ABSTRACT

Title of Dissertation:	MANAGING INNOVATIONS: INFORMATION AND CONTRACTS
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Innovation has been acknowledged by both researchers and practitioners as a vital tool to yield growth and maintain competitive advantages. However, firms face stiff challenges in managing innovations. Developing new product generally requires substantial resource input, but the success rate is usually low due to internal technical difficulties and external market uncertainties. Even with successful innovative products, it is not guaranteed that the innovators will be rewarded for their efforts and investments, as the return from innovations may be siphoned off by suppliers, customers, and competitors. To profit from innovations, firms need to first create value with the right R&D strategies, and further capture value in the execution of innovations when dealing with the relevant partners. This dissertation studies the management of innovations and addresses these two important issues respectively. In the first essay, we investigate how strategically managing information can improve the new product performances in competitive R&D markets. The new product development process is essentially a series of inter-linked

information processing activities: firms generate ideas, gather information from external environment to evaluate the feasibility and potential of the ideas, conduct research to create new knowledge and intellectual property, and finally commercialize the new knowledge into the market to generate value. We focus on how firms should acquire and manage external market information in competitive R&D markets, and how the information acquisition and management strategies impact their R&D investment decisions. The second essay studies how firms should manage the relationship with the relevant parties in the execution of innovations. The intrinsic uncertainty in the materialization of innovations, the intangibility of technical knowledge assets, and the difficulty of specifying and monitoring the performance of the other party, are the primary clauses that give rise to the hold-up problem in innovation partnerships -- that is, the R&D investment by a firm leaves it vulnerable to ex post opportunistic behaviors by its contracting partner (whether its supplier, customer, or joint venture partner). We study how the operational aspect of an evolving relationship may influence a firm's innate incentives to take advantage and `hold-up' the partner and mitigate the hold-up problem in innovation partnerships. The third essay extends the discussion of hold-up problem to general incomplete contracts and moral Darwinism. In conventional economic models, rational players are usually assumed to be self-interested and can take opportunistic actions to maximize their own payoffs, while socially desirable traits such as honesty and trust are often characterized as irrational and studied as deviations from tenets of rationality. However, these irrational traits are commonly observed in practice despite the widespread nature of incomplete contracts which have plenty of room for opportunism. This essay asks why traits such as honesty have not been weeded out by economic

Darwinism, and offers a justification that the choice of honesty emerges both as desirable and rational under very reasonable conditions.

MANAGING INNOVATIONS: INFORMATION AND CONTRACTS

By

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Dedication

To my family

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Chapter 1

Introduction to Dissertation

Innovation has been acknowledged by both researchers and practitioners as a vital tool to yield growth and maintain competitive advantages. However, firms face stiff challenges in managing innovations. Developing new product generally requires substantial resource input, but the success rate can be as low as 20% due to internal technical difficulties and external market uncertainties (*cf.* Mansfield and Wanger, 1975; Lauga and Ofek, 2008). Even with successful innovative products, it is not guaranteed that the innovators will be rewarded for their efforts and investments, as the return from innovations may be siphoned off by suppliers, customers, and competitors (Pisano and Teece, 2007). Hence, to profit from innovations, firms need to first create value with the right R&D strategies, and further capture value in the execution of innovations when dealing with the relevant partners. This dissertation studies the management of innovations and address these two important issues respectively. In the first essay, we investigate how strategically managing information can improve the new product performances in competitive R&D markets. The new product development process is essentially a series of inter-linked information processing activities: firms generate ideas, gather information from external environment to evaluate the feasibility and potential of the ideas, then conduct research to create new knowledge and intellectual property, and finally commercialize the new knowledge into the market to generate value. We focus on how firms should acquire and manage market information in competitive R&D markets – in particular, we spotlight two most important information acquisition channels in R&D markets: customers and competitors in the target market, and study how the strategic information acquisition and management decisions impact the R&D investment decisions and market structures. The second essay studies how firms should manage the relationship with the relevant parties in the execution of innovations. The intrinsic uncertainty in the materialization of innovations, the intangibility of technical knowledge assets, and the difficulty of specifying and monitoring the performance of the other party, are the primary clauses that give rise to the hold-up problem in innovation partnerships – that is, the R&D investment by a firm leaves it vulnerable to ex post opportunistic behaviors by its contracting partner (whether its supplier, customer, or joint venture partner). We study how the operational aspect of an evolving relationship may influence a firm's innate incentives to take advantage and 'hold-up' the partner and mitigate the hold-up problem in innovation partnerships. The third essay builds on the second essay and extends the discussion to general incomplete contracts and moral Darwinism. In conventional economic models, rational players are usually assumed to be self-interested and can take opportunistic actions to maximize their own payoffs, while socially desirable traits such as honesty and trust are often characterized as irrational and studied as deviations from tenets of rationality. However, these irrational traits are commonly observed in practice despite the widespread nature of incomplete contracts which have plenty of room for opportunism. This essay asks why traits such as honesty have not been weeded out by economic Darwinism, and offers a justification that the choice of honesty emerges both as desirable and rational under very reasonable conditions.

1.1 An Overview of Essay 1

The market for new products is typically plagued with a lack of information on several key dimensions such as market size and customer preferences. Not surprisingly then, better market information plays a defining role in improving the performance of firms which launch new products. Hence, many firms conduct *market research* to analyze key customers and market needs before key R&D decisions are made. The importance given to market research by firms can be gauged from the fact that the global spending on acquiring information on characteristics of a new-product market increased to a staggering $39 billion in year 2012[1]. For instance, Samsung has an astonishing number of 60,000 employees in various countries across the world dedicated exclusively to researching the market for their products through customer polls and third-party reports (Chen, 2013). Off-late, in addition to market research, *competitive intelligence* is gaining prominence where firms monitor their competitors in order to ascertain their key decisions. Eli Lilly's new product planning group routinely monitors competitors – such as what products rival firms are planning to introduce in the market and what kinds of input they use – to assess market rewards and forge its

[1]Report by the European Society for Opinion and Market Research: Global Market Research 2013. http://www.esomar.org/uploads/industry/reports/global-market-research-2013/ESOMAR-GMR2013-Preview.pdf

own R&D decisions (Ofek and Turut, 2008). A recent survey of 400 global companies by Fuld&Company finds that despite the recent economy downturn, the number of companies that spend over $1 million per year on competitive intelligence programs has doubled in the past five years (Competitive Intelligence Global Benchmarking Project Update 2013[2]).

But unlike market research, which relies on willing customers to reveal information, competitive intelligence ironically relies on the implicit 'participation' of scheming competitors – in the sense that CI can always be neutered if the rival conceals its decisions or information. And indeed several firms, notably Apple, excel at such concealment. Apple takes ironclad measures, such as strictly restricting access to key R&D areas, to using strong-arm tactics to gag employees from revealing information under the threat of "termination and prosecution to the fullest extent that our lawyers can", to prevent information from leaking out to competitors, see Lashinsky (2012).

Hence, key research questions that emerge are: Can competitive intelligence emerge as a viable information acquisition strategy even when competitors can conceal their decisions and information? Can it ever replace market research, i.e., would firms ever choose competitive intelligence over market research? Which (or both, or neither) information acquisition strategies should firms pursue in competitive R&D markets? How does the presence of competitive intelligence impact firms' market research decisions, R&D decisions, and industry welfare? (For instance, would firms alter their R&D investment strategies in light of potential competitive intelligence by rivals? Would competitive intelligence hurt or improve profits for a firm, some firms, the entire industry...?)

[2]http://www.fuld.com/Portals/17073/resource-center/white-papers/pdf/fuld-and-company-white-paper-global-benchmarking-project-update-2013.pdf

To address these questions, we develop a dynamic model where two risk-neutral firms compete for market shares in a new-product category by making costly R&D investments. The market value of the new product is uncertain, and the final profits are a function of the investment levels and the realized market value. A key feature of our model is that firms can actively manage their information – right from acquiring market information through market research, or acquiring information on competitor's decisions through competitive intelligence, or both, to being able to conceal or reveal either component. Additionally, our parsimonious model captures the key features of competitive R&D markets such as market uncertainty, information acquisition, firm heterogeneity, and sequence of innovations.

Our study provides the following novel results. First, we show that under very reasonable conditions, an asymmetric equilibrium exists (even when firms are symmetric ex ante) in which one firm forgoes market research but successfully acquires information on its rival though competitive intelligence, whereas the other firm does only market research. Hence, we prove that competitive intelligence can emerge endogenously as an optimal and viable information acquisition strategy even though (*i*) competitors can conceal their information; (*ii*) market research is costless; and (*iii*) market research can perfectly resolve market uncertainty and can also provide additional value through a better understanding of customer needs. In fact, we go one step further and prove that in this asymmetric equilibrium, the firm doing CI not only ascertains the competitors investment, but it can also perfectly *infer* the uncertain market size – hence, there is no information asymmetry in that equilibrium, both firms know the true market size even when only one firm conducts market research. A corollary of the above outcome is that competitive intelligence induces *sequential* innovations even when firms are ex ante symmetric – i.e., in this asymmetric equilibrium, the firm with superior market information invests early, and is the pioneer, while the one with inferior market information waits as a follower to conduct CI. We further show that competitive intelligence induces sequential innovation even when both firms do market research, but if one firm has a stronger 'market power' than the other firm. There is also a dark side to competitive intelligence in that it blunts the incentives for market research – there exist conditions under which neither firm does market research – for fear of potential competitive intelligence by the rival – even if MR is free, can perfectly resolve market uncertainty and also reaps additional benefits (such as higher margins) through a better understanding of customer needs. And finally, we show that competitive intelligence can *increase* total industry profits by *endogenously* creating a credible information channel between competing firms.

To our knowledge, this is the first paper that formally proves that competitive intelligence emerges endogenously in competitive R&D markets and establishes its nuanced interactions with the classical market research and investment decisions.

1.2 An Overview of Essay 2

Due to the inherent uncertainty and complexity, it is usually difficult to perfectly contract the exchange and use of technical knowledge, which gives rise to the hold-up threat in the execution of innovations. In the *hold-up problem* (*cf.* Klein *et al.,* 1978), a firm's *relationship-specific investments* – i.e., investments which are most useful within a specific relationship – leaves it vulnerable to *ex post* opportunistic behavior by its contracting partner (whether its supplier or its customer). For instance, suppliers in the automotive industry complain that "*Domestic OEMs typically leverage discussions around suppliers' innovation and then ask them to specify the innovation. Once done, they plagiarize the supplier-provided specification to various other suppliers in an attempt to beat down the price.*"(The 29th Annual Ward's Supplier Survey, Murphy 2007).

Two conditions interweave to create the possibility of hold-up: (*i*) relationship-specific investments, and (*ii*) non-contractible outcomes arising out of contract incompleteness. Both elements are present and common in the innovation partnerships. First, the delivery of the R&D investments is intangible technical knowledge, so once the innovator shows the information to the partner, it is almost impossible to revoke the contract and the resale value of the knowledge can drop significantly. Second, incomplete contracts are common in innovation partnerships, because of the substantial intrinsic uncertainty in the materialization of innovations and the difficulty of specifying and monitoring the use of technical information. Hence, the hold-up threat is prevalent in innovation partnerships.

The hold-up threat stifles investments and leads to inefficient outcomes. The remedies proposed to blunt opportunism (and thereby prevent hold-ups) under such enabling circumstances as provided by incomplete contracts, are often complex (e.g., sophisticated vertical contracts), and extreme (such as vertical integration). Several questions arise that we attempt to address in this research. Given the propensity to hold-ups, why is vertical integration not more widespread, and why do so many bilateral relationships thrive (as also noted by Coase, 2006)? Furthermore, why do so many of these firms employ simple contracts instead of the more sophisticated contracts proposed in the literature? How is the threat of holdup mitigated in practice (as the evidence indicates it must be)?

A possible unifying explanation for all the above questions is that firms do honor their contractual obligations, even when presented with opportunities to hold-up. As Macaulay (1963) argues: "... a key virtue of relational contracting is that parties can count on each other to abide by the spirit of the contract... one doesn't run to lawyers if he wants to stay in business because one must behave decently." The question that then arises is: Would firms *choose* to be irrationally *honest* (defined in this context as not holding up their contracting partners)?

This paper investigates how the operational aspect of evolving relationships may influence the a firm's innate incentive to 'hold-up' its innovation partner. In specific, we study a context of a vertical innovation relationship, wherein the upstream firm (a supplier) makes R&D investments to develop the innovation, and the downstream firm (a manufacturer) commercializes the new product to the end market. Since the market return of the new product relies on and is collected through the manufacturer's marketing and distribution channels, the manufacturer may hold-up the supplier once the investment is made and extract all the value generated by the innovation. The innovation partnership lasts for two periods. In each period, the sequence of events is as follows. In stage 1, the manufacturer asks the supplier to develop the innovation and contracts to pay the supplier a fraction of the future realized value of investment. In stage 2, the supplier decides on his effort level. In stage 3, the project value is realized. Finally, in stage 4, there is potential for hold-up: the manufacturer may renegotiate and pay the supplier a lower payment than the contracted value.

Our model has three essential features: (*i*) A dynamic (two-period) setting to capture repeated interactions between the manufacturer and its supplier; (*ii*) The manufacturers can be one of three types: *rational* (i.e., long-run expected utility maximizer who can hold up the supplier if it is optimal to do so, or play honest otherwise), *honest* (i.e., who never holds up the supplier), or *cheat* (short-run profit maximizer who always holds up the supplier); and (*iii*) A tendency for all types of manufacturer to *tremble into myopic behavior* – manufacturers may play their optimal myopic (single-period) strategy, even when this differs from their optimal dynamic strategy, for reasons ranging from bounded rationality to intra-firm incentive conflicts.

Our results show that, in a single period, the rational manufacturer outperforms the honest type – after all, the rational type can always mimic the honest-type's strategy. However, even in a minimal repeated relationship (i.e., over just two periods), the honest-type manufacturer may outperform the rational type, even though, as before, the rational type can always mimic the honest-type's strategy. This happens when the project is lucrative enough (low cost to value ratio, or large enough probability of realizing a 'high' investment value), or interactions are repeated several times. The following implications are imminent: (*i*) Honesty is rewarded in a repeated innovation partnership – it emerges *endogenously* as the optimal policy under very reasonable conditions. (*ii*) The hold-up threat is mitigated in two ways without resorting to complex and extreme measures suggested in the economics literature: First, honest type manufacturers are honest throughout (and honesty emerges endogenously as noted above). Second, rational type manufacturers play honest (i.e., they do not hold-up the supplier) in the earlier periods of a repeated relationship. As the hold-up problem is mitigated, all parties are better off in equilibrium.

1.3 An Overview of Essay 3

In conventional reputation games, a rational player, whose type is unknown to the other party, can selectively mimic a "committed" type in order to maximize his own profits. Thus, the rational player, who is an unconstrained profit-maximizer, always outperforms the type who is committed to (i.e., constrained by) a subset of strategies. This result hinges on the tacit yet critical assumption that, barring one type's (irrational) commitment, players are otherwise perfectly rational. As we prove, this result does not hold when both types are *equally* (even if so very mildly) bounded in their rationality in other dimensions: A type committed to *honesty* can outperform the unconstrained profit-maximizer even though the latter has access to a superset of strategies, including the option of mimicking the honest type.

We develop a dynamic (multi-stage, multi-period), analytical model of incomplete contracts between a principal and an agent in a repeated relationship. The principal is either an *unconstrained* or an *honest* profit-maximizer. The unconstrained principal, aptly characterized as 'opportunistic' or 'self-interested with guile' by Williamson (1985), maximizes his own payoff subject only to legal restraints. The honest principal ('self-interested without guile', Williamson, 1985) honors his contractual obligations even in the absence of legal restraints. This distinction between unconstrained and honest profit-maximizers particularly matters under incomplete contracts where, due to inadequate legal recourse under unforeseen contingencies, there can be a divergence between the letter and the spirit of the contract. Although our modeling choices– a finite horizon, different 'types' of the principal, incomplete and asymmetric information, and Bayesian players– are loosely similar to those of a 'reputations' model (*cf* Mailath and Samuelson 2006), our model incorporates several additional, demonstrably critical features such as honesty and a proclivity to tremble due to bounded rationality. Our research makes several contributions, which we summarize below:

- Under plausible conditions, the 'irrational' (honest) type of principal strictly outperforms the unconstrained type, even though the unconstrained principal can selectively mimic the honest principal's strategies. Thus, a commitment to honesty emerges endogenously as the optimal policy.

- In traditional reputation models, the unconstrained type outperforms the commitment type by selectively mimicking the latter's strategies. Without adequate contextual justification, the presumption of commitment types who are not profit-maximizers, and whose payoffs are strictly dominated, appears arbitrary and contradicts Economic Darwinism. The standard we propose for modeling irrationality to minimize arbitrariness is that the constrained profit-maximizer ("commitment type") should, at a minimum, outperform the unconstrained type under plausible conditions, so that the specific type of commitment assumed is not undermined by economic Darwinism.

- Conversely, given that some irrational traits (including ethical values such as honesty) are commonly observed, *despite* incomplete contracts, our model postulates a set of primitives (such as trembles) within the paradigm of economic modeling that explains the survival of these traits. Hence, our research provides a bridge between normative rationales for honesty– the province of Ethics – and profit-maximization, which is axiomatic in Economics, by providing a compelling *economic* rationale for honesty.

- In sum, Rubinstein (1998) argues that "...substantive rationality is actually a constraint on the *modeler* rather than an assumption about the real world..." Our proposed standard relaxes this constraint on the modeler, in order to accommodate plausible models of Bounded Rationality.

- Finally, in the context of incomplete contracts, we show that the principal can induce the agent to make optimal relationship-specific investments, using simple, finite-horizon contracts. Hence, we diverge from all previous explanations offered in the academic literature (including relational contracts and conventional reputation models) for the robustness and widespread use of simple contracts.

Chapter 2

Competitive Intelligence and Market Research in R&D Markets

2.1 Introduction

New products are plagued with uncertainty pertaining to characteristics of the new product market (such as market size, customer preferences, etc.). A classical way to mitigate this uncertainty is through *Market Research (MR),* which is defined as: *"Gathering, analyzing data about the market to reduce risk and enable better marketing decisions to be made. It includes: estimates of market size and potential, identification of key market characteristics and segments, forecasting market trends and gathering information on existing and potential customers."* (The Institute of Sales & Marketing Management). The importance given to market research by firms can be gauged from the fact that the global spending on acquiring information on characteristics of a new-product market increased to a staggering $39 billion in year 2012[1]. Without paying due diligence to MR, a firm could assess accurately the market potential of a new product. In 2004, Coca-Cola introduced C2 – a cola with half the calories and carbs but all the taste of the original Coke – paying only lip service to truly understanding what customers wanted. The product bombed. As it turned out, customers desired full flavor with no calories or carbs, a niche that was subsequently fulfilled by Coke Zero (Schneider and Hall 2011).

Off-late, in addition to market research, *Competitive Intelligence* (CI) – defined by the American Marketing Association as: *"The systematic gathering of data and information about all aspects of competitors' marketing and business activities for the purposes of formulating plans and strategies and making decisions"*– is garnering increased attention by firms to acquire useful information about new products. For example, in 1997, a new line of 'rising-crust pizzas' promised to revolutionize frozen pizza, which, until then, often tasted like the 'cardboard box that it came in'. Kraft, one of the largest packaged-food company in the US, was the pioneer who had perfected the rising-crust pizza after conducting extensive market research to ascertain customer preferences and likely demand. In 1997, the company had been test-marketing the product under the brand name of DiGiorno. Around that time, Schwan's Sales Enterprises, a food company based in Marshall, MN, was also working on its own line of rising-crust pizzas under the brand name of Freschetta. Schwan's wanted to know how aggressively Kraft planned to formally launch DiGiorno so that it could tailor its own response. Schwan's was interested in the production capacity of Kraft's plant that was to manufacture the DiGiorno's line of pizzas. Schwan's hired a professional

[1] Report by the European Society for Opinion and Market Research: Global Market Research 2013. http://www.esomar.org/uploads/industry/reports/global-market-research-2013/ESOMAR-GMR2013-Preview.pdf

CI firm to investigate Kraft's DiGiorno's business. The CI firm estimated Kraft's capacity to be a staggering 50,000 pizzas a day. Spurred on by this covert and vital information which revealed Kraft's aggressive launch plans for DiGrigio, Schwan's quickly scrambled resources and committed to an aggressive launch as well of its own brand of Freschetta pizzas. Although DiGrigio quickly became the number one brand in the 2.3 billion dollar rising-crust-pizza category, the covert information obtained by Schwan's helped establish Freschetta as the No. 2 brand, behind DiGiorno, at the end of 1999. (Penenberg and Berry 2000, Black 2011)

Although, as compared to market research, competitive intelligence is regarded as a relatively new discipline (Juhari and Stephens, 2006), it is growing rapidly and gaining loyal patrons in today's hyper-competitive business environment. Firms such as IBM, Coca Cola, 3M, GE, Intel, P&G and others – have invested heavily in developing their own in-house CI capabilities. Firms that do not possess in-house CI capabilities need not despair, for they can always leverage professional CI consulting firms, such as Fuld & Company, Ignite, Line of Sight, and CSIntell. A recent survey of 400 global companies by Fuld &Company finds that despite the recent economy downturn, the number of companies that spend over $1 million per year on competitive intelligence programs has doubled in the past five years (Competitive Intelligence Global Benchmarking Project Update 2013[2]). The pharmaceutical industry has one of the most aggressive competitive intelligence programs: the average yearly competitive intelligence budget for *a* pharmaceutical firm increasing sharply from $1.07 million in 2008 to $1.73 million in 2011, an increase of more than 60%

[2]http://www.fuld.com/Portals/17073/resource-center/white-papers/pdf/fuld-and-company-white-paper-global-benchmarking-project-update-2013.pdf

in just three years.[3].

Unlike MR, which relies on willing customers to acquire information, competitive intelligence ironically relies on the implicit 'participation' of scheming competitors – in the sense that CI can always be neutered if the competitors protect and conceal their decisions or information. And indeed some firms, notably Apple Computers, excel at such protection and concealment. Apple takes ironclad measures, such as strictly restricting access to key R&D areas, to using strong-arm tactics to gag employees from revealing information under the threat of "termination and prosecution to the fullest extent that our lawyers can", to prevent information from leaking out to competitors, see Lashinsky (2012). As a result, the effectiveness of CI is not guaranteed, but subject to the decisions and reactions from the competitors in the market. Hence, key research questions that emerge are: Can CI emerge as a viable information acquisition strategy even when competitors can conceal their decisions and information? Can it ever replace market research, i.e., would firms ever choose CI over MR? Which (or both, or neither) information acquisition strategies should firms pursue in competitive R&D markets? How does the presence of competitive intelligence impact firms' market research decisions, R&D decisions, and profitability?

To address these questions, we develop a dynamic model where two risk-neutral firms compete for market shares in a new product market by making costly R&D investments. The market size of the new product is uncertain, and the final profits are a function of the R&D investment levels and the realized market size. A key feature of our model is that firms can actively manage their information – right from acquiring market information through market research, or acquiring information on competitor's decisions through

[3]http://finance.yahoo.com/news/Pharmaceutical-Competitive-bw-1347521081.html

competitive intelligence, or both, to being able to conceal or reveal either component. To focus on purely on the informational implications, all the above information management activities, MR, CI, and concealment of information, are assumed to be costless in our model. Additionally, our parsimonious model captures the key features of competitive R&D markets such as market uncertainty, information acquisition, firm heterogeneity, and sequence of innovations.

Our study provides the following novel results. First, we show that under very reasonable conditions, an asymmetric equilibrium exists (even when firms are symmetric ex ante) in which one firm forgoes market research but successfully acquires information on its rival though competitive intelligence, whereas the other firm does only market research. Hence, we prove that competitive intelligence can emerge endogenously as an optimal and viable information acquisition strategy even though (*i*) competitors can conceal their information; (*ii*) market research is costless; and (*iii*) market research can perfectly resolve market uncertainty and can also provide additional value through a better understanding of customer needs. In fact, we go one step further and prove that in this asymmetric equilibrium, the firm doing CI not only ascertains the competitors investment, but it can also perfectly *infer* the uncertain market size – hence, there is no information asymmetry in that equilibrium, both firms know the true market size even when only one firm conducts market research. We also show that competitive intelligence induces *sequential* innovations even when firms are ex ante symmetric – i.e., in this asymmetric equilibrium, the firm with superior market information invests early, and is the pioneer, while the one with inferior market information waits as a follower to conduct CI. We find that the possibility of conducting competitive intelligence blunts the incentives for market research – there exist conditions under which neither firm does market research – for fear of potential competitive intelligence by the rival – even if MR is free, can perfectly resolve market uncertainty and also reaps additional benefits (such as higher margins) through a better understanding of customer needs. And finally, we show that competitive intelligence can *increase* total industry profits by *endogenously* creating a credible information channel between competing firms. To our knowledge, this is the first paper that formally proves that competitive intelligence emerges endogenously in competitive R&D markets and establishes its nuanced interactions with the classical market research and investment decisions.

2.2 Literature Review

Many researchers in marketing and new product development highlight the important role of market knowledge in new product development (e.g., Ottum and Moore 1997, Li and Calantone 1998, Atuahene-Gima 2005). A large body of literature focuses on the interplay between firms' strategic market orientation and new product development (e.g., Atuahene-Gima 1995, Gatignon and Xuereb 1997, Spanjol et al 2011), and provides insights on how gathering and using of different types of market information (e.g.,customer, competitor, and technology) affect new product success. However, most of these papers consider the relationship between market information and R&D investments or performance from a single firm's perspective, and only a few papers explicitly consider the strategic implication of competition – that is, how the rivals' actions may influence a firm's incentive to gather and use of market information in innovations. Lauga and Ofek (2009) study whether firms should acquire information about customer's horizontal or vertical preferences over two potential attributes before their new product design decisions. They show that a firm may choose not to acquire information even though the rival conducts such research and learn the true customer preference. Since firms simultaneously choose product designs in their model, firms cannot infer market information from the competitor's innovation decisions and there is no need for strategic information management. In a more related study, Ofek and Turut (2008) consider the incentive to learn about uncertain market reward in a competitive R&D market where an entrant compete with an incumbent. The entrant's choice between innovation and imitation may signal his market information to the incumbent. As a result, the incumbent has less incentive to do market research, and the entrant may need to strategically manage the market information in his innovation strategy. We also study the market information acquisition and management in competitive R&D projects, but our work differs from theirs in several ways. First, the information gathering about the competitor in their model is one-way and exogenous – the incumbent always observes the entrant's new product development approach (i.e., innovation or imitation) while the entrant observes nothing about the incumbent innovation strategy; by contrast, we allow both firms to do competitive intelligence and monitor the competitor's strategy, and what a firm observes through competitive intelligence is endogenously determined by both firms. Second, they only consider the case where two firms simultaneously determine the investment levels (after the entrant's product development approach), while in our model firms can choose both investment timing and levels and either simultaneous or sequential investments may occur.

