers are fully understood by a company's shareholders before a hedging program is put in place, and thus nothing should be compensated for profitable derivatives. However, empirical evidence shows that material effect of derivative gains on managerial rent. It thus reflects a fact that the level of sophistication of investors is to be improved. This research predicts a damage in contract efficiency as a consequence of reward for profitable derivatives.

In this chapter, I analyze the association between the cash compensation for derivative earnings and the contract efficiency. I find that, as investors treat the derivative performance as a measure of firm manager's financial skill, there is an effective conflict between firm manager and shareholders in respect of determining corporate financial hedging policy. I find a V–shaped relation of contracting efficiency against the price of firm product and the price of the underlying asset of hedging derivatives. Because the cash compensation for profitable derivatives is the key factor distorts the manager's objective function, I conclude that the conflict is essentially caused by such a managerial incentive scheme under the fair value based accounting standards for hedge.

Furthermore, I investigate how the contracting efficiency would be influenced by changing levels of financial constraints facing the firm, the hedging effectiveness of derivatives, and the concavity of cash compensation scheme. I demonstrate that the fair value based accounting standards do improve the alignment of the interests of firm manager and shareholders in some circumstances. Numerical results suggest that the conflict is alleviated to some extent through higher levels of financial constraints, stronger hedging abilities, and non–zero concavity of cash reward schemes. In particular, when the firm's profitability is above–average, the interests of the manager and shareholders can be perfectly aligned in the firm with high financial constraint, or with sufficient hedging ability, or with a non–zero concavity of cash reward.

However, my results also highlight that the conflict is particularly apparent when the operational profitability of the firm is below–average but not near distress, regardless of under which circumstances. In this case, the manager would choose to hedge much less than what shareholders really need. One explanation is that the manager acts somehow as a debtholder of the firm if there is cash compensation, and thus the manager is less willing to make investments in financial derivatives when the product price is lower than its long–term mean.

4.6. Appendix

4.6.1. Numerical Methods

The numerical solution of the model is obtained through a dynamic programming iteration. I use discretization to approximate the continuous state variables, following Terry and Knotek II (2011) and Tauchen (1986). In particular, I let $\log \theta_{1,t}$ and $\log \theta_{2,t}$ take values from intervals whose center is zero. In each range, 16 points are equally distributed. The value functions are represented as functions on the grid points.

The expectation is computed using the Gauss–Hermite quadrature method with $n = 11$ sample points. In the quadrature method, the Gaussian integral is approximated by

$$\int_{-\infty}^{\infty} e^{-\xi^2} f(\xi) d\xi \approx \sum_{i=1}^{n} \omega_i f(\xi_i),$$

where ξ_i are the roots of the Hermite polynomial $H_n(\xi)$ and the associated weights are given by

$$\omega_i = \frac{2^n n! \sqrt{\pi}}{n^2 \left[H_{n-1}(\xi_i)^2\right]}.$$

In the numerical solution, the optimal hedge ratio is computed through the backward deduction using the recursive formulas in Section 4.3. Stationary solutions are found by iterating the recursive procedure until the errors of the value functions between adjacent iterations are less than 10^{-5}. The procedures normally converge within 300 iterations.

Chapter 5

Concluding Remarks

5.1. Conclusions

This thesis thus far presents discussions on several aspects of corporate financial risk management. Specifically, Chapter 2 analyzes the incentives for derivatives hedging, Chapter 3 examines the determinants of hedging strategy, and Chapter 4 explores the association between managerial compensation scheme and contracting efficiency of corporate hedging decisions.

The major contribution of Chapter 2 is to reconcile some seemingly contrasting notions of the received theories regarding the hedging incentives. The example model shows that, in equilibrium, hedging could hardly be a convincing signal of the firm's quality, if market has no updating process. Further, the dynamic model makes three testable predictions that may have empirical implications. First, firms with an under–estimated profitability would have more incentive for hedging, especially when they obtain favorable profitability shocks, or in the boom market states, and vice versa. Second, corporate hedging policies are more sensitive to the profitability shocks and market states than the one predicted by the complete information models.

Third, hedging is more sensitive to the belief of outsiders when the firm realizes an unfavorable profitability shock, or when the market is in recession. The results of our dynamic model emphasize the importance of information asymmetry on corporate incentives for financial hedging and provide a possible explanation on the mixed empirical evidence on corporate hedging policies.

Chapter 3 delves deeper into the reasons for corporate hedging and exhibits the important explanatory roles played by firm's profitability, growth opportunity, and informational asymmetry. The theoretical model of the essay shows that the attractiveness of hedging to a firm is determined by both the value-enhancing and the transparency–enhancing potential of hedging. Based on the model predictions, the empirical study then examines the key model predictions by using hand–collected panel data on 62 the U.S. oil & gas firms' derivative usage for hedging commodity price risk, I find evidence in support of the theoretical model. First, I find a positive relation between a firm's profitability and hedging activity. Second, a firm's hedging incentive increases with the severity of informational asymmetry but this relation becomes negative for extremely high-level informational asymmetry. In addition, I find that informational asymmetry positively interacts with firms profitability. Third, the relation between growth potential and hedging decision is positive but modest in economical significance, and the marginal effect is negative. Finally, consistent with the theory and intuition, I show that a firm with less ability to access derivatives market is less likely to hedge.

The empirical findings contribute to the empirical risk management literature by analyzing corporate financial hedging activities of a comprehensive sample of oil and gas firms. Since the reliability of disclosures on firms' derivatives fair values for the purpose of hedging remains doubtful, I investigate only the sample firms' disclosure on physical hedge ratio or nominal volume of commodity hedged, following a sizable prior empirical literature, such as Rampini, Sufi, and Viswanathan (2014) and Rampini, Viswanathan, and Vuillemey (2017). The panel structure of the data in this essay allows me to exploit both cross–sectional and within–firm variation to assess the relationship between financial hedging and the focused variables. Many previous studies use only cross–sectional data and hardly exploit within–firm variation because they largely rely on dummy variables for financial hedging activities that have only limited within-firm variation.

In Chapter 4, I find that, as investors treat the derivative performance as a measure of firm manager's financial skill, there is an effective conflict between firm manager and shareholders in respect of determining corporate financial hedging policy. I demonstrate that the fair value based accounting standards do improve the alignment of the interests of firm manager and shareholders in some circumstances. Numerical results suggest that the conflict is alleviated to some extent through higher levels of financial constraints, stronger hedging abilities, and non–linear cash reward schemes. In particular, when the market price of the product of the firm is above–average, the interests of the manager and shareholders can be perfectly aligned in the firm with high financial constraint, or with sufficient hedging ability, or with a non-zero concavity of cash reward. The essay also highlights that the conflict is particularly apparent when the operational profitability of the firm is below-average but not near distress, regardless of under which circumstances.

Chapter 4 makes at least three contributions to the literature. First, my research extends the work DeMarzo and Duffie (1995) by proposing a more practical managerial incentive scheme. The career contract between the firm and manager includes both equity–based and cash–based compensation, which makes the objective of the firm manager differs from the objective of shareholders in respect of the choice of hedging policy. This has not been previously analyzed. Second, my research provides theoretical support for empirical works depicting managerial incentive for profitable derivatives. I capture the conflict between firm manager and shareholders by using a dynamic model that relieves the manager from the reputational considerations. Thus, the results are believed to be persistent. Third, I explore the association between the cash compensation for fair value based-accounting earnings and contracting efficiency in different situations respectively. To my best knowledge, my research is the first that shows that the degree of the conflict varies among different situations.

5.2. Discussions

Findings in this thesis shed lights upon many open research questions. For example, what difference does financial hedging really make? According to the Modigliani–Miller irrelevance proposition, since investors can manage financial risks on their own simply by holding well–diversified portfolios, reductions in the variability of corporate cash flows achieved by financial risk management can hardly create value. However, by accomplishing one or more of market frictions, it would enhance the value–adding effect of financial hedging and induce an incentive for financial risk management, as suggested by the aforementioned literature. To that extent, the real cost of protecting against downside losses is that the firm must forgo upside gains. One of the existing theories exploring such a trade–off is Babenko and Tserlukevich (2017).

Beyond the conventional scope, the model of Chapter 2 of this thesis emphasizes the importance of the information effect of financial hedging on external financing cost and firm value. Empirically, the strategic incentives for financial risk management deserves more attention. That is, do firms hedge for the purpose other than reducing convex external frictions? The answer could be yes, but the evidence is fairly limited as yet.[1] One suggestive research is Nain (2004) who argues that a firm's need to hedge depends on the extent of hedging in its industry. The author exhibits that firms choosing not to hedge foreign exchange risk in industries where

[1]See Aretz and Bartram (2010) for a discussion about the difficulty of measuring the value effect of financial hedging.

the use of foreign–exchange derivatives is common had 5% lower Tobin's Q than their hedged competitors.

Chapter 4 suggests that managerial compensation scheme could result in a distortion of hedging incentive and other financial decisions. Gladly, planned future research focusing on the empirical implications of the model predictions of Chapter 4 is ready for test. One pioneering research is Nikolov and Whited (2014) who use panel data structurally estimate how managerial compensation scheme affects the dynamic of corporate cash holdings decisions.

In addition, the results in Chapter 4 raise many questions regarding the effect of other issues on determining corporate financial hedging policy. Most notably, I do not consider cash holding, leverage, and taxation. Further normative research into how managerial rent affect corporate risk management is ideally to take these factors into account.

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