Our work is also related to the vast stream of literature that articulates the advantages and disadvantages of being first-movers or late-movers in competitive markets (e.g., Lieberman and Montgomery 1998, Shanker et al 1998, Boulding and Christen 2008). For instance, as a pioneer, one may indelibly stamp ones' brand name, formulate customer preferences and market standard, choose preemptive positioning and thereby enjoy higher profits than a "me too" follower. Of the more specific instance a disadvantage of being the second mover is the "cost" associated with waiting for information as a late mover (Shanker et al, 1998). However, as we show, the cost of waiting for information has an evil twin in the form of the cost imposed on the leader of strategically managing the information revealed to a waiting competitor. Hence, we complement the literature on the first/late movers' advantages and disadvantages by identifying (in most cases) a disadvantage for the leader of moving early, on account of superior private information. Among the papers that explicitly considers the strategic market entry decisions in the presence of competition, the one that is most related to ours is Narasimhan and Zhang (2000). In their stylized model, two competing firms can choose to enter a new market early when the market profitability is still uncertain, or late after the uncertain resolves. They show that the optimal entry timing strategy is determined by both the firm-specific pioneering advantages and laggard's disadvantages; as a result, firms with strong pioneering advantages may choose to wait, while firms with little pioneering advantages may choose to move early. Our paper echoes their results that the heterogeneity in firms' innovation capabilities or market powers impacts the optimal investment timing when firms have symmetric market information, but our model takes one step further in endogenizing the market information endowments. Our results show that competitive intelligence is an indispensable driver for sequential innovations, and that market information asymmetry also impacts firms' incentives to be a leader or a follower in a competitive new market. Our findings in identifying the linkage between market information acquisition and sequential innovation strategies constitute a novel contribution to existing literature.

Also related to our work is the stream of research that consider firms' information acquisition decisions regarding the uncertain market demand or uncertain production cost in existing product markets. For example, Raju and Roy (2000) and Christen (2005) study the incentives to acquire information about uncertain demand and cost respectively with Bertrand competition, and Li *et al* (1987) about uncertain demand with Cournot competition. Most of these papers assume that, after the information acquisition, firms simultaneously and independently choose their price or quantity levels; hence, the strategic impact of competition on the use of information is absent and there is no need to strategically manage the acquired information. Anand and Goyal (2009) study both the acquisition and the management of demand information by the incumbent firm in a Cournot competition, when his ordering quantity may be subsequently revealed by the supplier to an uninformed entrant. In their model only one firm (the incumbent) can acquire information, and the sequence of moves is exogenously given. Daughety and Reinganum (1994) consider a model similar to ours in the Cournot setting. Two ex ante symmetric firms both can acquire demand information, and they then can choose to produce in one of the two periods; if one firm sets the quantity decision early and the other late, the latter firm can perfectly observe the early mover's quantity level and may infer the demand information. They find that when the information acquisition is costly, asymmetric strategies can emerge in equilibrium – one firm acquires information and produces first, and the other does not acquire information and produces late. Our model is more general than theirs: firms can be either ex ante symmetric or asymmetric; also, the information about the competitor's strategy does not automatically reveal across periods in our model, but firms can conduct competitive intelligence to gather it. Our results show that even though it is costless to acquire information, firms may choose asymmetric information acquisition strategy and sequential innovations.

In summary, our study integrates the market information acquisition and management strategies with R&D investment decisions in competitive markets. Our novel model has the following essential features: (*i*) We endogenize the information endowment of firms by allowing each firm to select one or more information acquisition approaches: *market research* which helps firms to proactively understand the market characteristics and resolve market uncertainties, and *competitive intelligence* which enables firms to monitor the competitors' actions and reactively infer competitors' private information. (*ii*) We explicitly consider strategic information management for firms – a firm that acquires information through market research has the option to either reveal or hide his information especially when the competitor indulges in competitive intelligence. (Such information management potentially gives rise to a signaling game between the firms.) (*iii*) We endogenize the timing of investments: either firm can be the first-mover (leader) or second-mover (follower) in R&D investments. (*iv*) Our model explicitly incorporates firm-specific differences such as the ability in amplifying the value generated from market research.

2.3 The Model

Two firms, indexed by S and W, compete in the market for a new product. Let $x_S \geq 0$ and $x_W \geq 0$ be the R&D investments of firm S and firm W, respectively. The monetary costs of these investments are linear and identical for both firms: $C(x_i) = cx_i$, for $i \in (S, W)$. The R&D investments of the firms determine the 'attractiveness' of their products in the market, which in-turn determines the market shares through the well-known *Market Share Attraction* model, *c.f.* Bell et al. (1975).[4] Given the firms' investment levels in R&D x_S and x_W, firm S's market share λ_S is

$$\lambda_S = \frac{x_S}{x_S + x_W}, \tag{2.1}$$

and firm W's market share λ_W is

$$\lambda_W = \frac{x_W}{x_S + x_W}. \tag{2.2}$$

The market size of the new product market is uncertain and can be either 'high' or 'low'. Let $\tilde{Z}$ denote the uncertain market size, then $\tilde{Z}$ can be either low (Z_L) with probability p, or it can be high ($Z_H > Z_L$) with probability $(1 - p)$. These priors are common knowledge. We can denote the new product market as (p, Z_H, Z_L).

[4]The market share attraction model (hereafter, MSA) is well established in both the marketing and operations literature – see, for instance, Bell *et al.* (1975) , Karnani (1985), Monohan (1987) and Ofek and Sarvary (2003) in marketing; and Erat and Kavadias (2006), Federgruen and Yang (2009) in operations. MSA has an appealing structure in that the market share (the variable of interest) is based on "us/(us +them)" structure of investments, commonly seen in other models such as the much celebrated multinomial logit. In fact, in several markets, MSA has better predictive power than other models, *cf.* Naert and Weverbergh (1981). The R&D investments, such as x_i in our model, typically subsume all activities in developing and introducing new products, including applied research, product specification, pilot plant or prototype construction, investment in plant and equipment, and manufacturing and marketing startup. An alternative interpretation of the market share model is that of a 'contest' where firms compete for leadership in the market for a new product; the winning probabilities are the same as the market shares in the model (*c.f.* Ofek and Sarvary, 2003).

Before firms make their investment decisions, they can conduct market research, competitive intelligence, both, or none. For $i \in (S, W)$, we denote a firm i's market research decision as M_i if it conducts market research, or $\overline{M}_i$ if it does not conduct market research; and similarly, C_i denotes that firm i conducts competitive intelligence whereas $\overline{C}_i$ denotes no competitive intelligence undertaken by firm i. To ensure a fair comparison between the two information acquisition strategies, the cost of acquiring information through either market research or competitive intelligence is normalized to zero.

Market research serves two purposes. It perfectly resolves the uncertainty pertaining to market size $\tilde{Z}$; additionally, it also allows firms to gain a better understanding of customer needs (according to definition by AMA), which will enhance the value that firms can generate from one unit of sale of their products. For instance, in the pizza example discussed in the introduction, Kraft conducted extensive market research to not only understand how big the market really was for rising-crust pizzas, but it also executed elaborate studies to critically understand key customer needs and expectations from frozen pizzas, and how such needs can be met with the rising-crust variation. Microsoft and Silicon Graphics Inc. gained huge market success by proactively studying customers and incorporating customer preferences in their new products, Li and Calantone (1998). In fact, Microsoft attributes its huge success to a 'vigorous pursuit of customer knowledge in its new product development', *ibid.* Hence, a rigorous understanding of customer needs through market research by a firm $i \in (S, W)$ would *amplify* the value generated from the same customer base. We denote this value "amplification factor" of market research for a firm by $m_i \geq 1$ for $i \in (S, W)$. A higher value of m_i implies a market where customers have strong idiosyncratic needs which, when captured in the new product, generate a higher value, whereas $m_i = 1$ implies that the opposite case when there is no specific advantage to understanding finer nuances of the market, or if the firm is inept at capturing it, and the only information of value is statistical data on market size. Note that firms only can obtain this amplification factor m_i by conducting market research. Also, firms differ in their MR abilities: although both firms are equally adept at inferring the statistical market size, the parameter m_i is firm specific, i.e., one firm may be better at understanding customer needs and market idiosyncrasies than the other firm. Without loss of generality, we assume that the firm S, the Stronger firm, is better at understanding customer needs than firm W, the Weaker firm; hence, we assume that $m_S \geq m_W$.

Hence, the profit of a firm that does MR is:

$$\pi_i \left(x_i | M_i \right) = \begin{cases} \lambda_i m_i Z_H - c x_i \text{ with probability } (1-p) \\ \lambda_i m_i Z_L - c x_i \text{ with probability } p \end{cases}, \; i \in \{S, W\},$$

where λ_i are the market shares determined by equations 2.1 and 2.2 depending on whether a firm is Weak or Strong.[5]

A firm that does not conduct market research cannot directly ascertain the true market size – although it may be able to *infer* the true market size through competitive intelligence, see next subsection – and it certainly cannot obtain the amplification factor m_i associated with market research. Hence, the expected profit obtained by a firm that does

[5]Although the Market Share Attraction model has several nice properties, a very unsatisfying quirk of the model is that, when $m = 1$, the expected value of information is zero. That is, when $m = 1$, a firm generates equal profit (in expectation) with or without information on the true market size, which renders the firm indifferent towards acquiring information. This is clearly contrary to practice. The parameter m addresses this issue: with $m > 1$, ceteris paribus, a firm is better off acquiring information on the market size (due to the amplification in value induced by m) than to remain uninformed. Moreover, $m > 1$ renders our setup more conservative by tipping our model against finding support for CI. That is, despite exogenous benefits of exclusively acquiring information though market research (when $m > 1$), we find that a firm may forego market research in favor of CI.

not do MR is:

$$\pi_j \left(x_j|\overline{M}_j\right) = \lambda_j \tilde{Z} - cx_j,\ j \in \{S, W\}$$

where λ_j is once again the market shares determined by equations 2.1 and 2.2 depending on whether a firm is Weak or Strong.[6]

A firm can also conduct competitive intelligence (CI) to obtain information on the competitor's *decisions*. Consistent with market research, we assume that CI perfectly reveals the rival's investment, (x_{-i}), unless the opponent takes measures to conceal its investment. We assume that any such concealment of information is perfect and costless.

In effect, we make the following three assumptions regarding the information acquisition strategies:

Assumption 1: Market research is costless and perfectly resolves uncertainty on the market size. In addition firms can amplify market value $(m_i \geq 1)$ *through a better understanding of customer needs.*

Assumption 2: Competitive intelligence is costless and perfectly reveals the rival firm's decisions such as the investment, unless the rival takes measures to conceal its investment information.[7]

Assumption 3: A firm can perfectly conceal its investment information from the rival's CI. Moreover, any such concealment is costless.

[6] In effect, similar to Jensen and Meckling (1992) and Anand and Mendelson (1997), we parse information on potential market value into two components: The first, $\tilde{Z}$, is *statistical data* on market size which is *transferrable* to competing firms, or it can be inferred, such as through CI; and the other, $(m-1)\,\tilde{Z}$, is the *specific knowledge* on consumer tastes, which typically gets embedded in the various nebulous 'organizational routines' (*cf.* Nelson and Winter 1982), and hence is *nontransferrable.* A firm undertaking MR accrues both components and hence competes for a potential value of $m\tilde{Z}$; whereas the firm not doing MR can, at best, infer the true market size $\tilde{Z}$ through CI, but can never realize the specific and nontransferrable component $(m-1)\,\tilde{Z}$.

[7] Much of the information on competitors can typically be gleaned from public channels, such as company websites, news releases, patent disclosures, social media, etc., Sreenivasan (1998). Hence, the default option, unless firms conceal information deliberately, like Apple does, is that CI is successful.

The Sequence of Moves

Firms in our model make four decisions: (*i*) whether to conduct market research; (*ii*) whether to do competitive intelligence; (*iii*) how much and when to invest in R&D; and (*iv*) whether to conceal information on the R&D investment. These decisions emerge over three stages of the game. The first is the Market Research (MR) Stage, the second is the CI & Investment Stage and the third is the Payoff Stage. See Figure 2.1.

In the MR stage, firms decide whether to conduct market research, and if they do, they know the realized market size – $Z = Z_H$ or Z_L. In addition, they amplify the value from Z to $m_i Z$ through a better understanding of customer needs. At the end of the MR stage, firms' decisions on whether to conduct market research become public information.

Next, firms decide whether to do CI – this decision marks the start in the CI & Investment Stage, when and how much to invest in their R&D, and whether to conceal their investment decisions. A firm deciding to do CI aims to observe the rival firm's investment decisions, and he must invest after the rival firm to meaningfully utilize that information to shape its own investment. Hence, for ease of exposition, the CI & Investment stage is divided into two epochs – 'Early' and 'Late'. Firms can invest either in the Early or Late epoch (both not in both). A firm's CI monitors and reveals the rival's investment decisions (including both the investment timing and level) at the end of each epoch unless the rival firm chooses to conceal its investment decision (in which case, CI reveals nothing). (Note that investing late is akin to concealment since it does not allow the rival firm enough time to conduct CI and then also invest. Essentially, what this implies is that firms can always delay their investment enough to render rival's CI moot. To simplify exposition, in the

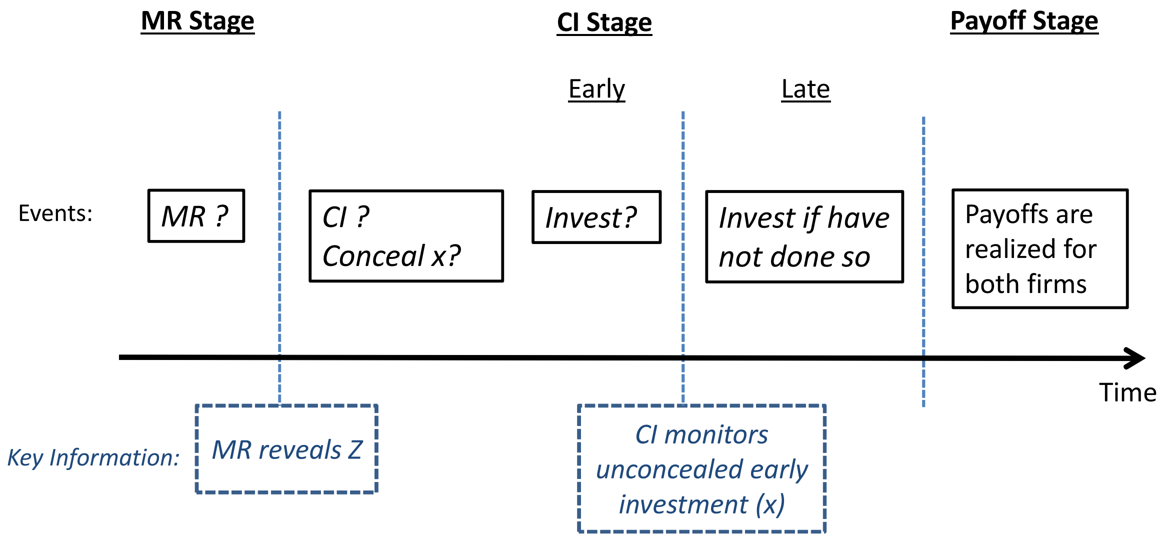

Figure 2.1: Sequence of events.

analysis we bundle moving late with concealing investment since both these actions induce exactly the same equilibrium outcomes.) Breaking the stage into 'Early' and 'Late' epochs captures praxis in that not all firms invest at the same time. Moreover, it allows us to tease out sequential investments that can evolve endogenously through CI.

Finally, in the payoff stage, firms introduce the products in the market and the payoffs are realized based on the market share model. (Although firms may invest sequentially in the CI & Investment stage, the final payoffs are independent of whether the firms *introduce* the products in the market sequentially or not.)

Notice that the sequence of moves is fluid, especially in the CI & Investment stage, in that the actual timing of investments, and whether firms conceal these, are locked only in equilibrium. (In fact, we can even leave the sequence of the three stages (with their embedded decisions) unspecified, and the equilibrium sequence and decisions will evolve endogenously.) In contrast, in most such game-theoretic models, the timing of moves is neatly laid out by the modeler – hence, firms are called upon to make moves in a tightly controlled and exogenously specified sequence (it is unlikely that firms in the real world operate through such *dues ex machina*).

2.3.1 Overview of the Analysis

Each firm starts the game with the identical information endowment: they are both uninformed about the true market size and have the same priors on $\widetilde{Z}$ (i.e., p, m_i, Z_H, and Z_L). However, before firms make their investment decisions, they can alter their information endowments through the various decisions that they make, specifically, whether to do MR and whether to do CI. But, the benefits of acquiring information through either channels do not accrue without trade-offs which must be factored in. Consider market research first. If a firm conducts market research, it then knows the realized market size, which can be used to tailor its investment. However, its investment decisions may be vulnerable to the rival's competitive intelligence and so can be the information on the realized market size which may be *inferred* by the firm undertaking CI. The trade-off for competitive intelligence is by no means simpler. With competitive intelligence, a firm may observe the competitor's investment level, and, may even be able to infer the realized market size. However, unlike market research, the effectiveness of competitive intelligence relies on the 'participation' of the competitor – the competitor can always neuter the threat of competitive intelligence by simply concealing its investment, or revealing the investments but so fudging them so as to render the embedded information on the realized market size indecipherable.

Hence, strategic tensions are considerably exacerbated since firms not only have to react to the rival's investment, but they also need to *anticipate* and factor the rival's information acquisition and concealment decisions, and all of these forge the firm's own strategy in terms of investments (timing and level), the channel(s) through which to acquire information and whether to conceal information.

The central thesis of our analysis, therefore, is this complex interplay among the information acquisition strategies, and their interaction with R&D investment strategies (both timing and level). On a broad note, all firms have conjectures about the other firm's strategies – such as whether the rival will do competitive intelligence and whether the rival will conceal information – and these conjectures must be correct in equilibrium. But at a more atomic level, the choices of information acquisition strategy can be such that it renders one firm better informed than its rival; hence, firms must form *beliefs* on their rival's information endowment, and then decide their own strategies as a function both of these beliefs as well as the rival's strategies. Hence, the equilibrium concept that we invoke is the Perfect Bayesian Nash Equilibrium (*cf.* Fudenberg and Tirole 1991), which specifies how beliefs evolve through the rival's strategies (in a Bayesian fashion to the extent possible), and then how strategies, as a function of these beliefs, must be *sequentially rational.* We will first analyze the CI & Investment subgame, and then fold it back to analyze the meta MR stage game.

2.4 The Competitive Intelligence and R&D Investment Strategies

Based on firms' market research decisions, four scenarios can arise at the beginning of this stage: *i*) (M_S, M_W) – both firm conduct MR and are informed about the realized market size; *ii*) $(\overline{M}_S, \overline{M}_W)$ – both firms are uninformed and only know the priors; *iii*) $(M_S, \overline{M}_W)$ – only firm S conducts MR and is informed about the realized market size, while firm W remains uninformed; and *iv*) $(\overline{M}_S, M_W)$ – only firm W conducts MR and knows the realized market size. In the first two cases, the two firms choose *symmetric* market research strategies, and in the last two cases, the firms choose *asymmetric* market research strategies. (However, because firms are ex ante identical, both cases (*iii*) and (*iv*) have identical analysis and are therefore considered together.) In the rest of this section, we specify how the equilibrium strategies unfold for each of these four cases.

2.4.1 Symmetric Market Research Strategies: (M_S, M_W), $(\overline{M}_S, \overline{M}_W)$

If firms choose the same market research strategies, then at the beginning of the CI & Investment stage they will have identical information about the market size (i.e., either both know the market size or both do not). In addition, if both do market research, each firm will obtain the amplification factor m_i, $i \in \{S, W\}$ and because firms have different abilities, market research can possibly generate asymmetry in otherwise symmetric firms. In either case, CI serves only to reveal the rival's investment x_{-i} – the transferrable information on market-size potentially embedded in the investment is either absent (when neither firm does MR in $(\overline{M}_S, \overline{M}_W)$) or is already known to the firm (when both do MR in (M_S, M_W)).

A firm can always conduct CI to observe the competitor's investment (x_{-i}), and then use this information to accordingly tailor its own investment. As can be seen from the best response functions below, each firm's optimal investment level is a concave function of the rival's x_{-i}: it should invest low when the rival choose a very low or very high investment level, and it should invest relatively high otherwise.

$$\begin{aligned} x_S^*(x_W|M_S, M_W, Z) &= \sqrt{\frac{x_W m_S Z}{c}} - x_W \\ x_W^*(x_S|M_S, M_W, Z) &= \sqrt{\frac{x_S m_W Z}{c}} - x_S \end{aligned}$$

But on the flip side, undertaking CI also implies waiting for the rival to invest (otherwise CI is meaningless), observing the rival's investment decisions, and only then deciding one's own. (Essentially, conducting CI implies being a follower in the investment game.) Hence, a firm, by investing early and not concealing information, can push its rival who undertakes CI into a corner by making large aggressive investments. (Indeed, as can be easily shown, firms' profit decrease in the rival firm's investment.) The following proposition resolves this tension and delineates the equilibrium when both firms have identical market research strategies.

Proposition 2.1 *When firms choose symmetric market research strategies in the MR stage, i.e., both do market research (M_S, M_W) or neither does market research ($\overline{M}_S, \overline{M}_W$), then:*

(i) If they have equal MR capability ($m_S = m_W$), there is no unique equilibrium. But in any equilibrium, the firms make identical investments and generate identical payoffs while sharing the market equally independent of their CI and information concealment strategies;

(*ii*) *If both firms do market research and have different MR capability* $m_S > m_W$*, the unique Pareto optimal equilibrium is that firm* W *does not do competitive intelligence and invests early without concealing its investment, whereas firm* S *does competitive intelligence and, hence, invests late. Moreover, in this equilibrium, firm* S *invests more, captures higher market share and earns higher profit than firm* W*.*

Part (i) of Proposition 2.1 indicates that when both firms remain symmetric, either when they do not conduct MR or both conduct MR but have equal MR capabilities (identical m_i), the two firms invest identically, get equal market shares and earn the same profit independent of whether they conduct CI or conceal information. In essence, when firms are symmetric, firms are indifferent between investing early or late. Hence, in our model there are no endogenous advantages to investing early or late, as is the case with sequential-move games in the literature on Cournot and Bertrand competition; nor does our model impose exogenous first-mover or second-mover advantages, as in models of product development, *cf.* Narasimhan and Zhang (2000). This is especially appealing since the driver of any induced sequentially in moves can now be isolated easily – such as difference in m_i, explained next – and more importantly, asymmetric information on market size, which is elaborated in the next section.

However, when firm S's MR capability is higher than firm W's ($m_S > m_W$), as in part (ii) of Proposition 2.1, the indifference breaks down – the unique equilibrium that emerges is that the weaker firm invests in the Early epoch *without* concealing its investment, whereas the stronger firm invests in the Late epoch while undertaking CI to monitor the weak firm's investment. Hence, sequential innovation, with a first and a second mover (who does CI), emerges endogenously when firms have heterogeneous MR capabilities. We call this the *capability effect*, and the intuition is as follows. The stronger firm has an inherent advantage over the weaker firm through m_S which amplifies the efficacy of its investments – for instance, for the same investments, the stronger firm garners a higher market value than the weaker firm. Hence, the dominant strategy of the weak firm is to move Early, and to not conceal its investment from the strong firm to show its commitment to 'set the tone' – a low bar, in fact – for the competition. And the stronger firm itself prefers moving Late and conducting CI since the stronger firm can then tailor its investment according to the weak firm's to optimize profit. In contrast, by not doing CI, the strong firm will equivalently 'play blind' in a simultaneous move game (whether it moves Early or Late) and end up over-investing without commensurate gains in market shares. (Notice that in the market share model, both firms investing high may not necessarily increase market share, but it certainly increases costs. For instance, a doubling of the investment by both firms will not change market shares but will certainly increase costs and lower profits.) Hence, equilibrium delineated in part (*ii*) of the proposition, where the weak firms moves Early, does not conceal its investment whereas the strong firm conducts CI and moves Late, emerges uniquely and, in fact, is Pareto optimal.

Our results mirror praxis. In the Internet browsers competition, Netscape rushed to market much faster than its stronger rival Microsoft, believing that "the new [weaker] company would have to move first, or else Microsoft could destroy it" (Quittner and Slatalla 1998). Coco-cola has often "let others come out, stand back and watch, and then see what it takes to take the category over" (Schnaars 1994). On the theoretical side, our results echo Narasimhan and Zhang (2000) in that firm-specific heterogeneity impacts the timing of entry into a new product market.

The above proposition shows that CI endogenously emerges as an equilibrium when there is no information asymmetry, i.e., the equilibrium in which one firm voluntarily reveals its investment (even when it can costlessly conceal it) and the other firm taps into this information through CI (and thereby acting as a follower in the investment game) emerges endogenously. This is the unique equilibrium when firms differ in MR capability, even if the difference is small, and one of the equilibria when firms have exactly the same capabilities. In effect, this equilibrium is the only *robust* equilibrium (since this is the only equilibrium that survives if the game, where firms have exactly the same capability, is perturbed ever so slightly). Moreover, CI endogenously serves as a channel to establish credible commitments between competing firms – the weaker firm can credibly demonstrate its low investment and ease the intensity of competition in the market, because the stronger firm's competitive intelligence apparatus will surely verify this commitment.

2.4.2 Asymmetric Market Research Strategies: $(M_S, \overline{M}_W)$, $(\overline{M}_S, M_W)$

Asymmetric market research strategies, i.e., $(M_S, \overline{M}_W)$ or $(\overline{M}_S, M_W)$, induce asymmetric information on the market size between the firms – the firm having undertaken market research, the *informed* firm, knows the realized market size, Z_H or Z_L; whereas the firm not undertaking market research, the *uninformed* firm, only has priors on market size. We refer to the informed firm as a *low type* if it learns that the realized market size is low, Z_L, and a *high type* if it learns that the realized market size is high, Z_H.

One key benefit of conducting market research is that it acquires accurate information about the realized market size, which in turn can be used to tailor one's R&D investment. In our model, everything else equal, the optimal R&D investments increase in market size – a firm optimally invests more when the market size is high, and less when the market size is low. However, this very act of tailoring investments to underlying market size by the informed firm would reveal the embedded market information to the uninformed firm conducting CI, allowing the uninformed firm to free-ride on the informed firm's market research. In our model, the formation of a *signaling game* is *plausible* wherein the informed firm moves early and reveals its investment, and the uninformed firm moves late, conducts CI and attempts to infer the realized market size through the informed firm's investment. One striking/unique features of our model is that such a signaling subgame is not assumed exogenously, as is the case with most papers that model and analyze information flows, *cf.* Anand and Goyal (2009) – there is no ex ante guarantee in our model that the informed firm will invest early and not conceal its investment, nor that the uninformed firm will conduct competitive intelligence and invest late – rather signaling evolves endogenously, if at all, through the strategies of both the informed firm (whether to invest early and conceal investment) and the uninformed firm (whether to conduct CI and invest late).

And if such a signaling game is indeed generated, the trade-off for the informed firm is the same as the one in a typical signaling game: Because the investments of firms are strategic substitutes, i.e., a firm's profit decreases in the rival's investment, the informed firm prefers that the uninformed rival *believes* that the market size is low and thereby makes low investment, which reaps higher profit for the informed firm. Consequently, the low type informed firm has incentives to 'assist' the uninformed rival to correctly infer the low market size, whereas the high type informed firm would like to erroneously convince the uninformed firm that the market size is low. Hence, in the parlance of Game Theory, specifically, the Perfect Bayesian Nash Equilibrium, the informed firm's choice of investment induces *beliefs* for the rival firm undertaking CI to infer the realized market size, and both types of informed firm prefer to induce beliefs that the market size is low.

Indeed, signaling may not arise at all if the informed firm simply conceals its investment, thereby also concealing the embedded information on the realized market size. This is different from extant literature, where concealing investments is either not allowed or is not successful (typically because of information *leakage*). Consequently, the only way in the literature to conceal and protect (private) information is to actually 'fudge' decisions such as investments (or related entities such as 'material quantities'), for instance by choosing the amount of investment independent of the underlying market information, so that the uninformed firm is unable to tease out the private information from the level of investments of the informed firm. Hence, a rather unappealing way to protect one's private information in extant literature is to not use that information. In contrast, in our model, we assume that firms can conceal information by simply concealing investments while still using the information about the realized market size to tailor the investments.

In essence, in our model, firms can do all of the following: (*i*) reveal investment as well as the underlying information of realized market size by choosing a distinct investment level for each possible market size (the *separating equilibrium);* (*ii*) reveal investment but conceal market-information by choosing the same investment level independent of the re-alized market size (i.e., throw away the private information about the realized market size through the *pooling equilibrium*); or (*iii*) conceal investments (and hence the private information about the realized market size), but still utilize the information about the realized market size to optimally tailor investments. Extant literature allows only (*i*) and (*ii*), but prohibits (*iii*).

The following proposition derives and establishes the Perfect Bayesian Nash equilibrium when only one firm acquires information, in terms of whether firms conceal information, whether they conduct CI, and their investment levels and timings.

Proposition 2.2 *When only one firm conducts market research, there exist thresholds* $\beta \geq 1$ *and* $0 < \overline{p} < 1$ *such that the Perfect Bayesian Nash equilibrium of the CI & Investment stage satisfies the following: For* $i \in \{S, W\}$,

(i) If $m_i \leq \beta$*, the firm who conducts market research (the informed firm) invests early* <u>*without*</u> *concealing its investment, and the firm who does not conduct market research (the uninformed firm) does competitive intelligence and invests late. Furthermore, if* $p \leq \overline{p}$*, the informed firm plays a* separating strategy, *i.e., it uniquely tailors its investment according to the realized market size; hence, the uninformed firm can perfectly infer the realized market size from the informed firm's investment. If* $p > \overline{p}$*, the informed firm plays a Pareto dominant* pooling strategy*, i.e., it chooses the same investment level for both market sizes; hence the uninformed firm cannot infer the realized market size from the informed firm's investment.*

(ii) If $m_i > \beta$*, the uninformed firm invests early and does not conceal its investment, and the informed firm does competitive intelligence and invests late.*

Consider first the special case $m_i = 1$, which implies that market information collected by the informed firm is purely the nonspecific statistical data on market size with no value to the specific knowledge on consumer needs and tastes. In this special case, the only asymmetry between the informed firm and the uninformed firm is that the informed firm knows the underlying market size whereas the uninformed firm does not. Because $m = 1 \leq \beta$, equilibrium specified in part (i) of the above proposition is played where a signaling game is endogenously formed. Consider first the case when $p \leq \bar{p}$ so that the *separating equilibrium* is played. Under this equilibrium, the informed firm invests early and, not only does it not conceal its investment, the informed firm, in fact, tailors the investment according to the market size (high investment for high market size and low investment for low market size). Consequently, the uninformed firm, by investing late, successfully conducts competitive intelligence and infers the embedded information about the realized market size in the informed firm's investment. In effect, there is no information asymmetry in equilibrium. However, the low type informed firm has to lower its investment (compared to what is optimal if both firms were informed) in order to separate out from the high type informed firm (the investment has to be low enough to dissuade the high type from mimicking the low type).

When $p > \bar{p}$, both types of informed firm invest the same amount regardless whether the realized market size is high or low, i.e., the investment level of the informed firm is agnostic to the underlying market size. Hence, the informed firm, although it reveals the investment to the uninformed firm, suppresses the embedded information on market size. But the downside is that the informed firm too is unable to utilize market information since its own investment does not reflect the underlying state of the market.

The trade-off between pooling and separating as a function of p is clear. For a high p, i.e., when priors for low market size are strong, the uninformed firm's investment is anyway small – hence, the low type informed firm pools with the high type informed firm rather than lowering its investment suboptimally in an effort to separate out. But when p is small, i.e, when the priors favor a high market size, the low type informed firm prefers to separate to prevent a high investment (based on priors) by the uninformed firm.

It is not surprising that the uninformed firm undertakes competitive intelligence, because it can potentially infer the market size by observing the informed rival's investment decision (and notice that $m = 1$, there is no built-in disadvantage for investing late anyway). It also makes sense that the low-type informed firm prefers to help the uninformed rival to correctly infer the low market size by revealing its investment; hence, the low type informed firm prefers to move early and reveal the investment. But it is indeed interesting that the high-type informed firm *chooses* to reveal its investment, especially in the separating equilibrium which also reveals that market size is high, despite knowing that the uninformed firm will do CI and despite being able to costlessly conceal its investment. The underlying reason is that in light of the low type informed firm's strategy of always revealing the investment to the uninformed firm, the very act of concealing investment by the high type informed firm convinces the uninformed firm that market size must be high, thus unraveling any attempt by the high type to conceal market information through concealing investment.[8]

[8]This unraveling of the high type's strategy of concealing investment, when the low type always reveals his own, does not depend on their being only two type. Here is a quick intuition. Suppose there are three types of informed firm, i.e.. the suppose the market size can be low, medium or high. Then the low type, as before, always reveals investment. Hence, if the medium and high types conceal their investment, the uninformed firm will invest based on posterior beliefs that the market is medium or high. But this investment by the uninformed firm can be profitably lowered by the medium type by revealing that market is medium. Hence, any concealment will reveal the market size to be high, thereby unraveling the strategy of concealing investment by any type.

Thus, by muting the capability advantage (by imposing $m = 1$), we distill and isolate the "*information effect*" that drives the informed firm to reveal its investment to the uninformed firm so that a signaling game is *endogenously* formed. (Note that the such signaling, where the informed firm invests earlier than the uninformed firm, is not always formed, such as under conditions of part (*ii*) of the above proposition.) But whether the underlying market size is conveyed to the uninformed firm depends on whether p is above or below a certain threshold $\bar{p}$.

However, as m_i increases, the informed firm gets 'stronger' since the same investment reaps in higher value. Hence, with increasing m_i the uninformed firm faces an onslaught of highly efficacious investments from the informed firm who, by investing early, can crush the uninformed rival, especially when $m_i > \beta$. To avoid being the follower to a highly capable informed firm, the uninformed firm (which is also weaker since it does not enjoy m_i) invests early to set the tone of competition, very much like part (*ii*) of Proposition 2.1, even if it cannot ascertain the informed firm's investment and hence with no chance of inferring the information about the realized market size. Given that they cannot signal low demand anymore, both types of informed firm invest late, successfully conduct CI while concealing their investments, and hence, private information about the realized market size.

So far we have identified the equilibrium outcomes in the CI & Investment stage for all the four possible outcomes that can arise after the MR stage. Our analysis shows that competitive intelligence emerges endogenously – there is always an equilibrium where one firm successfully conducts CI with the implicit participation of the rival who voluntarily reveals information. And in many reasonable cases, CI reveals not only the rival's investment, but the embedded information on market size as well. Our insights do not rely on there being only two states of market size (high or low), or that information collected through either MR or CI is perfect and noiseless.

Creating and establishing credible commitments can be notoriously difficult. Moreover, credibly exchanging information often requires vetting by neutral third parties. In contrast, we show that CI endogenously establishes a credible channel of communication between competing firms, which can be used to convey investments and market information – as a consequence, it serves as an effective commitment device without the need for third parties. Moreover, CI, together with the capability effect and information effects, induce sequential investments: firms with superior market information and weaker capability tend to speed to the new product market, while firms with less market information and stronger competitive skills are more likely to wait and observe. Hence, our results provide a new rational explanation to the mixed observations of first-mover and second-mover advantages in practice.

2.5 The Market Research Strategy

As our analysis clearly shows, information about the realized market size is critical in determining firms' competitive intelligence and investment strategies, and their payoffs in a competitive new product market. Information on market characteristics, such as market size, is typically not exogenously given – rather, firms actively conduct market research to gather and analyze information about customers and other characteristics in a new product market (*c.f.* Ottum and Moore 1997). Daughety and Reinganum (1994) also suggests, "...if asymmetries [between competitors] in information [about market demand] persist, there should be a reason and the reason should involve choice, possibly in conjunction with, but certainly not entirely supplanted by, chance."

In this section, we analyze the firms' strategies in the market research stage, given the outcomes in the CI & Investment stage. The trade-offs in conducting MR are self-evident and yet subtle at the same time. Clearly, acquiring information yields two benefits: it yields accurate information on the market size, and it generates the value amplification factor m_i. But at the same time, these decisions are made in a competitive market where the firm's information on the realized market size, is vulnerable to CI by the rival. This in turn imposes a burden of appropriately managing the market information, *a la* Proposition 2.2. At first glimpse, it might suggest that CI might be an inferior information acquisition strategy even if it infers the market size successfully because it would not be able to generate the amplification factor m_i for firms. But this strategy can indeed be optimal even when acquiring information through MR is free, as the following Proposition proves.

Proposition 2.3 *For a given new product market (p, Z_H, Z_L), the Nash Equilibrium market research strategies satisfy the following.*

(i) If both firms' value amplification factors from market research are very small, (i.e., $1 \leq m_W \leq m_S \leq \beta_0$), the unique equilibrium is $(\overline{M}_S, \overline{M}_W)$ where neither firm conducts market research.

(ii) If both firms' value amplification factors from market research are moderate, (i.e., $\beta_0 < m_W \leq m_W^*$ and $\beta_0 < m_S \leq m_S^*$), there are two asymmetric equilibria $(M_S, \overline{M}_W)$ and $(\overline{M}_S, M_W)$ where either firm but exactly one conducts market research.

(iii) If the weaker firm W's value amplification factor from market research is very small and the stronger firm S's is not too large, or if weaker firm W's is moderate while the stronger firm S's is large (i.e., $1 \leq m_W \leq \beta_0 < m_S \leq \beta$*, or,* $\beta_0 \leq m_W \leq m_W^*$ *and* $m_S^* < m_S \leq \beta$ *), the unique equilibrium is* $(M_S, \overline{M}_W)$ *where firm S conducts market research and firm W does not.*

(iv) If firm S's value amplification factor from market research is very large, or if both firms' value amplification factors from market research are large enough (i.e. $m_S > \beta$*, or,* $m_W > m_W^*$ *and* $m_S > m_S^*$*), the unique equilibrium is* (M_S, M_W) *where both firm conducts market research.*

Each firm needs to evaluate the following three forces associated with market research: (i) the value amplification factor from market research, m_i; (ii) the potential burden of strategically managing the information on market size if the competitor chooses not to conduct market research and a signaling game is to be played (i.e., when the firm's own $m_i \leq \beta$), as for the informed firm in proposition 2.2; and (iii) the potentially missed opportunity of forgoing market research and profiting from the competitor's under-investment distortion if the competitor chooses to conduct market research (when the competitor's $m_i \leq \beta$), as for the uninformed firm in proposition 2.2. The interplay between the benefits and the potential drawbacks of market research critically depends on firms' value amplification factor from market research, m_i. Figure 2.2 below visually demonstrates the above proposition, along with the respective competitive intelligence strategies under each equilibrium. The 45^0 line represents the case where the firms have symmetric value amplification factor from market research ($m_S = m_W$). In the figure, β_0 shows the minimum m_i required

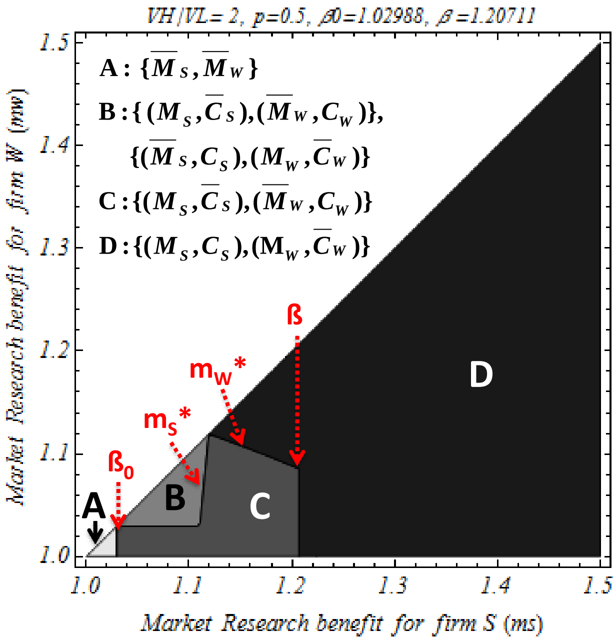

Figure 2.2: Equilibrium information acquisition strategies.

for either firm to offset the information management burden, while m_S^* and m_W^* are the minimum levels of m_S and m_W for the benefit of higher market value to overweigh the potentially value of forgoing market research and profiting from the informed competitor's investment distortion. Note that for $m_i > \beta$, there will be no signaling game even under an asymmetric market research structure, so the latter two forces will be absent.

In Region A, for either firm, the value amplification factor from market research is very small ($1 \leq m_W \leq m_S \leq \beta_0$). In light of the limited value of market research, it is a dominant strategy for a firm to not conduct market research, because the onus of strategically managing private information on market size is too much of a burden if the competitor is expected to forgo market research and it is more lucrative to force the competitor to distort the investment decisions if the competitor conducts market research.

Hence, as in part (i) of the above proposition, $(\overline{M}_S, \overline{M}_W)$ is the unique nash equilibrium. In the CI stage, proposition 2.1 is played where, given the symmetry of firms, all possible sequences and CI strategies are possible.

In Region B, the value amplification factor from market research for both firms are large enough to offset the information management burdens, so both firms are willing to conduct market research even if the competitor is expected to forgo market research; however, the benefits from market research are still smaller than the profits from the rival's investment distortion in an asymmetric information structure, so the firms still prefer to only do competitive intelligence if the competitor is expected to conduct market research. Hence, as in part (ii) of the above proposition, there are two asymmetric equilibria where exactly one firm acquires information from market research. In the CI stage, part (i) of the proposition 2.2 is played where the uninformed firm undertakes competitive intelligence to observe the competitor's investment actions and infer market size information. Interestingly enough, the weaker firm W with m_W may be the one to acquire information from market research, while the stronger firm S with m_S may choose to forgo the free market research and only rely on the competitor's signals.

In Region C, the unique equilibrium is that, the stronger firm S conducts market research, and the weaker firm W infers the market size information through competitive intelligence. The underlying reason is two folded. In the bottom rectangle part of the region $(1 \leq m_W < \beta_0 < m_S \leq \beta)$, it is a dominant strategy for the weaker firm W to not conduct market research due to its small m_W, while the stronger firm S prefers to conduct market research. In contrast, in the top part of the region ($\beta_0 \leq m_W \leq m_W^*$ and

$m_S^* < m_S \leq \beta$), it is a dominant strategy for the stronger firm S to always conduct market research because m_S is large enough (larger than m_S^*) to offset either potential drawbacks of market research discussed above; anticipating that the rival is acquiring information through market research, the weaker firm W prefers to just conduct competitive intelligence to infer information from the rival because $m_W < m_W^*$.

Finally, as m_W continues to increases and $m_W > m_W^*$ (i.e., in the top part of region D), the weaker firm W is also not willing to give up on the benefits of market research, so both firms conducting market research is the unique equilibrium. Interestingly, in the bottom part of region D, the weaker firm W also chooses to acquire information through market research even though its value amplification factor from market research is very small. This is because, we have $m_S > \beta$ so that the stronger firm S always conducts market research, and it can successfully hide its investment and avoid the information management burden if it is the only informed firm, as per part (ii) of proposition 2.2. Hence, for the weaker firm W, both potential drawbacks of market research are absent as there will be no signaling game to be played, and it should also conduct market research to learn the realized market size to tail its R&D investment. Because both firms conducting market research is the unique equilibrium, in the CI stage, proposition 2.1 is played where the weaker firm W invests first and the stronger firm S invests late and does competitive intelligence.

Corollary 2.1 *In a given new product market, the stronger firm S is more likely to conduct market research and invest early. Even when firms are ex ante identical, they may rely on different information acquisition strategies to resolve market uncertainty.*

Our equilibrium result shows that firms may acquire market information through different channels. Clearly, the firm with higher value amplification factor from market research has more incentive to do market research. However, it is also possible that the firm with weaker value amplification factor from market research chooses to conduct market research, while the firm with stronger value amplification factor from market research chooses to acquire information only through competitive intelligence, when both firms have moderate value amplification factor from market research.

2.6 The Impact of Competitive Intelligence

As a classic information acquisition tool, market research and its role of directly reducing uncertainties in new product market have been well studied by both researchers and practitioners. Yet, much less attention has been focused on the role of competitive intelligence in a competitive R&D market, especially its interaction with market research and R&D investment decisions. To tease out the impact of competitive intelligence, we first study a benchmark scenario where competitive intelligence is not possible, and then compare the equilibrium results of this benchmark with the results of our original model with competitive intelligence studied above.

The benchmark case is very similar to the original model except both firms *cannot* do competitive intelligence. That is, in the benchmark case, both firms can only choose to conduct up-front market research to resolve market uncertainty, before choosing their R&D investment decisions in the new product market. They cannot conduct competitive intelligence. As a result, they cannot observe their competitor's investment decisions or infer their competitor's private information about the market size through CI. The following proposition characterizes the equilibrium information acquisition strategies, investment strategies, and expected payoffs for the two firms in the benchmark model. (Let x_{i0} and π_{i0} denote firm i's investment level and excepted payoffs respectively in the benchmark model.)

Lemma 2.1 *When competitive intelligence is not possible, both firms will conduct market research. The equilibrium investment levels are* $x^*_{S0} = \frac{m_S^2 m_W Z}{c(m_S+m_W)^2}; x^*_{W0} = \frac{m_S m_W^2 Z}{c(m_S+m_W)^2}$, *and their payoffs in the R&D market are:* $\pi^*_{S0} = \frac{m_S^3 Z}{(m_S+m_W)^2}; \pi^*_{W0} = \frac{m_W^3 Z}{(m_S+m_W)^2}$.

In absence of competitive intelligence, firms cannot directly observe each other's investment decisions or infer private information about the market size. Hence, the tensions that hold back the firms from doing market research in our original model – namely, the potential strategic information management burden and potential benefits from the competitor's signaling distortion – do not exist in the benchmark case. As a result, both firms find it optimal to always conduct market research. This outcome echoes the conclusion in existing literature that market research is valuable in new product markets, helping firms to make better investment decisions. Also since firms cannot monitor their competitors' investment decisions through competitive intelligence, investing early or late has no impact on their information endowments and firms always choose their investment levels based only on their expectations about the competitor's R&D decision as if they "simultaneously" make their R&D decisions. The equilibrium investment levels and payoffs depend on their capabilities of amplifying the market value through market research.

We now compare the outcome in benchmark case to the results of our original model with CI in Proposition 2.3, to see how the presence of CI impacts firms' information acquisition and investment strategies. An immediate observation is that the availability of competitive intelligence reduces firms' incentives for market research, as summarized in the proposition below.

Proposition 2.4 *The availability of competitive intelligence blunts firms' incentives for market research: (i) It is possible that a firm chooses to acquire information only through competitive intelligence, although market research is free and guarantees perfect information and the benefit of value amplification factors while competitive intelligence relies on the competitor acquiring and revealing information through investment decisions; (ii) Furthermore, a firm may choose to forgo both market research and competitive intelligence, and remain uninformed when making R&D investment decisions.*

In the benchmark case, both firms will always conduct market research to acquire information. However, with the presence of competitive intelligence, (M_S, M_W) emerges in the equilibrium only in Region D in Figure 2.2 when the value amplification factors for both firms are large enough. In Regions B and C in Figure 2.2, one firm chooses to acquire information through competitive intelligence rather than market research, even though market research is free and guarantees perfect information about market size and the benefit of value amplification, while competitive intelligence relies on the competitor acquiring and revealing information. In Region A in Figure 2.2, both firms actually choose not to conduct market research and remain uninformed instead because of the information management burden introduced by the possibility of CI by the competitors.

Competitive intelligence also impacts firms' R&D investment decisions. With the possibility of CI, the two firms always invest sequentially, and the firm investing late can fully observe the pioneering competitor's investment decisions through competitive intelligence before choosing its own R&D investment level. When firms adopt symmetric market research strategies (in Regions A and D in Figure 2.2), the strong firm conducts competitive intelligence to observe the weak competitor's investment decisions and then utilize this information in choosing its own R&D investment level. When firms adopt asymmetric market research strategies (in Regions B and C in Figure 2.2), the presence competitive intelligence actually leads to an endogenously formed signaling game where the informed firm needs to strategically the market information signals in his investment decisions. The following proposition concludes the impact of competitive intelligence on firms' payoffs in a competitive R&D market.

Proposition 2.5 *(i) A firm may benefit from his competitor's competitive intelligence: although the firm investing early is vulnerable to its competitor's competitive intelligence, it may get a higher expected payoff than that in the benchmark case without competitive intelligence. (ii) Competitive intelligence can benefit the industry as a whole: the total expected payoff of the two firms can be higher than that in the benchmark case without competitive intelligence.*

Although competitive intelligence does reduce firms' incentive to do market research, it can actually increase the total payoff for the firms and benefit the industry as a whole. This is because, by helping firms monitoring their competitor's investment decisions, competitive intelligence essentially establishes a credible information channel between the competing firms, or more precisely, an information flow from the pioneering firm who invests early to the lagging firm who invest late. This allows the pioneering firm to actively or passively show his R&D investment commitment, or helps the lagging firm to better coordinate its R&D investment decision. Because the pioneering firm invests early, it cannot observe and utilize the competitor's investment decisions in tailing its own R&D investment level. In addition, its own investment decision and possibly his private superior information about the market size are vulnerable to the competitor's competitive intelligence. But the firm may still benefit from the competitor's competitive intelligence and get a higher payoff than that in the benchmark case. This is also because of the credible information flow established by competitive intelligence. The pioneering firm can strategically influence the lagging competitor's investment decisions by its own commitment in R&D investment through this communication channel enabled by competitive intelligence. However, his benefit from competitive intelligence will be smaller than that of the lagging firm who can utilize the information collected by competitive intelligence in choosing his investment level.

In our market share attraction model, the two firms are better off if they can share the new product market without over-competing with each other. Competitive intelligence indeed eases competition intensity by lowering the total R&D investments in the competitive R&D market. When firms choose the same market research strategies (in region A and D in Figure 2.2), the weak firm W strongly prefers to avoid head-to-head competition and lower its R&D investment. With the strong firm S's competitive intelligence, the weak firm can invests early and credibly commit to a low R&D investment, and the strong firm can invest late and also lower its own R&D investment after verifying the weak firm's investment level. The similar logic applies when firms choose asymmetric market research strategies (in region B and C in Figure 2.2), where the informed firm has incentive to under-invest to signal the private information about the market size. In either case, competitive intelligence enables the two firms to communicate and coordinate their investment decisions, and lower the competition intensity in the new product market. In fact, except for a small part of Region I, the benefit of information communication through competitive intelligence dominates the loss from reduced incentive in conducting market research, and the industry gets a higher total expected payoff when competitive intelligence is available.

2.7 Conclusion

Compared to the well studied Market Research, Competitive Intelligence is a relatively recent phenomenon. Our research is amongst the first to spotlight competitive intelligence, and shows how (and why) competitive intelligence emerges as an alternate channel to obtaining information. In specific, our key finding that competitive intelligence emerges even when firms have the option to costlessly conceal their information supports praxis in providing a novel explanation, centered around the need to strategically manage information, for the recent emphasis towards competitive intelligence. In addition, from a more theoretical perspective, our results shed light on the impact of CI on sequential innovation and industrial welfare. In fact, the endogenous evolution of CI in our model lends credence to several theoretical papers that assume that decisions and moves of the rival are observed by default.

Although we have kept our assumptions to a minimum, and the decisions in our setup evolve endogenously without being encumbered by an imposed sequence of moves – an exogenously specified sequence of moves is, in fact, ubiquitous in most such game theoretic models – our model remains stylized and rests on several assumptions, such as only two possible sizes of the market, perfect information through market research, etc. However, we can relax most of these assumptions without altering insights.

Our model of two horizontally competing firms is set within an R&D context. However, the scope and importance of competitive intelligence can be much broader and deeper than that – it can easily be extended to vertical firms or both horizontal and vertical firms; and not necessarily within R&D contexts. In fact, the presence of CI, which is now a billion dollar industry, will likely tweak the way firms make and execute decisions in the near future. All of this presents a fascinating avenue for future research.

Chapter 3

Trembling into Myopia: Honesty in the Dynamic Hold-up Problem

3.1 Introduction

In the classical *hold-up problem* (*cf.* Klein *et al.*, 1978; Milgrom and Roberts, 1992), a firm's *relationship-specific commitments* – i.e., commitments which are most useful in a specific relationship – leave it vulnerable to *ex post* opportunistic behavior by its contracting partner (whether its supplier or its customer). An illustrative example of the hold-up problem, as detailed in Milgrom and Roberts (1992), is in the location of coal-fired electricity-generating plants. For efficiency reasons, plants prefer locating near the source of energy (coal). However, building the plant near the coal-mine is a relationship-specific investment – once the plant is built near the coal-mine, it is locked into purchasing coal from the mine for the very reasons collocating is efficient in the first place. Hence, the plant is susceptible to being *held up* by the coal-mine. For instance, once a plant is collocated with the coal-mine, the mine can gouge the plant's profits by increasing (*renegotiating*) the price of coal. Locating the plant near customers (an alternative efficient arrangement) may not solve the hold-up problem either. For such plants, coal must be hauled from the mines to the plant – doing so by railroad is often the most cost-efficient. Once the rail-lines are setup between the plant and the mine, the plant can potentially hold-up the railroad company – for instance by paying lower than agreed tariff to the railroad – since these rail-lines are typically useless outside of hauling coal from the mine to the plant (the rail-line is a relationship-specific investment).

Two conditions are necessary for hold-ups to emerge (*cf.* Milgrom and Roberts, 1992). The first is relationship-specific commitments. As Pennings *et al.* (1984, page 308) note: "The more specialized [relationship specific] a firm's commitments, the more it entraps itself...fostering opportunistic behavior among the customers [contracting partners]." The second condition for hold-ups to emerge is *non-contractible outcomes* (arising out of *contract incompleteness*), which allow wiggle room for opportunistic ex post renegotiations. Figure 3.1 details the typical timeline for the hold-up problem (*cf.* MacLeod, 2002). The key features are: (*i*) The relationship-specific investment or effort (Stage 2); (*ii*) Noncontractible outcomes (Stage 3); and (*iii*) The possibility of renegotiation or hold-up (Stage 4).

The canonical example of General Motors (GM) Vs. Fisher Body illustrates how relationship-specific commitments and non-contractible outcomes can interweave to drive hold-ups. The following account of GM-Fisher Body dealings is based on Klein *et al.,* 1978; and Klein, 2007.

In the year 1919, car-design began shifting to closed metal bodies from open wooden

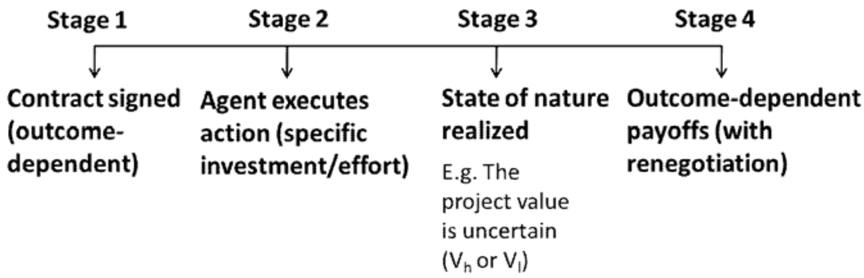

Figure 3.1: A typical timeline for the hold-up problem (cf. MacLeod 2002)

ones. In an effort to guarantee an adequate supply of closed-metal-bodies, GM asked its key supplier, Fisher Body, to make significant GM-specific commitments in dies and stamping machines. Fisher Body balked for fear of being held up by GM once these GM-specific commitments were made. To alleviate these fears, GM signed a 10 year exclusive cost-plus contract with Fisher Body, which stipulated that Fisher Body would be the exclusive supplier for all the closed-metal-bodies required by GM. To prevent a *reverse* hold-up, i.e., to prevent Fisher Body from exploiting the exclusivity to overcharge GM, a complex set of constraints was placed on the price. It was hoped that the exclusive contract with its built-in checks-and-balances would prevent either firm from holding up the other. This worked for a few years. Around 1924, two events colluded to significantly increase GM's demand for closed-metal-bodies: (*i*) there was a sudden surge in demand for GM products, especially the Chevrolets; and (*ii*) the industry adopted closed-metal-bodies in a big way. (According to GM's annual report of December 1924, more than 65% of the cars produced in the previous year had closed-metal-bodies.) This spike in demand was not anticipated by either GM or Fisher Body, and hence commensurate actions were not discussed in the original 1919 contract (i.e., the contract was incomplete despite its sophistication). General Motors therefore sought to renegotiate the original contract; in specific, it wanted Fisher Body to collocate its manufacturing plants with GM's assembly plants to economize on the costs of transporting closed-metal-bodies from Fisher Body's plants to GM's assembly plants. Fisher Body, however, once again balked for fear of being held-up. (Collocating the plants would have been another relationship-specific investment.) Because GM was locked into an exclusive contract with Fisher Body, it could not seek alternate source of supply, thereby incurring extremely high transportation costs. The impasse was finally resolved in 1926 when GM vertically integrated with Fisher Body. [Based on Klein *et al.,* 1978; Klein, 2007]

In the GM-Fisher Body example above, there were two instances of relationship-specific commitments: The first were the GM-specific dies and stamping machines procured by Fisher Body. The second was the commitment made by GM to exclusively purchase from Fisher Body (at essentially a cost-plus price) for a period of 10 years, which Fisher Body ultimately leveraged to hold up GM by refusing to collocate plants. There were also two instances of non-contracted outcomes: (*i*) There was an unanticipated spike both in the overall demand for cars and in the demand for closed-metal bodies; and (*ii*) Consequently, the need for collocation was not anticipated, and was hence not covered in the original 1919 contract. Thus, both relationship-specific commitments and incomplete contracts interweave to create the possibility of hold-up, leading to difficulties in vertical relationships, as in the case of GM and Fisher Body.

In fact, the field of operations management is replete with examples of incomplete contracts and relationship-specific commitments which together can lead to hold ups. For instance, firms in short clockspeed industries, such as electronics, face an inexorable pressure to launch new products quickly. To accelerate product launch, suppliers are contracted to build product-specific production capacity while the product is still being developed (so that the product can be manufactured as soon as development is finished). Consequently, such capacity contracts are typically incomplete since neither the procurement price nor the product specifications can be finalized when the contracts are signed, Sako (1992). Hence, with both relationship-specific commitments (in the form of product-specific capacity investments) and incomplete contracts in play, the potential for hold ups is writ large, *cf.* Taylor and Plambeck (2007), Sako (1992). Similar challenges are also faced by automotive manufacturers in getting their suppliers to build capacity for the rapidly evolving hybrid vehicles, Hoyt and Plambeck (2006).

In general, hold-ups (or even the fear of hold ups) stifle relationship-specific commitments, leading to inefficient outcomes. For instance, in the GM-Fisher Body example above, GM was forced to incur unnecessarily high transportation costs due to Fisher Body's refusal to collocate plants (as noted above, Fisher Body effectively held up GM by leveraging the exclusive cost-plus supply contract); Sako (1992) documents how Toshiba's UK suppliers typically balk at investing in relationship-specific capacity, for fear of being held up, unless price and design specifications are fixed (see discussion above).

The classical remedies proposed in the economics literature to mitigate the hold-up problem are often complex (e.g., sophisticated contracts which focus on minimizing incentive conflicts between firms even though contracts are incomplete; see, for instance, Bolton and Dewatripont 2005, chapter 12), and extreme (such as vertical integration); *cf.* Milgrom and Roberts (1992). (Incidentally, both these remedies were witnessed in G.M. Vs. Fisher Body.)

However, vertical integration is not widespread and, indeed, many bilateral relationships thrive with simpler vertical contracts instead of the more sophisticated contracts proposed in the literature, despite the wide prevalence of incomplete contracts and relationship-specific commitments which together can lead to hold ups. (Several eminent economists, notably Coase (1988, 2006) and Tirole (1999), have flagged this troubling inconsistency between theory and practice.) For instance, several Japanese suppliers of Toshiba – in contrast to the U.K. suppliers who, as noted earlier, are reluctant to invest in relationship specific capacity unless price and design specifications are fixed – willingly invest in capacity before prices and designs are finalized, and they are compensated by Toshiba without hold ups, Sako (1992). In fact, in many instances, these suppliers initiate investments in capacity, or start production, merely based on requests placed by phone or fax by the buyer. In another example, the practice of placing *soft orders* (orders that are not binding, and hence are not court enforceable) is common in the semi-conductor industry. Such soft orders reflect the best available forecast that the downstream manufacturer has at that point in time, and are used by the upstream suppliers to plan and initiate their capacity and production decisions. In fact, suppliers often invest in relationship-specific capacity based on these soft orders before more formal court-enforceable binding orders are placed, even though the threat of hold ups looms large, Taylor and Plambeck (2007), Cohen *et al.* (2003), Johnson (2003). Finally, for every Fisher Body, there is also an A.O. Smith, another supplier of closed metal bodies, with which GM had a harmonious relationship for many years, Coase (1988).

Several questions arise that we attempt to address in this research. Given the propensity to hold-ups, why is vertical integration not more widespread, and why do so many bilateral relationships thrive (as also noted Coase, 2006)? Furthermore, why do so many of these firms employ simple vertical contracts instead of the more sophisticated contracts proposed in the literature? In essence, how is the threat of hold-up mitigated in practice (as the evidence indicates it must be), without resorting to complex contracts and vertical integration? A possible unifying explanation for all the above questions is that firms do honor their contractual obligations, even when presented with opportunities to hold-up (as the following example shows). Macaulay (1963) argues that: "...a key virtue of relational contracting is that parties can count on each other to abide by the spirit of the contract... one doesn't run to lawyers if he wants to stay in business because one must behave decently." The question that then arises is: Why and when would firms *choose* to be irrationally *honest* (defined in this context as always honoring contractual terms and hence never holding up their contracting partners)?

We answer this question through a stylized dynamic economic model of an evolving relationship between a manufacturer and its supplier wherein the manufacturer has the opportunity to hold-up the supplier. Our model has three essential features: (*i*) A dynamic (multiperiod) setting to capture repeated interactions between a profit-maximizing manufacturer and its supplier; (*ii*) A manufacturer who is, with some probability, *rational, myopic* or *honest,*[1] although this particular trait cannot be discerned or signaled in advance[2]; and (*iii*) A tendency for *all* types of manufacturer to *tremble into myopic behavior* – manufacturers may play their optimal myopic (single-period) strategy, even when this differs from their optimal dynamic strategy, for reasons ranging from bounded rationality to intra-firm incentive conflicts. (Refer to Section 3.1.1 for an elaborate discussion on the fundamentals of our modeling framework, including trembles into myopia.)

We prove that: (*i*) The the mere possibility of honest manufacturers can elicit honest behavior from rational manufacturers, thereby mitigating the hold-up problem. (This result is similar in flavor to the well-known result in the reputations literature where even

[1]These traits are defined more formally in Section 4.2. But, in short, the honest manufacturer never holds up his contractual partner, the myopic manufacturer always holds up his contractual partner, and the rational manufacturer may or may not hold up his contractual partner, whichever gives him a higher payoff.

[2]In Frank's (1987) model, set in the context of evolutionary game theory, there exist exogenous characteristics that (imperfectly) signal honesty *before* interactions occur. Furthermore, interactions with an honest partner are *exogenously* rewarded with higher payoffs. Hence, both opportunistic and honest individuals within populations seek honest partners to interact with, given the ex ante (imperfect) signal of honesty. Given the propensity to interact with honest partners, Frank proves that in equilibrium populations must include a certain proportion of honest individuals. In contrast, in our paper, there is no ex ante signal of honesty nor is honesty rewarded exogenously with higher payoffs. Despite this, we prove that honesty can emerge as the optimal policy.

a small probability of *commitment type* who has one strategy, such as the honest type in our model, can force the rational type to mimic the commitment type's strategy for some periods of play. The contribution of this paper is in fleshing out the details and structural results within the context of the hold up problem in specific and incomplete contracts in general.) (*ii*) But more importantly, we go above and beyond the reputation literature in proving that, under very reasonable conditions, the honest manufacturer obtains greater profit than both the rational and the cheat manufacturer, even though the rational manufacturer's strategy space includes mimicking the honest manufacturer (but not vice-versa). And thus, the disconnect between practice and theory that was alluded to earlier can be bridged with honesty since the hold-up problem is mitigated without resorting to complex contracts or vertical integration.

3.1.1 Bounded Rationality: Transaction Cost Economics and 'Trembles into Myopia'

Bounded rationality is a sine qua non for studying real-life economics; as Rubenstein (1998, pg. 4) argues: "...substantive rationality is actually a constrained on the *modeler* rather than an assumption about the real world...[however] without [rationality] we are left with a strong sense of arbitrariness." Thus, to incorporate bounded rationality in our modeling framework, and yet to avoid the pitfalls of moving too far away from rationality – hence players in our model are *intendedly* rational but *limitedly* so, Simon (1964, p. xxiv) – our model makes two very measured and well-founded departures from the tenets of rationality: (*i*) Players are unable to write complete contracts enforceable in a court of law, which places our model squarely within the framework of *Transaction Cost Economics* (TCE) *cf.*

Williamson 1985; and (*ii*) Players can *tremble into myopia.*

Transaction cost economics. The contracting literature in neoclassical economics, such as the mechanism design approach, is oriented towards removing (ex ante) incentive misalignments between contracting parties thus enabling frictionless execution of contracts ex post. Such an approach not only requires anticipating *all* contingencies that may arise – thereby placing extraordinary demands on human faculties – but also assumes that disputes are effectively and costlessly adjudicated by the courts. The world of *Transaction Cost Economics (TCE), cf.* Williamson (1985), eases the gargantuan expectations on both fronts: it explicitly allows for *bounded rationality* whereby firms are unable to foresee "everything that might happen and unable to choose optimal actions at the blink of an eye" (Kreps 1990, Pg. 745) – hence, rather than anticipate all bridge crossings in advance at the time of signing the contract, only actual bridge crossings are addresses by the firms as the events unfold – nor are courts able to effectively settle all disputes.[3] Hence, in the world of TCE, the ex post costs of consummating a contract become at least as important as the ex ante costs of drafting the contract.

The friction in executing incomplete contracts is exacerbated by two elements: (i) Relationship specific investments (or *Asset specificity*), described earlier[4]; and (ii) *Opportunism* (described below).

Williamson (1985) describes opportunism as 'self-interest with guile'. An oppor-

[3]Macaulay argues that, in sharp contrast to neoclassical presumptions in both law and economics, contractual disputes are more often than not settled privately by parties without resorting to the court of law. In fact, Galanter (1981, Pg. 4) argues that "...in many instances the participants can devise more satisfactory solutions to their disputes than can professionals constrained to apply general rules on the basis of limited knowledge of the dispute."

[4]More formally, a transaction is said to have high asset specificity if, as the transaction develops, one side or the other or both become tied to and in the power of the other side, see Kreps 1990, Pg 747.

tunistic individual seeks to maximize his gains and can lie, cheat and deceive with impunity if it serves his purpose. Such opportunism is very much ingrained in the study of contracts in neoclassical economics as well. For instance, adverse selection and moral hazard problems are two well-studied instances of ex ante and ex post opportunism respectively. In our model, the rational manufacturer is an archetypal opportunistic player. In contrast, the *honest* manufacturer is self-interested but without guile.[5] He seeks to maximize his profits within the confines of the signed contract (ex post strategic behavior is denied). Williamson (1985) calls this the 'world of promise' where, despite asset-specificity and bounded rationality, the execution of the contract with an honest manufacturer is efficient and self-enforcing.

Trembles into myopia. Most business relationships have an 'ongoing' dynamic flavor – firms interact with each other repeatedly. Within the context of repeated interactions, an optimal (dynamic) strategy optimizes expected profits of a firm over all interactions – present and future. In contrast, a *myopic* strategy maximizes present gains while ignoring future interactions. The myopic strategy can be dynamically optimal under certain conditions (*cf.* Sobel, 1981; Anand, 2014), or it may be an optimal response to high uncertainty, poor information or risk aversion – especially in the presence of deliberation costs (*cf.* Conlisk, 1996). But in most dynamic contexts such as ours, the myopic strategy is suboptimal; however firms play it for various reasons ranging from bounded rationality (*cf.* Conlisk, 1996) to incentive conflicts within firms (*cf.* Anand and Mendelson, 1997). It is in this spirit that firms in our model can *tremble* into myopia where, with a small probability, they

[5] It can be argued that since the honest manufacturer in our model acts in accordance with a specified *behavioral* pattern – that of always honoring the contract – he is *behaviorally rational.* However, a behaviorally rational individual does not maximize a utility function (*cf.* Kreps 1990, pg. 747). In contrast, the honest manufacturer in our model maximizes profits and hence is more consistent with Williamson (1985)'s nomenclature of 'self-interested without guile'.

mistakenly play the myopic strategy.

A note on trembles. Beginning with the seminal paper by Selten (1975), *trembles* – where players mistakenly play unintended strategies – have been regarded as inevitable by game theorists. Trembles have mostly been used to *refine* the set of Nash equilibria and are conventionally not viewed as a constraint on the rationality of players even though trembles are mistakes in executing strategies. (Aumann (1997) ironically calls this particular use of trembles as super-rationality where players are rational not only on the equilibrium path but off the equilibrium path as well.) However, consistent with Aumann (1997, pg. 8), this paper takes the view that trembles are small departures from rationality where players make mistakes in executing strategies in the presence of debilitating factors such as deliberation costs. Moreover, much of economics has treated trembles as random and arbitrary (*cf.* Aumann 1997, pg 9.) without isolating the source of trembles, or the precise 'technology of errors' (Kreps 1990). For instance, in Selten (1975)'s seminal paper, players tremble with arbitrary probabilities to alternate strategies. Myerson (1978) allows for lower trembling probabilities for more expensive mistakes, but without a precise mapping between the cost of trembles and trembling probabilities. In contrast, trembles in our paper are not arbitrary: players, as noted above, tremble only to their myopic strategy in the presence of deliberations costs or incentive conflicts within firms.

3.2 The Model

A *m*anufacturer and a *s*upplier, indexed by m and s respectively, are engaged in a relationship that lasts for two periods. In each period, indexed by $i \in \{1, 2\}$, the

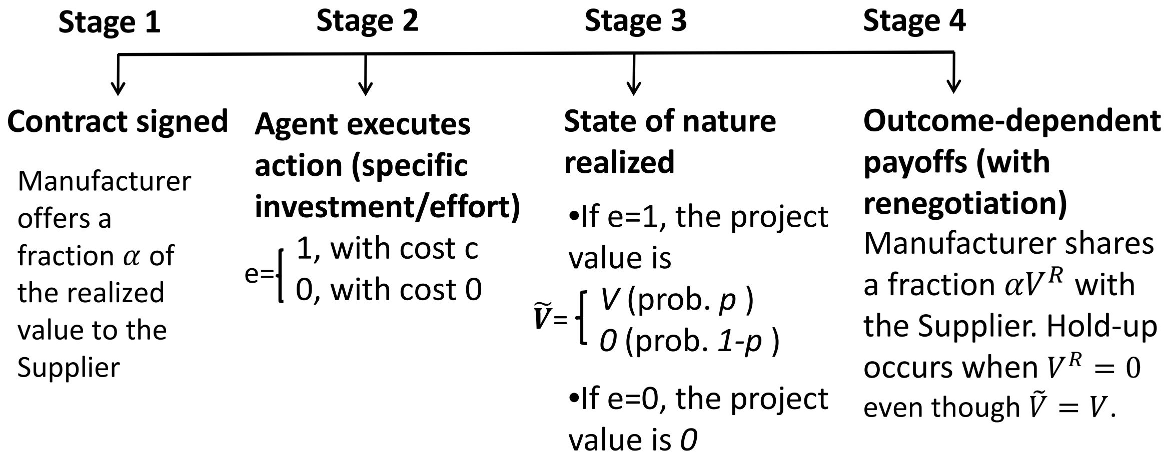

Figure 3.2: Sequence of events

supplier can make a relationship-specific investment e_i which generates a value of $\tilde{V}_i$ for the manufacturer. In return, the manufacturer promises a fraction of the realized value as compensation to the supplier. Both firms are risk-neutral, expected profit maximizers.

In specific, in *each* period i, there are four stages, see Figure 3.2. (The sequence of events in Figure 3.2 operationalizes Figure 3.1, which delineates the events in the classical hold up problem. Indeed, our sequence of events and the accompanying assumptions are consistent with classical papers on hold up, *cf.* MacLeod (2002).

In Stage 1, the manufacturer contracts with the supplier to share a fraction α_i of the potential project value $\tilde{V}_i$, which is realized in Stage 3. The payment (or part thereof) to the supplier must depend on the realized outcome $\tilde{V}_i$ otherwise the supplier has no incentive to invest at all. In fact, our assumed contractual form is optimal for the manufacturer, refer to Propositions 3.1, 3.2 and 3.3.

In Stage 2, the supplier decides his investment $e_i \in \{0, 1\}$ at a cost of $C(e_i)$, where $C(1) = c$ and $C(0) = 0$. Consistent with the literature on hold ups (*cf.* Klein *et al* 1978), the supplier cannot sell the value derived from his investment to any other firm, i.e., the supplier's investment is relationship-specific and has no value outside the supplier's relationship with the manufacturer. Moreover, consistent with models of hold up and moral hazard, the investment is non-contractible.

In Stage 3, the project value $\tilde{V}_i$ is realized. The project value $\tilde{V}_i$ is uncertain and is jointly determined by the supplier's investment level e_i and nature (e.g. uncontrollable market forces). In specific, $\tilde{V}_i = e_i (V_H - V_L) + V_L$ with probability p and $\tilde{V}_i = V_L$ with probability $(1 - p)$ with the following interpretation: A base value of V_L is guaranteed with minimal level of effort (normalized to $e_i = 0$). With higher effort at $e_i = 1$, an incremental value of $(V_H - V_L)$ is generated with probability p (hence total realized project value is V_H with probability p) whereas no such value is generated with probability $(1 - p)$, in which case realized value remains at V_L. Hence, the final value of the supplier's investment is both a function of the effort as well as idiosyncratic market forces represented by p. Furthermore, because V_L is guaranteed, it is contractible. However, the incremental value $(V_H - V_L)$ is *non-contractible*: Although the incremental value is observed by both parties in Stage 3, this value cannot be verified and arbitrated in a court of law. (The assumption that a portion of the realized value is unverifiable is ubiquitous in the literature on hold ups and is, in fact, one key reason which renders contracts incomplete in the first place (refer to Section 3.1.1). Additionally, the reader can consult Klein *et al* (1978), Klein (2000), Klein and Leffler (1981), Baker *et al* (1994) for practical underpinnings of this assumption.)

(In effect, when $e_i = 1$, $\tilde{V}_i = V_H$ with probability p and $\tilde{V}_i = V_L$ with probability

$(1-p)$, and when $e_i = 0$, $\tilde{V_i} = V_L$; where V_L is contractible whereas $(V_H - V_L)$ is not.)

In Stage 4, if no hold up occurs, the manufacturer pays the supplier the contracted share α_i of the *realized* value $\tilde{V_i}$. Hold up occurs if the manufacturer *renegotiates* a lower $V_i^R < \tilde{V_i}$. Consequently, the manufacturer pays $\alpha_i V_i^R$ to the supplier which is lower than the contractually committed share $\alpha_i \tilde{V_i}$. Renegotiation, if attempted, is successful since: (i) The supplier cannot sell the investment in the outside market because the investment is relationship specific; and (ii) The value $\tilde{V_i}$ is non-contractible; hence renegotiation cannot be challenged in a court of law.

(In summary, the manufacturer moves twice in each period: first in Stage 1 when he offers α_i and then again in Stage 4 when he pays the supplier, possibly with renegotiation. The supplier moves once in Stage 2 when he decides his investment e_i.)

The manufacturer can be one of three *types:* he can be *rational, honest* or *cheat.* The respective proportions of rational, honest and myopic firms are: q^r, q^h and q^c.

A *rational* manufacturer is a *dynamic* (i.e., long-run) profit maximizer who can willfully cheat (or hold up) his contacting partner, or can indeed selectively honor his contractual commitments, whichever gives him a higher long-run payoff. Hence, the rational type is the quintessential opportunistic player who is aptly characterized as 'self-interested with guile' by Williamson (1985).

The *honest* type is also 'self-interested' but, unlike the rational type, he is 'without guile' in the parlance of Williamson (1985). That is, the honest manufacturer too seeks to maximize his long-run profit, but he never holds up the supplier and always pays the contractual share $\alpha_i \tilde{V_i}$ to the supplier in every period.

The third *cheat* type is a myopic *short-term* profit maximizer who seeks to maximize only the current period's profit. In order to do so, the cheat type always holds up the supplier whenever such an opportunity presents itself. (That the optimal myopic strategy is to always hold up the supplier is proved more formally in Proposition 3.1.) We model the cheat type as a 'control' to both the honest and the rational types: He is a short-term profit maximizer in contrast to the rational and honest types; in addition, he is the mirror image of the honest type – whereas the honest type never holds up his contractual partner, the cheat type always does so. Moreover, the myopic type presents a very natural (and useful) benchmark given that the manufacturer in our model can tremble into myopia.

Finally, with a small probability m, *all* types of manufacturer tremble into myopia. That is, with probability m close to 0, the manufacture (any type and in any period) can play the myopic strategy (which maximizes his short-term payoff) even when it is dynamically optimal to not do so. Reasons for firms to tremble into the suboptimal myopic strategy range from bounded rationality to incentive conflicts within firms, as noted in Section 3.1.1.

Let q_{ij}^x denote the probability the supplier ascribes to the manufacturer of being type x at the beginning of Stage j in period i; where $x = r$ denotes the rational type, $x = h$ denotes the honest type and $x = c$ denotes the cheat type. (Hence, q_{ij}^x denotes the supplier's *beliefs* on the manufacturer's type.) For instance, the vector of beliefs at the start of a period 2 (i.e., before stage 1 of period 2) is $\bar{q}_{21} = \left(q_{21}^r, q_{21}^h, q_{21}^c\right)$. For simplicity, as noted earlier, the beliefs at the start of the relationship are simply indexed $\left(q^r, q^h, q^c\right)$.

To minimize clutter, we normalize $V_L = 0$, and denote $V_H = V$. All parameters c, V, p, m and $\left(q^r, q^h, q^c\right)$ are common knowledge. Also, for simplicity, no time discounting is considered.

3.3 Benchmarks: Dynamic Game with Complete Information

Ours is a dynamic game of incomplete information where the informed manufacturer – informed about his type; honest, rational or cheat – and the uninformed supplier – *un*informed about the manufacturer's type – interact over multiple stages across two periods. The supplier has initial *beliefs* – a probability assessment over the manufacturer's type – at the beginning of the game. These believes evolve as the game proceeds, and are forged both by the actions of the manufacturer and the observed outcomes. The resulting analysis involves a complex interplay of strategies and beliefs over two periods with multiples stages within each period. To better understand the tensions that shape the strategies of the two players, we first eliminate incomplete information (thereby negating the role of supplier's beliefs) by analyzing the following two dynamic games of *complete* information: (i) The manufacturer is known to be honest, the *honest-manufacturer-only* case; and (ii) The manufacturer is known to be either rational or cheat, the *rational (or cheat)-manufacturer-only* case. With a better understanding of the strategies and the tensions at play, we thereafter infuse the supplier's beliefs back in the mix (in Section 3.4) by analyzing the dynamic game of incomplete information.

3.3.1 The Honest-manufacturer-only Case

Under the first benchmark, we consider a finitely repeated relationship between the supplier and an honest manufacturer, i.e., $q^h = 1$. Since the honest manufacturer always pays the supplier the contracted share, there is no threat of hold up. However, the supplier still faces the risk of the investment failing in the market – in each period i, with probability $(1-p)$ the realized value $\widetilde{V}_i$ is zero resulting in zero payment to the supplier ($\alpha_i \tilde{V}_i = 0$ whenever $\tilde{V}_i = 0$). To induce the supplier to invest, the manufacturer, through his choice of α_i in Stage 1, must compensate the supplier for the cost of his investment as well as for the exogenous risk of the project failing. The following lemma establishes the unique subgame-perfect Nash equilibrium of this benchmark case.

Lemma 3.1 *If the supplier knows that the manufacturer is honest, the unique subgame-perfect equilibrium of any finitely repeated relationship is:*

(i) $p \geq (c/V)$. *In each period, the manufacturer offers* $\alpha_h^* = \frac{c}{pV}$ *in Stage 1. In Stage 2, the supplier invests, i.e.,* $e_h^* = 1$, *iff* $\alpha_h \geq \alpha_h^*$. *In Stage 4, the manufacturer always honors the contract, and pays the supplier* $\alpha_h^* \tilde{V}_i$. *The expected payoffs for the supplier and the manufacturer in each period are* $\pi^s = 0$; $\pi^h = pV - c$.

(ii) $p < (c/V)$. *The manufacturer does not offer a contract in Stage 1 of any period. Consequently, there is no investment by the supplier in Stage 2 and both players get zero profit in any period.*

Consider the last period in the relationship. In Stage 1, the honest manufacturer offers a share $\alpha_h^* = (c/pV)$ that is just large enough to induce the supplier to make the relationship-specific investment leaving the supplier zero payoff in expectation – anything higher directly eats into the honest manufacturer's profit since he gets the remaining $(1-\alpha_h)$ share of the realized project value (part (i) of the above Lemma). When the project is not lucrative in expectation (i.e., when the cost exceeds the expected value, $c > pV$), even an $\alpha_h = 1$ cannot induce the supplier to invest. In this case, the manufacturer simply gives up and does not offer any contract in equilibrium; consequently, there is no investment by the supplier.

Since the last period has a unique equilibrium, which is equivalent to the equilibrium of a one-shot (single-period) game, the unique equilibrium of any period in a finitely repeated relationship is identical to the equilibrium of the terminal period (Gibbons 1992, pg. 84), as detailed in the Lemma above.

3.3.2 The Rational (or cheat)-manufacturer-only Case

Suppose the supplier knows that the manufacturer is rational, i.e., $q^r = 1$. In this case, the remuneration of the supplier is subject to not only the exogenous risk of the project failing as before, but also the risk of being held up – even if the project is successful, the rational manufacturer can take advantage of the relationship specificity of the investment and renegotiate a $V_i^R < \tilde{V}_i$. Hence, in this case, the contracted α_i in Stage 1 must compensate for the exogenous risk of the project failing and also for the risk of hold up.

As the following lemma proves, a rational manufacturer *always* renegotiates in the absence of the honest type; hence, the distinction between the rational and cheat types is rendered moot in this particular context. The lemma below, which establishes the unique subgame-perfect Nash equilibrium of this benchmark game, is thus crafted more generally and applies to any probability distribution over types that places zero probability on the presence of honest types.

Lemma 3.2 *If the supplier knows that the manufacturer is not honest, i.e. if the supplier believes that the manufacturer is either rational or cheat, then the unique subgame-perfect equilibrium of any finitely repeated relationship is as follows: In Stage 4 of any period* i*, the manufacturer renegotiates* $V_i^R = 0$ *when the realized value is* V*, and honors the contract if the realized value is* 0*. Consequently, in Stage 2 of the period, the supplier does not invest, i.e.,* $e_i^* = 0 \ \forall \alpha_i$*.*

Consider, again, the last period of the repeated relationship. When the project fails and $\tilde{V}_i = 0$, the manufacturer's decision in Stage 4 is trivial because the payment to the supplier is anyway zero and hence renegotiation (equivalently, hold up) is pointless.[6] However, when the realized value $\tilde{V}_i = V$, renegotiation is profitable, and in the absence of future interactions, it is a dominant strategy for the rational manufacturer to hold up the supplier and gobble the entire V in Stage 4 through renegotiating a $V^R = 0$. (The cheat type, by definition, always renegotiates whenever $\tilde{V}_i = V$.) In fact, as the following Corollary establishes, the rational type always holds up the supplier in the *terminal* period of any finitely repeated game, with or without complete information.

Corollary 3.1 *The rational manufacturer always renegotiates in the terminal period when* $\tilde{V} = V$*.*

Thus, in the last period, the supplier gets hit with zero payment irrespective of the

[6]The zero payment to the supplier is an outcome of normalizing V_L to zero. In effect, the supplier gets paid a minimal amount of $\alpha_i V_L$ which can be thought of as the contractible portion of the outcome, *cf.* Bolten and Scharfstein (1990), Plambeck and Taylor (2006).

project value: If the project fails, the payment is anyway zero and if the project succeeds, the manufacture gobbles up the entire value through renegotiation. Thus, anticipating zero payment in Stage 4 irrespective of whether the project succeeds or not, the supplier does not make any investment in Stage 2 of the last period not withstanding how high the contracted α_i is.

Through backward induction, it is easy to see that the same result emerges in every period of the finitely repeated relationship – the rational (or cheat) manufacturer always makes zero payment to the supplier in Stage 4 (whether through renegotiation or because the project fails) and the supplier thus has no incentive to invest in Stage 2. In other words, if the supplier knows for sure that the manufacturer is not honest, no contract or investment is possible in a *finitely repeated* relationship.

The outcome of no effort, although stark because low effort is normalized to zero, replicates the well-known result where rational firms scale back their relationship specific commitments because of the potential for hold ups, *cf.* Hart (1995). The outcome also mirrors the arguments proposed in the Social Contract Theory of ethics (*cf.* Rachels and Rachels, 2010) where, in the absence of honesty with the accompanying fear of being at the receiving end of opportunistic behavior, contracts break down and hence economic exchange is rendered impossible. Clearly, as emphasized earlier, this is contrary to empirical evidence in the real world. But, as we show below, with the introduction of the honest type, more plausible outcomes commensurate with observations in the real world emerge.

3.4 Dynamic Game with Incomplete Information

As we saw in the benchmark games with complete information, the supplier faces two risks: (i) the risk of the project failing – with probability $(1-p)$ the project is unsuccessful due to idiosyncratic market forces; and (ii) the risk of hold up in Stage 4 – with probability $\left(1-q^h\right)$ the manufacturer is either a cheat or is rational, and both these types hold up the supplier in the benchmarks. The first risk is fixed and is exogenous to the model itself. However, in the benchmarks, the second risk was exogenously fixed as well because we imposed q^h as either 0 or 1.

Consider now the game of *incomplete* information where the supplier is unsure of the manufacturer's type at the beginning of the two period relationship, i.e., suppose that $0 < q^h < 1$. Immediately, the risk of being held up in Stage 4 is not polarized to any one extreme as in the benchmark games of complete information. But more importantly, the risk is not exogenously fixed either and it *evolves* as the game unfolds in line with the evolution of the supplier's beliefs, which in turn are forged by the manufacturer through his strategies. For instance, if the manufacturer holds up the supplier in Stage 4 of period 1, the supplier must update his beliefs to $q_{21}^h = 0$, i.e., he must believe that the manufacturer cannot be honest (since the honest type never renegotiates).

More generally, the supplier has the following information when deciding his investment: He observes α_i in Stage 1 of the current period i and, in addition, if period 2 is in play, he knows the outcomes of the previous period – specifically the realized value and whether the manufacturer renegotiated. Based on the manufacturer's actions and the observed outcomes, the supplier updates his beliefs in a Bayesian fashion.

Hence, when deciding his strategy, the manufacturer must consider not just the (static) tensions inherent in the benchmark games of complete information (such as compensating the supplier, through the contracted α_i, for the risks that the supplier faces), but also the impact of his strategies in shaping the evolving beliefs of the supplier. For instance, holding up the supplier may now be suboptimal for the rational type in period 1 of the relationship because, as noted above, the supplier then believes with probability 1 that the manufacturer is not honest reverberating with zero future payoff for the manufacturer per Lemma 3.2. Hence, the long-term (dynamic) payoff of the players are a function of both the strategies and beliefs; consequently, the manufacturer can, *and should,* forge these beliefs – the probability ascribed to him by the supplier of being of a certain type – through his choice of strategies.[7] Hence strategies of the manufacturer, to the extent that they impact the beliefs that the supplier holds, must be *dynamically* optimal in that they must optimize not just the payoff in the current period, but the *joint* payoff of current and all future periods.

The central thesis of the analysis then is the *joint* determination of both strategies and beliefs and their impact on the equilibria and the payoffs in a dynamic (multi-period-multi-stage) context.[8] The appropriate equilibrium concept is thus the *Perfect Bayesian*

[7]Such formulation of beliefs and their role in forging equilibrium outcomes – including payoffs to the players – is critical and is given much importance in standard signaling games where the informed player moves just once (*cf.* Anand and Goyal, 2009). In our setting, with signaling opportunities spread across multiple stages over two periods, the supplier's beliefs are especially critical because beliefs, through the supplier's investment as noted above, determine the manufacturer's payoff in both the current and future periods.

[8]Given the temporal nature of the supplier's beliefs, with the manufacturer enjoying multiple opportunities to shape these, beliefs can in fact be interpreted as the manufacturer's *reputation, cf.* Kreps *et al*, (1982). The manufacturer can enhance his reputation – which, like beliefs, is the probability ascribed to him by the supplier of being of a certain type – by a certain kind of play. For instance, the manufacturer can enhance his reputation for being honest, which translates to the supplier ascribing him a (weakly) *lower* probability of being rational, by 'acting' as if he were the honest type, such as by offering the same share α_i to the supplier as the honest type does in Stage 1 and then by not holding up the supplier in Stage

Nash equilibrium (PBNE) which requires an explicit specification of both strategies and beliefs, both on and off the equilibrium path.

We first consider how the strategies and beliefs interact together in a (static) single period. The analysis of the single period also serves to establish the equilibrium of the last period of any finitely repeated game.

3.4.1 The Single Period (Equivalently, The Last Period) Equilibrium

In a single period with incomplete information (equivalently, the last period of the two-period game with incomplete information), the supplier is unsure of the type of manufacturer that he is facing; unlike in the benchmark games of complete information where the supplier knows whether he is facing the honest type or not. Let $\vec{q}_{21} = (q^r_{21}, q^h_{21}, q^c_{21})$ be the supplier's beliefs at the start of the period 2.

In a single period, because there are no future interactions, the dominant strategy for the rational manufacturer is to hold up the supplier (refer to Corollary 3.1). Hence, the supplier faces both the risk of being held up by the rational and cheat types as well as the risk of the project not succeeding. However, unlike in the benchmark case with no honest types, the likely presence of honest types with probability q^h_{21} mitigates some of the risk of hold up, which now occurs only with probability $\left(1 - q^h_{21}\right)$. Consequently, to induce the supplier to invest, the manufacturer must propose an α_2 which is at least large enough to cover the above two risks for the supplier as well as the supplier's cost of investment.

4. On the other extreme, if the manufacturer holds up the supplier, his reputation can be permanently sullied – the supplier is then convinced that the manufacturer is rational – resonating with minimal payoff in future periods. Reputation effects are thus folded within our analysis through the supplier's beliefs; in fact, some known results in the reputations literature emerge as a special case of our analysis when the trembling probability $m = 0$.

In addition, there is one more facet of α_2 that arises because even the single period game is a dynamic game of incomplete information with an embedded signaling game. In Stage 1, the manufacturer proposes α_2 before the supplier makes his investment. Thus, based on the announced α_2, the supplier can revise his beliefs on the manufacturer's type. This presents an opportunity for the honest manufacturer to possibly signal his type through α_2 and thus separate from the rational and cheat types.

Proposition 3.1 below establishes the PBNE of a single period (equivalently, the last period of a multiperiod relationship) in terms of (*i*) the equilibrium α_2 offered by each type of manufacturer in Stage 1; (*ii*) the equilibrium investment e_2 by the supplier in Stage 2; (*iii*) the equilibrium payment to the supplier in Stage 4; and (*iv*) the beliefs of the supplier after Stage 1.

Proposition 3.1 *The PBNE for a single period (equivalently, the last period) when the supplier's beliefs over the manufacturer's type are* $\vec{q}_{21} = (q_{21}^r, q_{21}^h, q_{21}^c)$ *is as follows:*

Case I:$p \geq \frac{c}{q_{21}^h V}$

In Stage 1, all types of manufacturer offer $\alpha_2^*(p, c, V, \vec{q}_{21}) = \dfrac{c}{q_{21}^h pV}$. *In Stage 2, the supplier makes relationship-specific investment* $e_2^* = 1$ *iff* $\alpha_2 = \alpha_2^*$, *consistent with his belief* $\vec{q}_{22}$ *(at the beginning of Stage 2) that*

$$(q_{22}^r, q_{22}^h, q_{22}^c) = \begin{cases} (q_{21}^r, q_{21}^h, q_{21}^c), \text{ if } \alpha_2 = \alpha_2^* \\ \left(\frac{q_{21}^r}{q_{21}^r + q_{21}^c}, 0, \frac{q_{21}^c}{q_{21}^r + q_{21}^c}\right), \text{ if } \alpha_2 \neq \alpha_2^* \end{cases} \tag{3.1}$$

In Stage 4, the honest manufacturer always honors the contract (that is, he never holds up the supplier). The rational manufacturer and the cheat manufacturer honor the contract iff $\tilde{V}_2 = 0$, *and hold up the supplier iff* $\tilde{V}_2 = V$ *with the renegotiated* $V_2^R = 0$.

The expected payoffs for the supplier, the rational manufacturer, the honest manufacturer and the cheat manufacturer respectively are $\pi_2^{s*} = 0$; $\pi_2^{r*} = pV$; $\pi_2^{h*} = pV - \frac{c}{q_{21}^h}$; $\pi_2^{c*} = pV$;

Case II: $p < \frac{c}{q_{21}^h V}$.

The manufacturer does not offer any contract. Consequently, there is no investment by the supplier and all players get zero profit.

In Stage 4, the honest type pays the contractual share $\alpha_2 \tilde{V}_2$ to the supplier with no renegotiation. The cheat renegotiates whenever $\tilde{V}_2 = V$. The rational type too finds it optimal to renegotiate since there are no future interactions with the supplier. Anytime the manufacturer renegotiates (whether the cheat or the rational type), it is optimal to grab the entire surplus, i.e., the renegotiated $V^R = 0$.

To induce the supplier to invest, at a minimum the contractual α_2 offered in Stage 1 must compensate the supplier for his cost of investment and for the risks of not getting paid (either because the project fails or because the manufacturer is not honest). But because α_2 also serves as a signaling device – based on the contracted α_2, the supplier updates his belief on the manufacturer's type – the choice of α_2 by the manufacturer can be more involved than simply maximizing the manufacturer's profit subject to meeting the participation constraint of the supplier; the manufacturer must also consider the beliefs that the choice of α_2 induces after Stage 1.

To elaborate, from the honest manufacturer's perspective, an α_2^* which induces the supplier's investment and yet leaves the supplier with exactly zero surplus in expectation is optimal. The rational and the cheat types, on the other hand, can promise any $\alpha_2 > \alpha_2^*$ to induce the supplier to invest because they renegotiate zero payment to the supplier in Stage 4 anyway. However, any α_2 different from the one that the honest type finds optimal to contract with backfires since it convinces the supplier that the manufacturer is not honest (i.e. the manufacturer is either rational or a cheat), leading to zero investment by the supplier per Lemma 3.2. Hence both the rational and the cheat types promise the same α_2 that the honest type contracts with, thereby *pooling* with the honest type in Stage 1. Because α_2^* is optimal for the honest manufacturer, all types contract with $\alpha_2 = \alpha_2^*$. Equation 3.1 captures the corresponding belief structure for the supplier.

The share α_2^*: (i) compensates the supplier (in expectation) for his cost of investment as well as the two risks that the supplier faces; (ii) maximizes the profit of the honest manufacturer subject to the constraint in (i) above; and (iii) serves as a signaling device in Stage 1 since any $\alpha_2 \neq \alpha_2^*$ convinces the supplier that the manufacturer is not honest. Because the equilibrium α_2^* is completely determined by the honest manufacturer, the honest type, despite the simplicity of his payment strategy in Stage 4, is indeed a strategic player who seeks to maximize his profits through optimizing α_2.

The optimal α_2^* increases if the cost c increases, the project potential V decreases, the success rate p decreases, or the probability of honest type $\left(q_{21}^h\right)$ decreases, since the supplier requires a larger share of the project value to offset his investment cost and the risks of either the project not succeeding or of getting held up. In specific, if, at the start of the last period, the supplier is convinced that the manufacturer is honest, the required contractual share coincides with that of Lemma 3.1, i.e., $\alpha_2^*|_{q_{21}^h=1} = \alpha_h^*$, which is just enough to cover (in expectation) the investment cost and only the exogenous market uncertainty.

The supplier invests under the conditions of Part I of the proposition when the share α_2^* is large enough to compensate the supplier for his cost of investment and the risks of not getting paid in Stage 4. Hence, in contrast to Lemma 3.2, the presence of the honest manufacturer – even with a probability strictly less than one – makes the economic contract possible even in a single-period relationship.

When q_{21}^h is extremely low, or if the project is not lucrative enough (i.e., if the cost of investment c is too high compared to its potential value V, or the success rate p is low), the honest manufacturer needs to pay the supplier from his own pocket ($\alpha_2 > 1$) to induce investment. In this case, there is no investment in equilibrium by the supplier (part II of proposition 3.1).

3.4.2 The First Period Equilibrium

In the first period, by definition, the honest type always honors the contract, and the cheat type always renegotiates with $V_1^R = 0$ whenever $\tilde{V}_1 = V$. However, the single period (or myopic) strategy of holding up the supplier can backfire for the rational manufacturer in period 1 since this convinces the supplier that the manufacturer is not honest resonating with zero payoff the next period. Hence, in contrast to a single-period game (or the last period of a multiperiod relationship) where the rational manufacturer could renegotiate with impunity, the presence of a future period softens the incentives for the rational manufacturer to renegotiate in Stage 4 of the first period. Specifically, two factors hone the rational manufacturer's incentives to hold up the supplier in Stage 4 of period 1. First, the lure of future payoffs: When p is high, there is a high probability that the investment in the forthcoming period 2 is successful ($\tilde{V}_2 = V$ with high enough probability); by not renegotiating in Stage 4 of period 1, i.e., by pooling with the honest type and paying the contracted $\alpha_1 V$ to the supplier, the rational manufacturer can hide his type and gobble the entire $\tilde{V}_2$ in period 2 (per proposition 3.1). The second factor is the size of the payment (α_1) to the supplier in the current period: When α_1 is small, the rational manufacturer has stronger incentives to share a relatively small fraction of the realized value with the supplier and keep the game rolling onto the next period.

In effect, by giving $\alpha_1 V$ to the supplier in period 1, the rational manufacturer stands to gain pV in period 2; by renegotiating and keeping the entire V in period 1 itself, the rational manufacturer reveals his type and gets zero payoff in period 2. Hence, if α_1 is (weakly) more than p, the cost of being honest by sharing the large share α_1 with the supplier is too high compared to the value of future spoils; hence the rational manufacturer prefers to renegotiate in period 1. Conversely, if α_1 is less than p, he prefers waiting for future spoils by not holding up the supplier in period 1.

For exactly the same reasons advanced earlier in the context of period 2, the choice of α_1 is controlled by the honest manufacturer (as in period 2, all types of manufacturer offer the same contract in Stage 1 of period 1 as the honest type). Hence, as before, the honest manufacturer cannot separate in Stage 1. But he can trigger a separation from the rational type in Stage 4 through his choice of α_1, which can precipitate the incentives of the rational manufacturer to renegotiate in Stage 4. In specific, the honest manufacturer can either: (*i*) Induce the rational type to hold up the supplier in Stage 4 by offering an $\alpha_1 \geq p$, and hence he can *separate* from the rational type (the *separating* strategy); or (*ii*) Induce the rational type to play honest in Stage 4 through $\alpha_1 < p$ thereby pooling with the honest type (the *pooling* strategy). Hence, in the first period, in addition to tailoring α_1 to accomplish the three objectives detailed earlier, the honest manufacture can strategically use α_1 to signal honesty in Stage 4 of period 1 – which is the fourth facet of α_i.

As the following proposition establishes, the above tension for the honest type is resolved in one of two ways depending critically on the project success rate p and the probability the supplier ascribes to the manufacturer being a cheat q^c.

Proposition 3.2 *The PBNE of the first period of the two period game is as follows:*

Case I: $p^2 > \frac{c}{V(1-q^c)}$

In Stage 1 the manufacturer (any type) offers $\alpha_1^{*Pool} = \frac{c}{p(1-q^c)V} < p$. *In Stage 2 the supplier makes relationship-specific investment* ($e_1^* = 1$) *iff* $\alpha_1 = \alpha_1^{*Pool}$ *consistent with his belief* $\vec{q}_{12}$ *(at the beginning at Stage 2 of period 1) that*

$$(q_{12}^r, q_{12}^h, q_{12}^c) = \begin{cases} (q^r, q^h, q^c), & \text{if } \alpha_1 = \alpha_1^{*Pool} \\ (\frac{q^r}{q^r+q^c}, 0, \frac{q^c}{q^r+q^c}), & \text{if } \alpha_1 \neq \alpha_1^{*Pool} \end{cases} \tag{3.2}$$

Finally, in Stage 3, both the honest and the rational manufacturer honor the contract regardless of the realized value. The cheat manufacturer honors the contract iff $\tilde{V}_1 = 0$, *and holds up the supplier iff* $\tilde{V}_1 = V$ *with the renegotiated* $V_1^R = 0$.

The supplier's updated belief (after Stage 4 of period 1, or equivalently, at the start of period 2) $\vec{q}_{21}$ *is:*

$$(q_{21}^r, q_{21}^h, q_{21}^c) = \begin{cases} (q_{12}^r, q_{12}^h, q_{12}^c), & \text{if } \tilde{V}_1 = 0 \\ (\frac{q_{12}^r}{q_{12}^r+q_{12}^h}, \frac{q_{12}^h}{q_{12}^r+q_{12}^h}, 0), & \text{if } \tilde{V}_1 = V \text{ and the manufacturer does not renegotiate} \\ (0, 0, 1), & \text{if } \tilde{V}_1 = V \text{ and the manufacturer renegotiates} \end{cases} \tag{3.3}$$

In the second period, the outcome is the same as stated in proposition 3.1 with $\vec{q}_{21}$ *given by equation* (3.3).

The total expected payoffs across the two periods are:

$$\Pi^s = 0; \Pi^r = 2pV - \frac{c}{1-q^c}; \Pi^h = 2pV - \frac{c}{1-q^c} - \frac{(1-pq^c)c}{1-q^c-q^r}; \Pi^c = 2pV - p^2V$$

II) If $p^2 \leq \frac{c}{(1-q^c)V}$

In Stage 1 the manufacturer (either type) offers $\alpha_1^{*Sep} = \frac{c}{p(1-q^r-q^c)V} > p$. *In Stage 2 the supplier makes relationship-specific investment* ($e_1^* = 1$) *iff* $\alpha_1 = \alpha_1^{*Sep}$ *consistent with his belief (after Stage 1) that*

$$(q_{12}^r, q_{12}^h, q_{12}^c) = \begin{cases} (q^r, q^h, q^c), \ \text{if } \alpha_1 = \alpha_1^{*Sep} \\ (\frac{q^r}{q^r+q^c}, 0, \frac{q^c}{q^r+q^c}), \ \text{if } \alpha_1 \neq \alpha_1^{*Sep} \end{cases} \tag{3.4}$$

In Stage 4, the honest type manufacturer honors the contract. Both the rational type manufacturer and the cheat type manufacturer honor the contract iff $\tilde{V}_1 = 0$, *and renegotiate* $V_1^R = 0$ *iff* $\tilde{V}_1 = V$.

The supplier's updated belief (after Stage 4) is:

$$(q_{21}^r, q_{21}^h, q_{21}^c) = \begin{cases} (q_{12}^r, q_{12}^h, q_{12}^c), \ \text{if } \tilde{V}_1 = 0 \\ (0,1,0), \ \text{if } \tilde{V}_1 = V \text{ and the manufacturer does not renegotiate} \\ (\frac{q_{12}^r}{q_{12}^r+q_{12}^c}, 0, \frac{q_{12}^c}{q_{12}^r+q_{12}^c}), \ \text{if } \tilde{V}_1 = V \text{ and the manufacturer renegotiates} \end{cases} \tag{3.5}$$

In the second period, the outcome is the same as stated in proposition 1 with $\vec{q}_{21}$ *given by equation (3.5).*

The total expected payoffs across the two periods are:

$$\Pi^s = 0; \Pi^r = 2pV - p^2V; \Pi^h = 2pV - \frac{2-p(q^r+q^c)}{1-q^r-q^c}c; \Pi^c = 2pV - p^2V$$

Consider Part I of the proposition. When p is high, the α_1 ($> p$) required to induce the rational type to renegotiate (and thus separate) is too high which eats into the payoff of the honest type. Hence, the honest type announces an $\alpha_1^* < p$ and, consequently, the rational types honors the contract in Stage 4. (Recall that the rational type finds it lucrative to renegotiate only when $\alpha_1 > p$.) And because the rational type's incentives to renegotiate are completely controlled by the honest type through α_1, the supplier is convinced upon seeing an $\alpha_1 < p$ that he will not be held up by the rational type in period 1. Thus, with the risk of being held up alleviated (now only the cheat type renegotiates), the honest type can contract with a lower $\alpha_1^* = \frac{c}{p(1-q^c)V}$ in equilibrium (compared with the α_2^* of the single period), but still leave the supplier with zero payoff.

Under the equilibrium of part I of the proposition, the supplier is convinced that the manufacturer is the cheat type upon observing renegotiation in Stage 4. However, when $\tilde{V}_1 = V$ and the manufacturer does not renegotiate, although the supplier is convinced that the manufacturer is not a cheat, he cannot parse this information further to determine if the manufacturer is indeed honest or just pretending to be one. But on a positive note, because the supplier can always rule out the cheat type upon being paid honestly when $\tilde{V}_1 = V$, he ascribes a higher probability to the manufacturer being honest in period 2 (i.e., $q_{21}^h \geq q^h$), and hence the supplier invests again in period 2 for a smaller α_2 (as per proposition 3.1). When $\tilde{V}_1 = 0$, because all types of manufacturer honor the contract, no new information on the manufacturer's type can be learned, i.e., $\vec{q}_{21} = \vec{q}_{12}$. Equation (3.3) captures the supplier's updated belief after period 1.

When p decreases or q^c increases (i.e., if the supplier believes that the expected project value is lower or that the manufacturer is a cheat with a higher likelihood), the supplier demands a higher share α_1 to compensate for the higher risks of the project not succeeding or of being held up by the cheat manufacturer; hence, the α_1^{*Pool} of part 1 increases and, at some point, tips on the higher side of p thereby making it lucrative for the rational type to renegotiate in period 1 itself. (Refer to the discussion before the proposition.) That is, when $\alpha_1^{*Pool} = \frac{c}{p(1-q^c)V} \geq p$ (which translates to $p^2 \leq \frac{c}{(1-q^c)V}$, case II of proposition 3.2), the pooling equilibrium breaks down; instead, the separating equilibrium is played where, given the high α_1^* relative to p, the rational type renegotiates and grabs the entire $\tilde{V}_1$ in Stage 4 of period 1. Consequently, since now even the rational manufacturer holds up the supplier, the honest type needs to offer an even higher share to entice the supplier to invest, i.e., the equilibrium $\alpha_1^{*Sep} = \frac{c}{pV(1-q^c-q^r)} > \alpha_1^{*Pool}$. The supplier updates his belief according to equation (3.5): Upon being held up, the supplier is convinced that the manufacturer is not honest and $q_{21}^h = 0$; if, on the other hand, the realized value is V and the supplier is not held up, in light of both the rational type's and the cheat type's strategy of holding up the supplier, the supplier is convinced he is dealing with the honest type and $q_{21}^h = 1$. As before, when $\tilde{V}_1 = 0$, all types of manufacturer honor the contract and hence no new type information can be learned, i.e., $\vec{q}_{21} = \vec{q}_{12}$.

The following corollary summarizes propositions 3.1 and 3.2 in terms of the strategies of the rational manufacturer in Stage 4 (the strategies of the other two types are more tightly bound by their types and are the same across the two periods) – in effect, the corollary below delineates the optimal dynamic strategy of the manufacturer:

Corollary 3.2 (*i*) *When p is high (part I of Proposition 3.2), the optimal dynamic strategy* *for the manufacturer in Stage 4 is to play Honest in period 1 and Renegotiate in period 2.*

(*ii*) *When p is relatively small (part II of Proposition 3.2), the optimal dynamic strategy for the manufacturer in Stage 4 is to Renegotiate in both periods 1 and 2. (That is, the myopic strategy is optimal.)*

Unlike long-term relationships with no honest types (Lemma 3.2), or the single period relationship with some probability of honest types (Proposition 3.1) – in both instances, the threat of hold up looms large – the presence of honest types in a long-term relationship can mitigate the hold up problem in two ways: (*i*) Under part I of the Corollary 3.2, the rational type turns honest which reduces the threat of hold up in period 1; and (*ii*) Under part II of Corollary 3.2, the honest type weeds out the rational type through a carefully chosen α_1^* – because the rational type opts to renegotiate in period 1, no hold up in period 1 convinces the supplier that the manufacturer is honest leading to zero threat of hold up in period 2.

Corollary 3.3 *Long-term repeated relationship with even a small probability of the presence of honest types can alleviate the hold-up problem.*[9]

Despite the fact that honesty mitigates the hold up problem, the honest type has lower payoff than the rational type manufacturer ($\Pi^h < \Pi^r$, see proposition 3.2) – by definition, the rational type manufacturer has a larger strategy space and can freely mimic the honest type if necessary. Indeed, in any dynamic relationship with n periods,

[9]Our results are thus consistent with the overall result in the reputations literature (*cf.* Kreps *et al*, 1982) where even a small probability of the existence of a 'commitment type' who has only one strategy (such as the honest manufacturer in our example who always honors the contract) can force the rational type to mimic the commitment type. However, our model and anlaysis is specialized to the hold up problem which has not been specifically addressed by the reputations literature.

the rational type, even when he finds it optimal to honor the contract in the first $n-1$ periods (thus mimicking the honest type and earning the same profit as the honest type for the $n-1$ periods), boosts his payoff over and above the honest type's by grabbing the entire surplus in the last period. (And if the rational type cheats earlier, it is because it is optimal to do so, and hence he still makes higher payoff than the rational type.) So then the question that was posed in the introduction remains pertinent: Why do we see honest types when economic Darwinism should have weeded them out?[10]

As we prove in the next section, trembles and myopia can collude together to provide the enabling conditions for the honest type's payoff to exceed the rational (and cheat) type's, thereby providing an *economic* rationale for honesty.

3.5 Dynamic Game with Trembles

The honest and the cheat manufacturer have just one strategy – the honest manufacturer never holds up the supplier whereas the cheat type always does so – consequently, the cheat and the honest types face no strategic tension in Stage 4 of any period. In contrast, the rational manufacturer has two elements in his strategy space – he can either hold up the supplier or play honest. In period 2, however, the rational type never plays honest – the only strategy that he ever implements in period 2 is to renegotiate independent of parameter values (Proposition 3.1). Hence, similar to the cheat and honest types, the

[10]If the question is posed more generally, such as why we see *commitment* types – after all, the honest type is an example of a commitment type who has just one strategy – the question of their existence is equally tantalizing for the reputation literature, which has simply assumed the presence of commitment types. In fact, due to a lack of a compelling reason for their presence, commitment types are often deemed 'irrational' since they do not maximize utility, *cf.* Aumann (1997, pg.9); but this interpretation is rather unappealing in economic models of reputation which are otherwise steeped in rationality.

rational type faces minimal cognitive burden in period 2. But the rational type needs to be much more calculative in period 1. Based on parameter values, his optimal dynamic strategy differs: he can either play honest (part I of proposition 3.2) or he can renegotiate (part II of proposition 3.2). Hence, because the rational type faces a cognitive burden of choosing strategies in period 1, he is susceptible to slipping up ever so slightly and playing a suboptimal strategy as a consequence in stage 4 of period 1. (Such mistakes are identified as *trembles* in the literature, *cf.* Aumann 1997.) In specific, under part I of proposition 3.2, the optimal dynamic strategy of playing honest is at odds with the myopic strategy of renegotiating. Because myopia is a very natural and reasonable alternative (for the reasons detailed in Section 3.1.1 such as deliberation costs, cognitive limitations and incentive conflicts within firms), the rational type can *tremble into myopia* where he mistakenly plays his myopic strategy even when it is dynamically suboptimal to do so.[11]

Within the context of our model, *all types* of the manufacturer can play the myopic strategy with probability m. However, in light of the above discussion, trembles clearly have no impact on the honest and the cheat types simply because there is no alternate strategy to tremble to. Trembles have no impact on the rational type either in period 2 or in period 1 when p is small (part (*ii*) of Proposition 3.2) – in both these cases, the myopic strategy

[11]The procurement paradigm at General Motors in the 90s presents a fascinating example of incentive conflicts within firms which can lead to a suboptimal choice of the myopic strategy. In the 1990s, General Motors (GM) routinely leaked its suppliers' design innovations to their competitors in order to trim sourcing costs. Leakage, though arguably lucrative in the short run for GM, blunted the suppliers' incentives to innovate, thus hurting GM in the long run. To restore its sullied reputation, GM mandated a company-wide no leakage policy which would, once again, provide incentives for the suppliers to innovate. (Hence, no-leakage can be thought of as the optimal dynamic strategy in contrast to the myopic strategy of leaking which reaped only short-term rewards.) However, despite its best efforts, GM was unable to completely curb leakage – one key reason was that employees, driven by short-term (myopic) performance objectives, continued leaking design innovation to other suppliers ignoring the long-term consequences of their actions. (In effect, GM was prone to 'trembling into myopia'.) GM finally surrendered and asked its suppliers to patent their innovations to legally preclude leakage. (Based on Murphy 2007).

of renegotiating is anyway optimal (essentially, the rational type trembles into the same strategy that he is implementing). Additionally, trembles are also ruled out when $\tilde{V}_1 = 0$ because there is no value to renegotiate over. In essence, trembles impact the rational type only in period 1, and only when $\tilde{V}_1 = V$ and the rational types intends to play honest.

Finally, both the supplier and the manufacturer (all types) are aware that there is the potential to tremble to the myopic strategy with probability m and they optimally incorporate this possibility in their strategies and beliefs.

The following proposition establishes the PBNE of the two period game when the manufacturer can tremble, in terms of the strategies of the players, the beliefs of the supplier and the profits of the player for all parameter values.

Proposition 3.3 *The equilibrium for the first period of the two-period game with trembles is as follows:*

Case I: $p^2 > \frac{c}{(1-mq^r-q^c)V}$

In the contract stage the manufacturer (any type) offers $\alpha_1^{m*Pool} = \frac{c}{p(1-mq^r-q^c)V} < p$. *In the effort stage the supplier makes relationship-specific investment* ($e_1^{m*} = 1$) *iff* $\alpha_1 = \alpha_1^{m*Pool}$ *consistent with his belief* $\vec{q}_{12}^{m}$ *(after Stage 1 of period 1) that*

$$(q_{12}^{rm}, q_{12}^{hm}, q_{12}^{cm}) = \begin{cases} (q^r, q^h, q^c), & \text{if } \alpha_1 = \alpha_1^{m*Pool} \\ (\frac{q^r}{q^r+q^c}, 0, \frac{q^c}{q^r+q^c}), & \text{if } \alpha_1 \neq \alpha_1^{m*Pool} \end{cases} \tag{3.6}$$

Finally, in the payment stage, if $\tilde{V}_1 = 0$, *all types of manufacturer honor the contract; if* $\tilde{V}_1 = V$, *the honest type honors the contract, the cheat type holds up the supplier with* $V_1^{Rc*} = 0$, *while the rational manufacturer honors the contract with probability* $(1-m)$ *and renegotiates with* $V_1^{Rr*} = 0$ *with probability* m.

The supplier's updated belief (after Stage 4 of period 1, or equivalently, at the start of period 2) $\vec{q}_{21}^{m}$ *is:*

$$(q_{21}^{rm}, q_{21}^{hm}, q_{21}^{cm}) = \begin{cases} (q_{12}^{rm}, q_{12}^{hm}, q_{12}^{cm}), \ \text{if } \tilde{V}_1 = 0 \\ (\frac{(1-m)q_{12}^{rm}}{(1-m)q_{12}^{rm}+q_{12}^{hm}}, \frac{q_{12}^{hm}}{(1-m)q_{12}^{rm}+q_{12}^{hm}}, 0), \ \text{if } \tilde{V}_1 = V \text{ and the manufacturer does not renego} \\ (\frac{mq_{12}^{rm}}{mq_{12}^{rm}+q_{12}^{cm}}, 0, \frac{q_{12}^{cm}}{mq_{12}^{rm}+q_{12}^{cm}}), \ \text{if } \tilde{V}_1 = V \text{ and the manufacturer renegotiates} \end{cases} \quad (3.7)$$

In the second period, the outcome is the same as stated in proposition 3.1 with $\vec{q}_{21}^{m}$ *given by equation* (3.7)*.*

The total expected payoffs across the two periods are:

$$\Pi^{sm} = 0; \Pi^{rm} = (2-mp)pV - \frac{c(1-m)}{1-mq^r-q^c}; \Pi^{hm} = 2pV - \frac{c}{1-mq^r-q^c} - \frac{(1-p(mq^r+q^c))c}{1-q^r-q^c}; \Pi^{cm} = 2pV - p^2V$$

Case II: $p^2 \leq \frac{c}{(1-mq^r-q^c)V}$

In the contract stage the manufacturer (any type) offers $\alpha_1^{m*Sep} = \frac{c}{p(1-q^r-q^c)V} > p$*. In the effort stage the supplier makes relationship-specific investment* ($e_1^{m*} = 1$) *iff* $\alpha = \alpha_1^{m*Sep}$ *consistent with his belief (after Stage 1) that*

$$(q_{12}^{rm}, q_{12}^{hm}, q_{12}^{cm}) = \begin{cases} (q^r, q^h, q^c), \ \text{if } \alpha_1 = \alpha_1^{m*Sep} \\ (\frac{q^r}{q^r+q^c}, 0, \frac{q^c}{q^r+q^c}), \ \text{if } \alpha_1 \neq \alpha_1^{m*Sep} \end{cases} \quad (3.8)$$

In the payment stage, if $\tilde{V}_1 = 0$*, all types of manufacturer honor the contract; if* $\tilde{V}_1 = V$*,the honest type manufacturer honors the contract, while both the rational type manufacturer and the cheat type manufacturer renegotiate with* $V_1^{Rr*} = V_1^{Rc*} = 0$.

The supplier's updated belief $\vec{q}_{21}^{m}$ *(after Stage 4 of period 1) is:*

$$(q_{21}^{rm}, q_{21}^{hm}, q_{21}^{cm}) = \begin{cases} (q_{12}^{rm}, q_{12}^{hm}, q_{12}^{cm}), \ \text{if } \tilde{V}_1 = 0 \\ (0,1,0), \ \text{if } \tilde{V}_1 = V \text{ and the manufacturer does not renegotiate} \\ (\frac{q_{12}^{rm}}{q_{12}^{rm}+q_{12}^{cm}}, 0, \frac{q_{12}^{cm}}{q_{12}^{rm}+q_{12}^{cm}}), \ \text{if } \tilde{V}_1 = V \text{ and the manufacturer renegotiates} \end{cases} \quad (3.9)$$

In the second period, the outcome is the same as stated in proposition 1 with $\vec{q}_{21}^{m}$ *given by equation (3.9).*

The total expected payoffs across the two periods are:

$$\Pi^{sm} = 0; \Pi^{rm} = 2pV - p^2V; \Pi^{hm} = 2pV - \frac{2 - p(q^r + q^c)}{1 - q^r - q^c}c; \Pi^{cm} = 2pV - p^2V$$

When $\tilde{V}_1 = V$, the tension facing the rational type in period 1 is the same as in Proposition 3.2: when $\alpha_1 \geq p$, the manufacturer prefers grabbing the entire value now through renegotiating $V_1^{Rr} = 0$; and for $\alpha_1 < p$, the lure of the future payoff in period 2 keeps the rational manufacturer honest in period 1. With one caveat – when $\alpha_1 < p$, with probability m the rational manufacturer trembles and plays the myopic strategy (which is to renegotiate and hold up the supplier) even though the dynamically optimal strategy is to honor the contract. For this reason, the actions of the rational manufacturer are not completely controlled by the honest type through α_1 – there is no guarantee that even with $\alpha_1 < p$, the supplier will not be held up by the rational type. Thus, the honest manufacturer has to augment the contractual share in Stage 1 to $\alpha_1^{m*Pool} = \frac{c}{pV(1-mq^r-q^c)} \geq \alpha_1^{*Pool}$ of proposition 3.2 to compensate the supplier for the additional risk of the rational type trembling and holding up the supplier.

As before, not only does α_1^{m*Pool} increases as p decreases or q^c increases, but now α_1^{m*Pool} also increases in m and q^r. That is, anticipating higher chance of being *accidentally* held up by the rational manufacturer, either when the manufacturer is more likely to be rational for a given m or when the rational manufacturer mistakenly chooses the suboptimal myopic strategy more often (higher m for a given q^r), the supplier asks for a higher contractual share (i.e., a larger α_1) to compensate his risk of being held up. When eventually $\alpha_1^{m*Pool} > p$, the rational manufacturer renegotiates and holds up the supplier in period 1 itself if $\tilde{V}_1 = V$; the honest manufacturer thereby needs to further increase the contractual share to $\alpha_1^{m*Sep} = \frac{c}{pV(1-q^r-q^c)} = \alpha_1^{*Sep} \geq \alpha_1^{m*Pool}$, in order to compensate the supplier for the risk of always being held up by the rational type. Notice that when the rational manufacturer *chooses* to always hold up the supplier even in period 1, the myopic payment strategy is also dynamically optimal, so the equilibrium strategies and outcomes in part II of the proposition 3.3 are identical to those without trembles in part II of proposition 3.2. Also, when $m = 0$, the equilibrium of Proposition 3.2 emerges; hence, our proposed equilibria are robust to trembles in the classical sense.

The following Lemma establishes the impact of trembles on the manufacturer's payoff.

Lemma 3.3 *The trembling probability* m *impacts the manufacturer's expected payoff across two periods as follows.*

(i) When $m < \frac{1-q^c-c/(p^2V)}{q^r} = m^{Pool}$ *(equivalently, part I of proposition 3.3),*

The rational manufacturer's payoff decreases as m *increases, i.e.,* $\frac{\partial \Pi^{rm}}{\partial m} < 0$*;*

The cheat manufacturer's payoff is independent of m*, i.e.,* $\frac{\partial \Pi^{cm}}{\partial m} = 0$*;*

The honest manufacturer's payoff increases in m *for* $m < \frac{p(1-q^c)-\sqrt{p(1-q^c-q^r)}}{pq^r}$ $(=$

$m^h) < m^{Pool}$, and decreases in m otherwise.

(ii) When $m \geq \frac{1-q^c-c/(p^2V)}{q^r}$ (equivalently, part II of proposition 3.3), all types of manufacturer's payoffs are independent of m.

Consider first part (i) of the the Lemma, which coincides with part I of proposition 3.3. The rational manufacturer's profit decreases in m for two reasons: First, trembles prevent him from implementing his dynamically optimal strategy of playing honest in period 1. Second, α_1^{m*Pool} increases in m – so even when the rational manufacturer executes his optimal strategy of honoring the contract in period 1, he has to pay the supplier a higher share of the realized value, leaving himself lower profit in period 1. The cheat type's strategy of always renegotiating whenever $\tilde{V}_i = V$ renders it tremble-proof and also independent of the share α_i offered to the supplier; hence his payoff is independent of m.

Although the honest manufacturer too has a simple tremble-proof strategy, but unlike the cheat type, his payoff is impacted by trembles in two ways. First, as noted before, when m increases, the contractual share α_1^{m*Pool} increases which lowers the honest manufacturer's payoff in period 1. But there is a second more subtle reason which favors the honest type as m increases: because the rational manufacturer can tremble into renegotiation, upon seeing honest behavior in period 1, the supplier ascribes a higher probability to the manufacturer being honest (as per equation 3.7, q_{21}^{hm} increases in m) which results in a lower contractual share that the honest manufacturer needs to pay the supplier in period 2 – i.e., α_2^m decreases as m increases through enhanced reputational capital enjoyed by the manufacturer in period 2. Hence, a higher trembling probability m: (i) increases α_1^{m*Pool} which lowers the honest manufacturer's payoff in period 1, and (ii) decreases α_2^{m*}

which increases the honest manufacturer's payoff in period 2. For m small, the latter effect dominates so the honest manufacturer's total payoff is increasing in m; when m is large, the increased cost in period 1 overweighs the savings in period 2 and the honest manufacturer earns a lower total expected payoff as m increases.

Under part (ii) of the Lemma, when $m \geq m^{Pool}$, which coincides with part II of proposition 3.3, the rational manufacturer *chooses* to renegotiate in period 1; hence trembles have no effect on any type of manufacturer.

A comparison of the total profits of the three types of manufacturer is shown in figure 3.3 as a function of the prior probability of the honest type (horizontal axis) and the probability of trembles (on the vertical axis).

Region 1 corresponds to part II of proposition 3.3 where the optimal dynamic strategy of the manufacturer is to renegotiate in period 1 itself. Consequently, the strategy of the rational and cheat types coincides earning them identical profit, which is more than the profit of the honest type (clearly the optimal dynamic strategy in this region is to hold up the supplier in period 1 itself, which is at odds with the honest type's strategy).

Regions II, III and IV in figure 3.3 correspond to part I of proposition 3.3. Even though the payoff of the rational type is susceptible to trembles in these three regions (unlike the cheat type), the rational type makes higher profit than the cheat type in these regions because the rational type attempts to implement the optimal dynamic strategy of playing honest in period 1 – he succeeds with probability $(1 - m)$ – whereas the cheat type is constrained to be suboptimally myopic.

Corollary 3.4 *Despite possessing a tremble-proof strategy, the cheat type never obtains a*

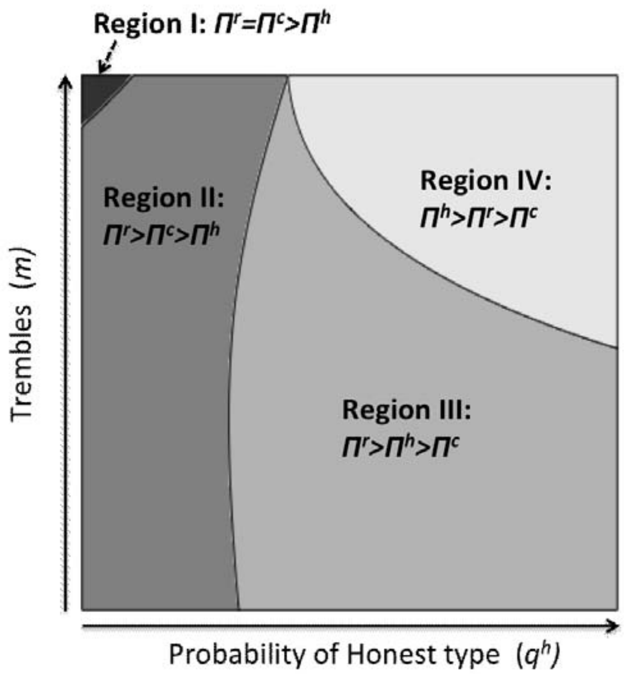

Figure 3.3: Profits of the three types of manufacturer as a function of q^h and m.

higher payoff than the rational type for any m, p, c or V.

When the probability of honest types is small enough, such as in Region II of Figure 3.3, the burden of contracting is rather onerous for the honest type – because of the high probability of cheat and rational types, the supplier demands a greater share of the value as compensation for the risk of hold up thereby hurting the profitability of the honest type. However, as the probability of the honest type increases, the supplier's share decreases in equilibrium, thus increasing the profit of the honest type. So much so that the honest type can accrue a higher payoff than the cheat type in Regions III and IV despite both having tremble-proof strategies.

Now consider the relative profits of the honest and the rational types in regions III and IV which are characterized by a high enough probability of the presence of honest type. In both these regions, the rational manufacturer attempts to pool with the honest manufacturer by honoring the contract in Stage 4 of period 1. For a given q^h, as m increases, i.e., as one travels from Region III in the figure upwards to Region IV, the payoff of the rational manufacturer decreases per part (i) of Lemma 3.3, whereas the honest type's payoff first increases then decreases, refer to the discussion below Lemma 3.3. However, there exists a critical threshold on m, call it m^*, beyond which, i.e., in Region IV, the honest type's payoffs are higher than the rational type's payoff.

Theorem 3.1 *In a two-period dynamic relationship with trembles, the honest type outperforms both the rational type and the cheat type iff $m^*(c, p, V, \vec{q}) < m < m^{Pool}$, where $m^*(c, p, V, \vec{q})$ is the smaller root of the following equation:*

$$\frac{p^2 V}{c} = \frac{1}{1 - mq^r - q^c} + \frac{1 - mpq^r - pq^c}{m(1 - q^r - q^c)}$$

(The condition $m^*(c, p, V, \vec{q}) < m < m^{Pool}$ guarantees that the probability of trembles ought to be high enough, but not so high that the rational type finds it optimal to renegotiate in period 1 itself.)

The simple tremble-proof strategy of the honest type trumps the richer strategy of the rational type. In essence, the *curse of dimensionality, i.e.,* the richness of the rational type's strategy space, works against him in the presence of cognitive limitations and managerial myopia (which together can lead to trembles into myopia). However, it must be emphasized that merely possessing a simple tremble-proof strategy is no guarantee for surpassing the rational type's payoffs; after all, even the cheat type has a simple tremble-proof strategy but is never able to make a higher profit than the rational type for *any* parameter value.

3.6 Conclusion

Our results show that, in a single period, the rational manufacturer outperforms the honest type – after all, the rational type can always mimic the honest-type's strategy. However, even in a minimal repeated relationship (i.e., over just two periods), the honest-type manufacturer may outperform the rational type, even though, as before, the rational type can always mimic the honest-type's strategy. This happens when the project is lucrative enough (low cost to value ratio, or large enough probability of realizing a 'high' investment value), or interactions are repeated several times. The following implications are imminent: (i) Honesty is rewarded in a repeated innovation partnership – it emerges *endogenously* as the optimal policy under very reasonable conditions. (ii) The hold-up threat is mitigated in two ways without resorting to complex and extreme measures suggested in the economics literature: First, honest-type manufacturers are honest throughout (and honesty emerges endogenously as noted above). Second, rational-type manufacturers play honest (i.e., they do not hold-up the supplier) in the earlier periods of a repeated relationship. As the hold-up problem is mitigated, all parties are better off in equilibrium.

Within the context of the hold up problem in operations, this paper proves that an honest firm, which never hold up its contractual partner, can earn a higher payoff than the quintessential rational firm, even when the rational firm has a larger strategy space than the honest firm (i.e., the rational firm may or *may not* hold up its contractual partner whereas the honest firm *never* holds up its contractual partner). In fact, one should say that the honest firm makes higher payoff than the rational firm *because* it has a smaller strategy space, which renders its strategy robust and immune to trembles. In effect, if one discards the tenet of unbounded rationality, and realistically assumes that people often make mistakes in implementing strategies, then the choice of honesty emerges both as *desirable* and rational under very reasonable conditions. (However, merely having a tremble proof strategy cannot guarantee a higher payoff than conventional rationality. For instance, the cheat type, although possessing a tremble-proof strategy, never outperforms the rational type.)

Honest behavior in *some* transactions can be explained by a rational response to mimic honesty (as in the reputations literature) or it can be explained by the threat of punishments for dishonest behavior (as in the literature on infinite-horizon relational contracts). However, it must be emphasized that such explanations do not prove that honesty as a trait is the optimal policy; on the contrary, these explanations further buttress the already strong paradigm of conventional rationality that leads to selective honesty as a form of opportunism. In contrast, this paper makes honesty (as a trait) the centerpiece of the analysis, and at the same time provides an economic rationale to its existence through the operational lens of hold ups and incomplete contracts.

Finally, as Williamson (1985) posits (emphasis ours): "Any attempt to deal seriously with the study of economic organization must come to terms with the combined ramifications of *bounded rationality*, *opportunism* and *asset specificity* [relationship-specific commitments]." Our research makes a genuine attempt to integrate all three.

Chapter 4

Honesty in Incomplete Contracts: The Case of Moral Darwinism

4.1 Overview

In conventional reputation games (*cf.* Kreps *et al.* 1982), a rational player, whose type is unknown to the other party, can selectively mimic a "committed" type in order to maximize his own profits. Thus, the rational player, who is an unconstrained profit-maximizer, always outperforms the type who is committed to (i.e., constrained by) a subset of strategies.[1] This result hinges on the tacit yet critical assumption that, barring one type's (irrational) commitment, players are otherwise perfectly rational. As we prove, this result does not hold when both types are *equally* (even if so very mildly) bounded in their rational-

[1] The commitment type has been described variously as irrational– "in the sense that they do not maximize utility"– or even "crazy" (Aumann, 1997, Mailath and Samuelson 2006).

ity in other dimensions[2]: A type committed to *honesty* (defined below) can outperform the unconstrained profit-maximizer even though the latter has access to a superset of strategies, including the option of mimicking the honest type.

We develop a dynamic (multi-stage, multiperiod), analytical model of incomplete contracts between a principal and an agent in a repeated relationship. The principal is either an *unconstrained* or an *honest* profit-maximizer. The unconstrained principal, aptly characterized as 'opportunistic' or 'self-interested with guile' by Williamson (1985), maximizes his own payoff subject only to legal restraints. The honest principal ('self-interested without guile', Williamson, 1985) honors his contractual obligations even in the absence of legal restraints. This distinction between unconstrained and honest profit-maximizers particularly matters under incomplete contracts where, due to inadequate legal recourse under unforeseen contingencies, there can be a divergence between the letter and the spirit of the contract. Although our modeling choices– a finite horizon, different 'types' of the principal, incomplete and asymmetric information, and Bayesian players– are loosely similar to those of a 'reputations' model (*cf* Mailath and Samuelson 2006), our model incorporates several additional, demonstrably critical features such as honesty and a proclivity to tremble due to bounded rationality. Our research makes several contributions, which we summarize below:

- Under plausible conditions, the 'irrational' (honest) type of principal strictly outperforms the unconstrained type, even though the unconstrained principal can selectively mimic the honest principal's strategies. Thus, a commitment to honesty emerges endogenously as the optimal policy.

[2]Bounded rationality manifests in our model as "trembles", which are "small departures from rationality" (Aumann, 1997).

- In traditional reputation models, the unconstrained type outperforms the commitment type by selectively mimicking the latter's strategies. Without adequate contextual justification, the presumption of commitment types who are not profit-maximizers, and whose payoffs are strictly dominated, appears arbitrary and contradicts Economic Darwinism. Reputation models work around this concern by showing that the equilibrium, which typically has the unconstrained type faking commitment, is robust even when the probability of the commitment type's existence is arbitrarily close to zero. Nevertheless, the *possibility* of the specific (and, as discussed above, sub-optimal and arbitrary) irrational type must influence players' beliefs.[3] This criticism is in the spirit of Rubinstein (1998), that "... there are an infinite number of "plausible" models [incorporating irrationality] that can explain social phenomenon; without [rationality], we are left with a strong sense of arbitrariness." The standard we propose for modeling irrationality to minimize arbitrariness is that the constrained profit-maximizer ("commitment type") should, at a minimum, outperform the unconstrained type under plausible conditions, so that the specific type of commitment assumed is not undermined by economic Darwinism.

- Conversely, given that some irrational traits (including ethical values such as honesty) are commonly observed, *despite* incomplete contracts, our model postulates a set of primitives (such as trembles) within the paradigm of economic modeling that explains the survival of these traits. Hence, our research provides a bridge between normative rationales for honesty– the province of Ethics – and profit-maximization, which is axiomatic in Economics, by providing a compelling *economic* rationale for honesty.

[3]More technically, a belief in the possibility of the *specific* irrational type assumed in the model must interfere with the "common knowledge" of rationality, see Aumann (1992).

- In sum, Rubinstein (1998) argues that "...substantive rationality is actually a constraint on the *modeler* rather than an assumption about the real world..." Our proposed standard relaxes this constraint on the modeler, in order to accommodate plausible models of Bounded Rationality.

- Finally, in the context of incomplete contracts, we show that the principal can induce the agent to make optimal relationship-specific investments, using simple, finite-horizon contracts. Hence, we diverge from all previous explanations offered in the academic literature (including relational contracts and conventional reputation models) for the robustness and widespread use of simple contracts.

4.2 The Model

A *P*rincipal and an *A*gent, both risk-neutral, expected-profit maximizers and indexed by P and A respectively, engage in a contractual relationship spanning a finite horizon of $N \geq 2$ periods.[4] In any period $i \in \{1, ..., N\}$, events evolve in four stages; see Figure 4.1. (Our timeline with four stages is similar to the sequence of events assumed in the literature on incomplete contracts, *cf.* Hart and Moore $(1988, 1999)$, Tirole (1999).)

In stage 1, the principal offers a contract. If the agent accepts the contract, she invests e_i in stage 2 that generates a non-transferable value $\tilde{V}_i(e_i)$ for the principal in stage 3.[5] Finally, the agent is paid in stage 4, possibly after *renegotiation*.

[4] Risk neutrality is a fairly standard assumption in the literature on incomplete contracts, *cf.* Hart and Moore $(1988, 1999)$, Tirole (1999). A risk-averse agent is easy to model, but would add clutter without changing insights.

[5] "Non-transferability" of value rules out the possibility of the principal's "selling the firm" to the agent. For example, $\tilde{V}_i(e_i)$ could be the value of one of several subprojects (such as R&D) contributing to the principal's project. Each subproject has no independent value.

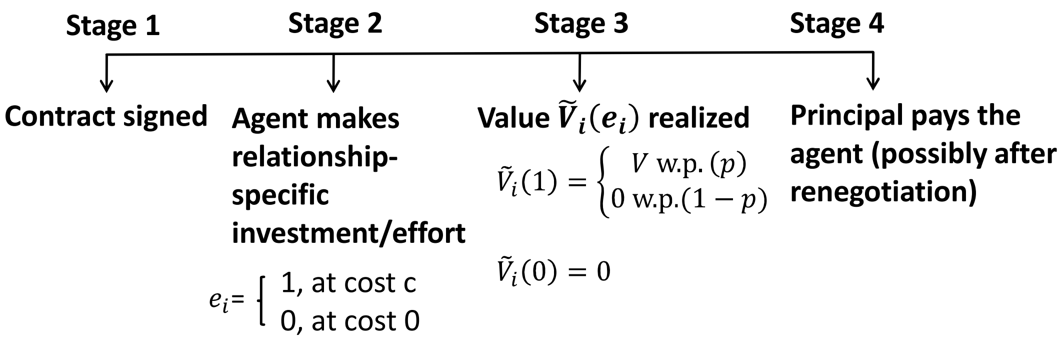

Figure 4.1: Sequence of events in period $i \in \{1, 2...N\}$.

The agent's investment (equivalently, effort), e_i, is unobservable and *relationship-specific*; further the principal has residual property rights. The investment/effort can be either 'high' ($e_i = 1$) or 'low' ($e_i = 0$). The cost of investment is $C(e_i)$,where $C(1) = c > 0$ and $C(0) = 0$. The value $\tilde{V}_i(e_i)$ is observable to both parties, and has contractible and non-contractible components (i.e., components that can and cannot be verified and arbitrated by a court of law). Conservatively, we normalize the contractible component to 0. (As will become clear later, relaxing this assumption strengthens our results.) Thus, $\tilde{V}_i(e_i)$ is fully non-contractible. Furthermore, $\tilde{V}_i(e_i)$ is jointly determined by e_i and nature. In specific, $\tilde{V}_i(e_i) = e_i V$ with probability p, and 0 otherwise, where $pV > c$. Thus, $\tilde{V}_i(1) = V$ with probability p and 0 with probability $(1 - p)$, and $\tilde{V}_i(0) = 0$ identically.

The principal's *type*, which is *u*nconstrained or *h*onest, and indexed by u and h respectively, drives outcomes in stage 4. The unconstrained principal may renegotiate his contractual payment to the supplier, whereas the honest principal never renegotiates. We let q_i and $(1 - q_i)$ denote the probabilities that the agent assigns at the beginning of period i to the principal being honest and unconstrained respectively; $q_1 \in (0, 1)$ is common knowledge.

As the relationship proceeds, the agent updates his beliefs q_i in Bayesian fashion. The principal is susceptible to trembles– mistakes made in executing strategies– due to *bounded rationality* (*cf.* Aumann, 1997). With a small probability m, the principal trembles into *myopia*; i.e., he inadvertently plays his optimal myopic (single-period) strategy instead of his optimal dynamic strategy. This specific form of trembles is by no means critical to the model, but is appealing in dynamic contexts, wherein a combinatorial explosion of feasible actions– the *curse of dimensionality* (Bellman, 1957) – amplifies the effects of bounded rationality and leads to myopia.[6] In the interests of parsimony, we assume that only the principal trembles, and the fact of his trembling is common knowledge. An additional conservative assumption is that the principal has only one 'trembling opportunity' per period (in stage 4). In practice, a period could consist of dozens of interactions, and thus present several type-revealing trembling opportunities across multiple stages. Relaxing this assumption would further favor our results.

It is readily seen that the optimal myopic strategy (equivalently, the last-period strategy) for the unconstrained principal is to always renegotiate in stage 4, whereas the honest principal does not have access to this strategy. Hence the honest principal never renegotiates; as a result, his optimal stage 4 strategies in both static and dynamic settings are identical. (Because the honest principal's feasible strategies in stage 4 is a singleton set, he is in fact tremble-proof under *any* model of trembles– trembling into myopia being but one instance. In general, tremble-proofness can be an artifact of either unbounded rationality

[6]Myopic policies ignore the effects of current actions on future periods, and hence, are rarely optimal in dynamic contexts. (See Anand (2014) for interesting exceptions.) Yet, managers choose myopic policies for several reasons, including: an inability to navigate complex and multiple objectives (Conlisk 1996, Ethiraj and Levinthal 2009), incentive conflicts (Stein 1989, Noe et al 2012, Thanassoulis 2013), takeover threats (Stein, 1988), a looming equity offering (Mizik and Jacobson 2007) and a desire to signal their competence in the labor market (Laverty, 1996).

or a deliberate trimming of one's feasible strategies. However, tremble-proofness is not a sufficient condition to outperform the unconstrained type who trembles. The principal's commitment to *honesty* is critical in our context; see chapter 3.)

All parameters c, V, p, N, m and q_1 are common knowledge. For simplicity, no time discounting is considered, and we denote the total payoffs over the relationship horizon for the agent, the unconstrained principal and the honest principal by Π^A, Π^u and Π^h respectively.

4.3 Results

Observe that the unconstrained principal has access to two alternative strategies in stage 4 of any period: He can either renegotiate (thus revealing his type and ending the relationship) or mimic the honest type and not renegotiate. Renegotiation in the first period itself would cut short the dynamic aspect of the relationship, collapsing the game into a trivial, single-period interaction. Hence, we focus on the more interesting case wherein the unconstrained Principal wants the relationship to continue for at least two periods, and hence mimics the honest type in stage 4 of the first period. Factors that favor the Principal's continuing the relationship beyond the first period are high values of: *(a)* the probability of success p in the next period, *(b)* prior probability q_1 of the principal being honest, and *(c)* the potential payoff V/c from future iterations of the relationship. A sufficient technical condition which we will assume for the rest of this paper is that $\frac{pV}{c} > \frac{2-p(1-q_1)}{pq_1}$.

We now derive the Perfect Bayesian Nash Equilibrium (PBNE) in pure strategies for $N \geq 2$. Sufficient conditions for *any* contract to maximize the principal's payoffs are:

(i) The agent exerts the first-best level of effort; and *(ii)* The agent's individual rationality constraint binds, i.e., she is indifferent between accepting and rejecting the offered contract. As we prove in Theorem 4.1, these conditions can be met by a sequence of period-length contracts wherein the payment offered to the agent is $\alpha_i^x \tilde{V}_i$, where $0 \leq \alpha_i \leq 1$ and x, the principal's type $\in \{u, h\}$. (This implies, for example, that the principal cannot improve his payoffs by offering a single, complex contract at the outset.)

Theorem 4.1 *A pure-strategy PBNE for the dynamic (N-period) game, for $N \geq 2$, is as follows:*

Period i $(< N)$: The agent will accept a contract in period i (and hence, the game proceeds to period i) if and only if *there was no renegotiation in periods* 1 *through* $(i-1)$. *Both types of the principal offer $\alpha_i^* \tilde{V}_i$ in stage 1, where $\alpha_i^* = \frac{c}{(1-m(1-q_i))pV}$; the agent invests in stage 2, setting $e_i^* = 1$; and in stage 4, the optimal dynamic strategy for both types of the principal is to not renegotiate, i.e., to pay $\alpha_i^* \tilde{V}_i$ to the agent. (Renegotiation occurs with probability m, when the unconstrained principal trembles into myopia.)*

Updated Beliefs: At the beginning of period $(i+1)$, the agent's posterior belief that the principal is honest is:

$$q_{i+1} = \begin{cases} q_i, \ \textit{if } \tilde{V}_i = 0 \ \textit{(By default, the principal does not renegotiate)} \\ \frac{q_i}{q_j + (1-q_i)(1-m)}, \ \textit{if } \tilde{V}_i = V \ \textit{and the principal does not renegotiate} \\ 0, \ \textit{if } \tilde{V}_i = V \ \textit{and the principal renegotiates} \end{cases} \quad (4.1)$$

Period N: The agent will accept a contract in period N (and hence, the game proceeds to period N) if and only if *there was no renegotiation in periods* 1 *through* $(N-1)$. *Both types of the principal offer $\alpha_N^* \tilde{V}_N$ in stage 1, where $\alpha_N^* = \frac{c}{q_N pV}$; the agent invests in* *stage 2, setting* $e_N^* = 1$*; and in stage 4, the unconstrained principal renegotiates (and pays* 0 *to the agent), whereas the honest principal pays* $\alpha_N^* \tilde{V}_N$ *to the agent.*

Theorem 4.1 reflects the differences in principals' strategies across the terminal and non-terminal periods. In the terminal period N, the unconstrained principal always renegotiates in equilibrium. In the non-terminal periods 1 through $(N-1)$, the strategies of both types of the principal are to not renegotiate; yet, the risk of renegotiation is not entirely eliminated because the unconstrained principal can tremble into myopia. The offers of $\alpha_i^* = \frac{c}{(1-m(1-q_i))pV}$ for $i = 1, ..., N-1$ and $\alpha_N^* = \frac{c}{q_N pV}$ reflect the respective probabilities $(1 - m(1 - q_i))$ and q_N of no renegotiation, keeping the agent just indifferent between accepting and rejecting the contract.

The next Theorem proves that for *any* repetitive relationship, the honest principal's payoffs are *strictly* greater than those of the unconstrained principal under plausible conditions.

Theorem 4.2 *(i)* $\forall N \geq 2$, $\exists m_N^* \in (0,1)$ *such that* $\Pi^h > \Pi^u$ if $m > m_N^*$.

(ii) m_N^* *is strictly decreasing in* N.

(iii) $\lim_{N \longrightarrow \infty} m_N^* = 0$.

(iv) $\forall N$, m_N^* *is strictly decreasing in* q_1, p *and* V, *and strictly increasing in* c.

Part *(i)* of Theorem 4.2 shows that for any N, including even for just one repetition of the relationship ($N = 2$), the honest type's payoffs can be strictly greater than the unconstrained type's. Part *(ii)* of the Theorem proves that m_N^* is decreasing in N. Thus, as N increases, the honest type's payoffs are greater than the unconstrained type's for progressively smaller trembling probabilities that asymptotically converge to 0 by part *(iii)*

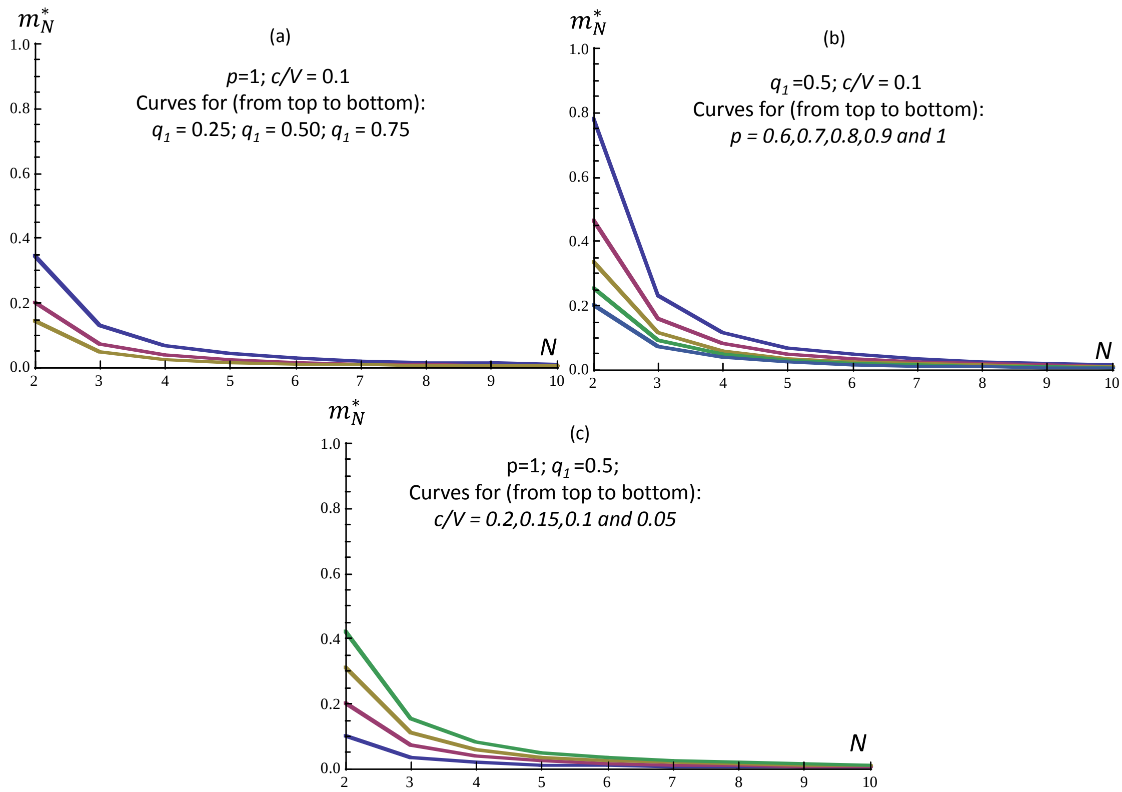

Figure 4.2: m_N^* against N for different parameter values.

of the Theorem. Part *(iv)* formalizes the intuition that since trembles by the unconstrained type abruptly terminate the game, parameter values that increase future expected payoffs – high p, q_1 and V, and low c – favor the honest type.

Figures 4.2(a)-(c) illustrate Theorem 4.2 for varying values of N, p, q_1 and c/V. As N, p, q_1 or V/c increase, m_N^* falls; hence, the honest type outperforms the unconstrained type at ever smaller m. The effect of N is particularly dominant. As N grows, m_N^* falls rapidly for any combination of parameter values, and becomes very small beyond $N \approx 6$.

The next Theorem fixes the trembling probability m and analyzes the effect of varying the number of interactions N.

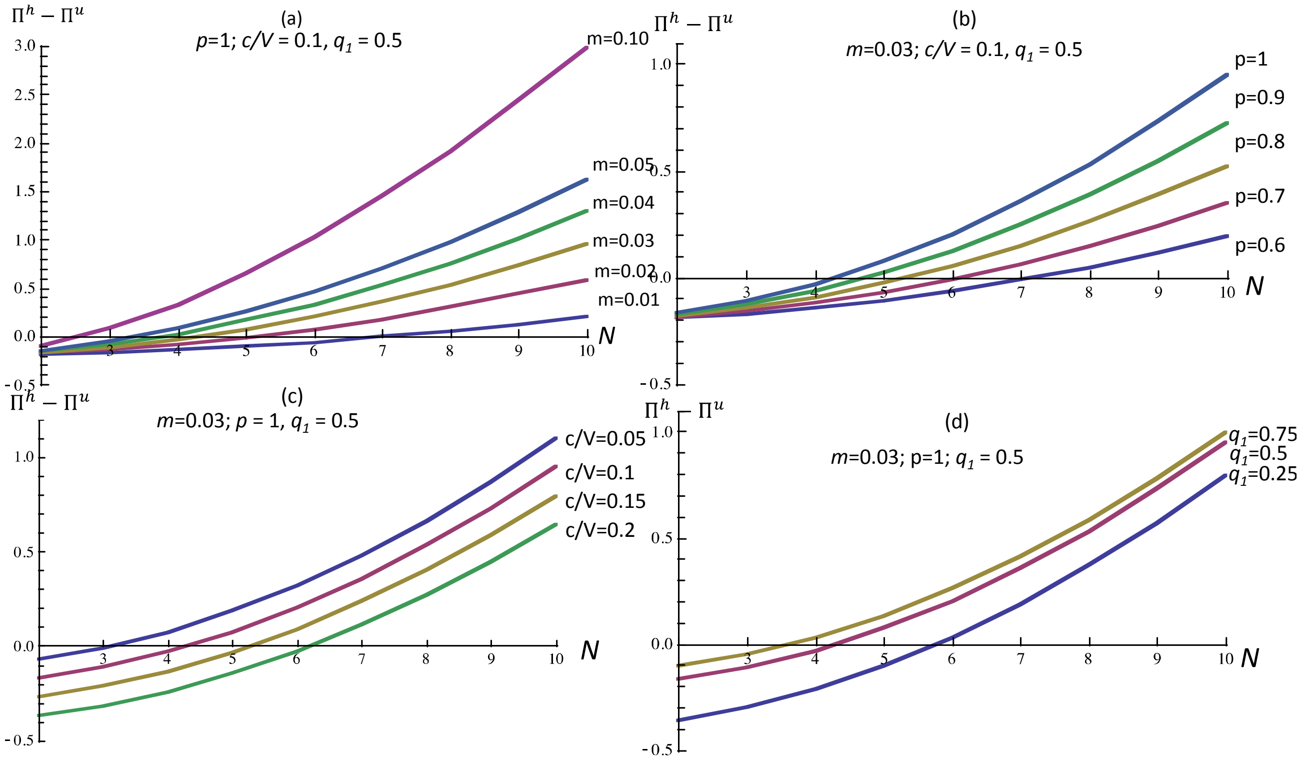

Figure 4.3: Profits difference between honest principal and unconstrained principal for different parameter values.

Theorem 4.3 *(i)* $\forall m \in (0,1)$, $\exists N_m^*$ *such that* $\Pi^h > \Pi^u$ *if* $N > N_m^*$.

(ii) N_m^* *is decreasing in* m, q_1, p *and* V, *and decreasing in* c.

Theorem 4.3 proves that for any arbitrary trembling probability m, howsoever small, the honest type will outperform the unconstrained type provided the relationship is repeated long enough (for more than N_m^* periods). Figures 3(a)-(d) show that $\Pi^h - \Pi^u$ increases with N and intersects the x-axis at or just to the right of N_m^*. In all cases, N_m^* is quite modest– ranging from 2 to 7 periods. In practice, a period itself could consist of many potentially type-revealing interactions, whereas our model allows at most one tremble per period. Thus, honesty can pay off in relationships spanning only a few periods.

Consistent with part *(ii)* of Theorem 4.3, N_m^* is decreasing in m, q_1, p and V, and decreasing in c in the figures.

Recall that we had normalized the contractible (non-renegotiable) component to 0, and thus, $\tilde{V}_i(e_i)$ was fully non-contractible. Relaxing this assumption, while easy to do, would further punish the unconstrained type for his trembles and favor the honest type.

Figures 4.2 and 4.3 also suggest that, when atomistic principals in a population endogenously choose their types, m^* is a tipping point for self-enforcement of honesty: For any initial fraction of honest principals in the population, if $m > m^*$, the result $\Pi^h > \Pi^u$ should nudge this fraction to 1; Conversely, if $m < m^*$, the fraction of honest principals should converge to 0. This raises interesting questions for future research about equilibrium outcomes when societies vary in their cultural norms such as honesty.

4.4 Discussion of Modeling Assumptions

In order to keep the analysis tractable and to flesh out the insights in the cleanest possible way, our model is parsimonious with several simplifying assumptions. (Although, at a broad level, the context of hold ups is not particularly necessary for our results to hold; our model and analysis apply equally well to the overall context of incomplete contracts.) We discuss these assumptions below. We also discuss whether our key insights change as we relax these assumptions.

A1. Effort is binary. The agent makes an all-or-nothing investment decision in stage 2 of each period. In practice, firms may not only choose whether to invest, but also how much to invest. Hence, we also analyze a more complex model with continuous effort and convex costs. Our key results are robust to either model specification. For expositional clarity, we present the simpler model in the paper.

A2. Value is binary and independent across periods. For simplicity we assume that (*i*) the project value is binary; (*ii*) the project value and the corresponding probabilities are stationary across periods; and (*iii*) the investment in the current period has no impact on the potential value in the next period. We can relax all of these assumptions without changing results and insights.

For (*i*) , the insights remain unaltered if the value $\tilde{V}$ is drawn from a continuous distribution, or from a discrete distribution with more more than two possible values. As in the current model, the unconstrained type will find it optimal to renegotiate to the minimal value V_L in the terminal period. In the earlier period, the unconstrained type will find it optimal to renegotiate if $\tilde{V}$ is more than some threshold (the renegotiated value will once again be V_L), whereas for a value less than the threshold, he will not renegotiate. Hence, the essence of the analysis and the insights remain unaltered.

For (*ii*) and (*iii*) it is even simpler to incorporate both extensions without changing insights. In particular, for (*iii*) , the value $\tilde{V}_2$ in period 2 can be modeled as a function of the investment in period 1. For instance, $\tilde{V}_2 = \tilde{V}_1(1 + \beta e_1)$; where $\beta > 0$ implies that the effort in period 1 increases the potential value in period 2, whereas $\beta < 0$ implies the converse. Our current model coincides with $\beta = 0$, which is both conservative and neutral.

A3. Model of trembles: Our model of trembles is parsimonious and has several appealing features. First, because trembles are part of the equilibrium play, and because players are aware of the possibility of trembles, players in our model blunt the impact of trembles, wherever possible, through appropriate strategies. For instance, the unconstrained principal optimally plays honest *less* often to avoid trembling. In contrast, classical papers have modeled trembles that are imposed by the modeler to refine equilibria without the players in the game necessarily accounting for these when they decide their strategies. Second, trembles prove to be *type revealing* in the specific context of our model, which is critical to the insights developed in this paper. Hence, whether trembles are unidirectional only into myopia, or they are arbitrarily determined, is of secondary importance. However, trembles into myopia not only provide a much needed 'technology of error', they are also conservative and minimalistic. For instance, they limits the mistakes players can make – the unconstrained type could have trembled into playing honest when he intends to play the myopic strategy of holding up the agent, but such trembles are precluded in our model. (As an aside, such random trembles are difficult to justify, and even if modeled, they will not change insights.) Moreover, allowing the players to tremble in only stage 4 of a period is in a similar spirit of keeping the trembles at a minimum. Finally, as emphasized above, the only kind of trembles necessary in our model are the ones that reveal type; any other forms of trembles (or mistakes), such as miscalculating beliefs, etc., will only clutter analysis without changing insights.

A4. After renegotiation, the principal makes zero future payoff. It is logical in our model that the principal makes zero future payoff once he renegotiates in a period because the agent knows that the principal is not honest. There are two ways to relax this assumption: (*i*) With some probability, the agent does not discern that he has been held up in a period and therefore he continues his relationship with the principal for the next period; and (*ii*) the principal gets some residual future payment after renegotiating. It is easy to incorporate both these extensions, but fundamental insights remain unchanged.

Essentially, in our model, reputation is permanently sullied. But our findings are not contingent on this. All we need is reputational loss. Quoating from Klein (1996): "...the transactor engaged in hold up will face increased cost of doing business in future. Potential trading partners will become less willing to rely upon the transactor's promises and demand more favorable and/or explicit contract terms...[for instance,] they can find more expensive to purchase inputs in future." (pg 11).

*A*5. *Finite horizon model.* Although the number of periods in our model can be arbitrarily large, the horizon is finite, i.e., there is a known time beyond which all interactions cease. An infinitely repeated game is ill-suited for our setup for the following reasons: (*i*) The analysis is unsatisfactory because multiple equilibria are possible due to the folk theorem; and (*ii*) It artificially tips the scale in favor of the honest type, and against the unconstrained type, as the cost of cheating can be made arbitrarily large by using an appropriately 'grim' trigger strategy.

Hence, the finite period model is the most conservative without biasing the model in favor of our results since it favors the unconstrained type – the unconstrained type to renegotiate with impunity in the last period – despite which we show that honest type can accrue higher payoff than the unconstrained type.

4.5 Conclusion

The simple tremble-proof strategy of the honest type trumps the richer strategy of the unconstrained type. In essence, the *curse of dimensionality, i.e.,* the richness of the unconstrained type's strategy space, works against him in the presence of cognitive limitations and managerial myopia (which together can lead to trembles into myopia). (However, merely having a tremble proof strategy cannot guarantee a higher payoff than conventional rationality. For instance, the cheat type, although possessing a tremble-proof strategy, never outperforms the rational type, see chapter 3.)

In fact, we have been so numbed by the idea of opportunism and rationality in economic models that such desirable traits as honesty and trust are often characterized as irrational and studied as deviations from the tenets of rationality. This paper offers an explanation that not only suggests why traits such as honesty have not been weeded out by economic Darwinism, but also offers a *rational* justification for honesty. The choice of honesty emerges both as *desirable* and rational under very reasonable conditions. As the Nobel laureate Williamson (1989, pg. 140) notes: "Those forms of organization that serve to economize on bounded rationality [such as by selecting a simple strategy of honesty] and safeguard transactions against the hazards of opportunism [again, a strategy of being honest does that] will be favored...." Such favoritism ensures that traits such as honesty can co-exist with the classical paradigm of the unconstrained rational man.

Appendix A

Technical Appendix to Chapter 2

Technical condition: $1 \leq m_i \leq 2$ and $\frac{Z_H}{Z_L} \leq \left(\frac{m_i+1-p}{1-p}\right)^2$ (or $m_i \geq \frac{(1-p)\left(\sqrt{Z_H}-\sqrt{Z_L}\right)}{\sqrt{Z_L}}$).

A.1 Proof of Proposition 2.1

Consider the case when both firms choose to do market research (M_S, M_W). Suppose that market research reveals the true market size to be Z (Z can be Z_H or Z_L, the analyses of which are parallel). The two firms' maximize their expected payoffs as follows:

$$\begin{aligned}\pi_S\left(x_S|M_S, M_W, Z\right) &= \max_{x_S \geq 0} \frac{x_S}{x_S + x_W} m_S Z - c x_S \\ \pi_W\left(x_W|M_S, M_W, Z\right) &= \max_{x_W \geq 0} \frac{x_W}{x_S + x_W} m_W Z - c x_S\end{aligned}$$

Clearly, the firms' optimal investment levels are functions of both the realized market size Z and the rival's investment decision. In specific, $x_S^*(x_W|M_S, M_W, Z) = \sqrt{\frac{m_S x_W Z}{c}} - x_W$, and $x_W^*(x_S|M_S, M_W, Z) = \sqrt{\frac{m_W x_S Z}{c}} - x_S$.

Depending on the firms' choices of whether to conduct competitive intelligence, when to invest, and whether to conceal information on his investment, three possible game configurations can occur:

(I) **Firm S observes x_W before choosing his own x_S**, which happens when firm S does competitive intelligence and invests late *while* firm W invests early and does not conceal his investment. The equilibrium results are

$$x_S^* = \frac{m_W(2m_S - m_W)Z}{4cm_S}; x_W^* = \frac{m_W^2 Z}{4cm_S}$$
$$\pi_S^* = \frac{(2m_S - m_W)^2 Z}{4m_S}; \pi_W^* = \frac{m_W^2 Z}{4m_S}$$

(II) **Firm W observes x_S before choosing his own x_W**, which happens when firm W does competitive intelligence and invests late *while* firm S invests early and does not conceal his investment. In this case, the equilibrium results are

$$x_S^* = \frac{m_S^2 Z}{4cm_W}; x_W^* = \frac{m_W (2m_W - m_S) Z}{4cm_W}$$
$$\pi_S^* = \frac{m_S^2 Z}{4m_W}; \pi_W^* = \frac{(2m_W - m_S)^2 Z}{4m_W}$$

(III) In all situations other than the two above, **neither firm i observes the competitor's x_j before choosing their own investment levels**, so the equilibrium results are:

$$x_S^* = \frac{m_S^2 m_W Z}{c(m_S + m_W)^2}; x_W^* = \frac{m_S m_W^2 Z}{c(m_S + m_W)^2}$$
$$\pi_S^* = \frac{m_S^3 Z}{(m_S + m_W)^2}; \pi_W^* = \frac{m_W^3 Z}{(m_S + m_W)^2}$$

It can be easily seen that when $m_S = m_W$, the three configurations essentially have the same equilibrium outcomes – the two firms choose identical investment levels and generate identical payoffs, and they always share the market equally. Hence, there is no unique equilibrium for the CI, investment timing and information concealment strategies.

When $m_S > m_W$, both firms make the highest payoffs under configuration (I). Hence, the unique equilibrium is that firm W does not do competitive intelligence and invests early without concealing his investment, while firm S does competitive intelligence and invests late. In the equilibrium, firm S invests more and captures higher market share than firm W ($x_S^* = \frac{m_W(2m_S - m_W)Z}{4cm_S} > x_W^* = \frac{m_W^2 Z}{4cm_S}$), and firm S earns higher profit than firm W ($\pi_S^* = \frac{(2m_S - m_W)^2 Z}{4m_S} > \pi_W^* = \frac{m_W^2 Z}{4m_S}$).

The analysis of the $\left(\overline{M}_S, \overline{M}_W\right)$ case is very similar to the above, simply by replacing m_S and m_W with 1, and Z with $Z_\mu = pZ_L + (1-p)\,Z_H$. Hence, the equilibrium results is identical to the case where $m_S = m_W$.

A.2 Proof of Proposition 2.2

Since the two asymmetric market research strategies cases have parallel analysis, below we only analyze the $\left(M_S, \overline{M}_W\right)$ case in detail. After the market research stage, the two firms are asymmetric in two dimensions: firm S is perfectly informed about the realized market size Z_H or Z_L, and in addition he obtains the amplification factor m_S for the market value; in contrast, firm W remains uninformed about the market size $\widetilde{Z}$ and he does not gain any amplification factor for the market value.

Again, depending on the firms' choices of whether to conduct competitive intelligence, when to invest, and whether to conceal information on the investment, three possible game configurations can occur where one (or neither) firm may observe the rival's investment level and then optimize his own investment decision accordingly. The asymmetry between firms' information endowments introduces a new element to the game: upon observing the informed firm's investment level x_S (such as when configuration (ii) is in play), the uninformed firm W may be able to infer the informed firm S's private knowledge of the statistical market size and may further utilize this newly inferred market size information in choosing his own x_W. In other words, under some combinations of firms' CI and investment strategies, a signaling game may be endogenously formed and CI may help convey statistical market size information from the informed firm to the uninformed firm. We show the equilibrium outcome details under each of these three configurations below.

(I) **Firm S observes x_W before choosing his own investment level.**

This forms a Stackelberg game with asymmetric information but no signaling: the uninformed firm W chooses his investment level based only on the prior knowledge about the uncertain market size $\widetilde{Z}$, while the informed firm S can optimize his investment level with both his private information about the realized market size (Z_H or Z_L) *and* the observation of x_W :

$$
\begin{aligned}
\pi_W\left(x_W|M_S,\overline{M}_W\right) &= \max_{x_W\geq 0} p\frac{x_W}{x_{SL}+x_W}Z_L+(1-p)\frac{x_W}{x_{SH}+x_W}Z_H-cx_W \\
\pi_{SL}\left(x_{SL}|M_S,\overline{M}_W,Z_L,x_W\right) &= \max_{x_{SL}\geq 0}\frac{x_{SL}}{x_{SL}+x_W}m_SZ_L-cx_{SL} \\
\pi_{SH}\left(x_{SH}|M_S,\overline{M}_W,Z_H,x_W\right) &= \max_{x_{SH}\geq 0}\frac{x_{SH}}{x_{SH}+x_W}m_SZ_H-cx_{SH}
\end{aligned}
$$

And the equilibrium outcomes are as follows:

$$x^*_W = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{4cm_S}$$
$$x^*_{SL} = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)\left(2m_S\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)}{4cm_S}$$
$$x^*_{SH} = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)\left(2m_S\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)}{4cm_S}$$
$$\pi^*_W = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{4m_S}$$
$$\pi^*_{SL} = \frac{\left(2m_S\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_S}$$
$$\pi^*_{SH} = \frac{\left(2m_S\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_S}$$

(Because configuration (II) is the most complex situation, we move its analysis to the last.)

(III) **Neither firm i observes the competitor's x_j before choosing their own investment levels.**

In this case, there is also no change in the uninformed firm W's beliefs about the market size. The two firms solve the following program

$$\begin{aligned}
\pi_W\left(x_W|M_S,\overline{M}_W\right) &= \max_{x_W\geq 0} p\frac{x_W}{x_{SL}+x_W}Z_L+(1-p)\frac{x_W}{x_{SH}+x_W}Z_H-cx_W \\
\pi_{SL}\left(x_{SL}|M_S,\overline{M}_W,Z_L\right) &= \max_{x_{SL}\geq 0} \frac{x_{SL}}{x_{SL}+x_W}m_SZ_L-cx_{SL} \\
\pi_{SH}\left(x_{SH}|M_S,\overline{M}_W,Z_H\right) &= \max_{x_{SH}\geq 0} \frac{x_{SH}}{x_{SH}+x_W}m_SZ_H-cx_{SH}
\end{aligned}$$

And the equilibrium outcomes are:

$$x_W^* = \frac{m_S\big((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\big)^2}{c(1+m_S)^2}$$
$$x_{SL}^* = \frac{m_S\big((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\big)\big((1+m_S)\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\big)}{c(1+m_S)^2}$$
$$x_{SH}^* = \frac{m_S\big((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\big)\big((1+m_S)\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\big)}{c(1+m_S)^2}$$
$$\pi_W^* = \frac{\big((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\big)^2}{(1+m_S)^2}$$
$$\pi_{SL}^* = \frac{m_S\big((1+m_S)\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\big)^2}{(1+m_S)^2}$$
$$\pi_{SH}^* = \frac{m_S\big((1+m_S)\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\big)^2}{(1+m_S)^2}$$

(II) **Firm W observes x_S before choosing his own investment level**

If the informed firm S chooses a *separating strategy* (i.e.,he chooses different investment levels for different market size states, or $x_{SL} \neq x_{SH}$), then the uninformed firm W can perfectly infer the realized market size from x_S before choosing his investment level. While if the informed firm S chooses a *pooling strategy* (i.e.,he chooses the same investment level for both market size states, or $x_{SL} = x_{SH} = x_P$), then the uninformed firm W cannot infer anything from x_S. Through the following lemmas, we first identify the existence conditions for the *separating equilibrium* and the *pooling equilibrium* respectively, and then check which equilibrium will be chosen by the players.

- **The separating equilibrium.**

Lemma A.1 *There always exists a separating PBNE for $m_S \leq 2$ in the game when the uninformed firm W conducts competitive intelligence and invests late:*

The informed firm S invests early with

$$x_{SL}^* = x_{SL}^- = \frac{m_S^2(Z_H-\sqrt{Z_H(Z_H-Z_L)})^2}{4cZ_L} \quad \textit{if } Z = Z_L$$
$$x_{SH}^* = \frac{m_S^2 Z_H}{4c} \quad \textit{if } Z = Z_H$$

The uninformed firm W invests late with

$$x^*_{WL} = \frac{m_S(Z_H-\sqrt{Z_H(Z_H-Z_L)})(2Z_L-m_S(Z_H-\sqrt{Z_H(Z_H-Z_L)}))}{4cZ_L} \text{ if } \Pr(Z=Z_L)=1$$
$$x^*_{WH} = \frac{m_S(2-m_S)Z_H}{4c} \text{ if } \Pr(Z=Z_L)=0$$

consistent with his belief that

$$\Pr(Z=Z_L) = \left\{ \begin{array}{c} 1, \text{ if firm } S \text{ invests early and } x_S \le x^-_{SL} \\ \\ 0, \text{ otherwise} \end{array} \right\}$$

The payoffs for the two firms are

$$\begin{aligned}
\pi^*_{SL} &= \frac{m_S^2(Z_H-\sqrt{Z_H(Z_H-Z_L)})(2Z_L-(Z_H-\sqrt{Z_H(Z_H-Z_L)}))}{4Z_L} \\
\pi^*_{SH} &= \frac{m_S^2 Z_H}{4} \\
\pi^*_{WL} &= \frac{(2Z_L-m_S(Z_H-\sqrt{Z_H(Z_H-Z_L)}))^2}{4Z_L} \\
\pi^*_{WH} &= \frac{(2-m_S)^2 Z_H}{4}
\end{aligned}$$

Proof. For a pure strategy separating equilibrium to exist, the x^*_{SL} and x^*_{SH} must emerge as a simultaneous solution to the following constrained optimization program:

$$\pi_{SL} = \max_{x_{SL}\ge 0} \frac{x_{SL}}{x_{SL}+x^*_{WL}(x_{SL})} m_S Z_L - c x_{SL}$$
$$\pi_{SH} = \max_{x_{SH}\ge 0} \frac{x_{SH}}{x_{SH}+x^*_{WH}(x_{SH})} m_S Z_H - c x_{SH}$$

subject to :

(The incentive compatibility for both types of informed firm)

$$\frac{x_{SH}}{x_{SH}+x^*_{WH}(x_{SH})} m_S Z_L - c x_{SH} \le \frac{x^*_{SL}}{x^*_{SL}+x^*_{WL}(x^*_{SL})} m_S Z_L - c x^*_{SL} \quad \text{(A.1)}$$
$$\frac{x_{SL}}{x_{SL}+x^*_{WL}(x_{SL})} m_S Z_H - c x_{SL} \le \frac{x^*_{SH}}{x^*_{SH}+x^*_{WH}(x^*_{SH})} m_S Z_H - c x^*_{SH} \quad \text{(A.2)}$$

where

$$x_{WL}^{*}(x_{SL}) = \arg\max_{x_{WL}\geq 0} \frac{x_{WL}}{x_{SL}+x_{WL}} Z_L - c x_{WL} = \left(\sqrt{\frac{x_{SL}Z_L}{c}} - x_{SL}\right)^{+}$$
$$x_{WH}^{*}(x_{SH}) = \arg\max_{x_{WH}\geq 0} \frac{x_{WH}}{x_{SH}+x_{WH}} Z_H - c x_{WH} = \left(\sqrt{\frac{x_{SH}Z_H}{c}} - x_{SH}\right)^{+}$$

The LHS of the IC constraints (equations A.1 and A.2) are the off-equilibrium profits that each type of informed firm would get if he chooses to mimic the other, and the RHS are the equilibrium profits when they truthfully reveal their types.

Constraint A.1 does not bind, as only the high type informed firm has incentive to mimic and pretend to be a low type. So $x_{SH}^{*} = \frac{m_S^2 Z_H}{4c}$, $x_{WH}^{*} = \frac{m_S(2-m_S)Z_H}{4c}$, and the optimization program reduces to

$$\pi_{SL} = \max_{x_{SL}\geq 0} \frac{x_{SL}}{x_{SL}+x_{WL}^{*}(x_{SL})} m_S Z_L - c x_{SL} \tag{A.3}$$

subject to :

$$\frac{x_{SL}}{x_{SL}+x_{WL}^{*}(x_{SL})} m_S Z_H - c x_{SL} \leq \frac{x_{SH}^{*}}{x_{SH}^{*}+x_{WH}^{*}(x_{SH}^{*})} m_S Z_H - c x_{SH}^{*} = \frac{m_S^2 Z_H}{4} \tag{A.4}$$

$$\text{where } x_{WL}^{*}(x_{SL}) = \sqrt{\frac{x_{SL}Z_L}{c}} - x_{SL} \tag{A.5}$$

The LHS of equation A.4 is the profit of the high type informed firm S if he pretends to be the low type *and* the uninformed firm W were to believe that the true state is low. The RHS is the profit that the high type gets by choosing his optimal separating investment level of $x_{SH}^{*} = \frac{m_S^2 Z_H}{4c}$. Hence, if LHS dominates the RHS (i.e., if constraint A.4 does not hold), then the high type has incentive to mimic the low type. This happens whenever the investment level of the low type falls in the interval $\left(x_{SL}^{-}, x_{SL}^{+}\right)$ where x_{SL}^{-}, x_{SL}^{+}

are respectively the smaller and larger solution of the equation $(LHS - RHS = 0)$.

$$x_{SL}^{+-} = \frac{m_S^2(Z_H \pm \sqrt{Z_H(Z_H - Z_L)})^2}{4cZ_L}$$

Since $Z_H - \sqrt{Z_H(Z_H - Z_L)} < Z_L < Z_H + \sqrt{Z_H(Z_H - Z_L)}$, the unconstrained optimal investment level for the low type $(\frac{m_S^2 Z_L}{4c})$ falls into to the above interval, i.e., $\frac{m_S^2 Z_L}{4c} \in \left[x_{AL}^{*-}, x_{AL}^{*+}\right]$. This means, if the low type informed firm merely optimizes his payoff in equation A.3, the high type informed firm will always mimic him, so natural separation does not exist.

To successfully separate from the high type, the low type informed firm has to distort his investment level to be either smaller than x_{SL}^{-} or larger than x_{SL}^{+}. By substituting x_{SL}^{-} and x_{SL}^{+} to the payoff function A.3, it is easy to see x_{SL}^{-} yields the low type informed firm higher payoff. Hence, the low type informed firm distorts his investment level and under-invests with x_{SL}^{-}, consistent with the uninformed firm's belief that:

$$\Pr(Z = Z_H) = \left\{ \begin{array}{c} 0, \text{ if firm } S \text{ invests early and } x_S \leq x_{SL}^{-} \\ \\ 1, \text{ otherwise} \end{array} \right\}$$

The last thing is to check whether the low type has incentive to unilaterally deviate from the separating equilibrium. For instance, he can deviate and puts a quality $\widetilde{x}_{SL} > x_{SL}^{-}$ such that the uninformed firm believes that he is a high-type according to the belief structure in the lemma. Hence, for the low type, his payoff becomes

$$\widetilde{\pi}_{SL} = \max_{\widetilde{x}_{SL} > x_{SL}^{-}} \frac{\widetilde{x}_{SL}}{\widetilde{x}_{SL} + x_{WH}^{*}(\widetilde{x}_{SL})} m_S Z_L - c\widetilde{x}_{SL}; \text{ where } x_{WH}^{*}(\widetilde{x}_{SL}) = \sqrt{\frac{\widetilde{x}_{SL} Z_H}{c}} - \widetilde{x}_{SL}$$

clearly,

$$\widetilde{\pi}_{SL} \leq \max_{\widetilde{x}_{SL} \geq 0} \frac{\widetilde{x}_{SL}}{\widetilde{x}_{SL} + x_{WH}^{*}(\widetilde{x}_{SL})} m_S Z_L - c\widetilde{x}_{SL} = \frac{m_S^2 Z_L^2}{4Z_H}$$

Therefore,

$$\begin{aligned}\pi^*_{SL} - \widetilde{\pi}_{SL} &> \frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_L)})(2Z_L - (Z_H - \sqrt{Z_H(Z_H - Z_L)}))}{4Z_L} - \frac{m_S^2 Z_L^2}{4Z_H} \\ &= \frac{m_S^2 (Z_H - Z_L) \left(Z_L^2 - \left(Z_H - \sqrt{Z_H(Z_H - Z_L)} \right)^2 \right)}{4Z_H Z_L}\end{aligned}$$

Because $Z_H - \sqrt{Z_H(Z_H - Z_L)} < Z_L$, we always have $\pi^*_{SL} - \widetilde{\pi}_{SL}$. So the low-type informed firm has no incentive to deviate.

Hence, there always exists a separating PBNE, and the details of the equilibrium strategic, beliefs and outcomes are shown in lemma above. ■

- **The pooling equilibrium.**

Define the expected market size $Z_\mu = pZ_L + (1-p)\, Z_H$

Lemma A.2 *For* $p \geq 1 - \frac{Z_L}{Z_H}$ *There exists a Pareto-dominant pooling equilibrium in the game when the uninformed firm* W *conducts competitive intelligence and invests late:*

The informed firm S *invests early with* $x^*_{SP} = \frac{m_S^2 Z_L^2}{4cZ_\mu}$

The uninformed firm W *invests with* $x^*_{WP} = \frac{m_S(2Z_\mu - m_S Z_L)Z_L}{4cZ_\mu}$, *consistent with his beliefs that*

$$\Pr(Z = Z_L) = \left\{ \begin{array}{c} 1, \textit{ if } x_S < \frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu} \\ p, \textit{ if } \frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu} \leq x_S \leq x^*_{SP} \\ 0, \textit{ if } x_S > x^*_{SP} \end{array} \right\}$$

The payoffs of the two firms are

$$\begin{aligned}\pi^*_{SLP} &= \frac{m_S^2 Z_L^2}{4Z_\mu} \text{ if } Z = Z_L \\ \pi^*_{SHP} &= \frac{m_S^2 Z_L(2Z_H - Z_L)}{4Z_\mu} \text{ if } Z = Z_H \\ \pi^*_{WP} &= \frac{(2Z_\mu - m_S Z_L)^2}{4Z_\mu}\end{aligned}$$

Proof. The pooling equilibrium is proved through a series of lemmas as follows.

■

Lemma A.3 *The highest investment level where a pooling equilibrium can be sustained is*

$$x_{(SP)\max} = \frac{m_S^2 Z_L^2}{4cZ_\mu}$$

Proof. We first establish the optimal preferred pooling investment levels, x^*_{SLP} and x^*_{SHP}, for the low and high type informed firm respectively. Suppose $\exists x_{SP}$ such that upon observing this investment level, the uninformed firm is unable to infer the realized market size and sticks to his priors. Hence, the uninformed firm W invests:

$$x^*_{WP}(x_{SP}) = \arg\max_{x_{WP}\geq 0} \frac{x_{WP}}{x_{SP} + x_{WP}} Z_\mu - c x_{WP} = \left(\sqrt{\frac{x_{AP} Z_\mu}{c}} - x_{AP}\right)^+$$

Therefore, the low type and high type informed firm S solve the following optimization program respectively:

$$\begin{aligned}\pi_{SLP} &= \max_{x_{SLP}\geq 0} \frac{x_{SLP}}{x_{SLP} + x^*_{WP}(x_{SLP})} m_S Z_L - c x_{SLP} \\ \pi_{SHP} &= \max_{x_{SHP}\geq 0} \frac{x_{SHP}}{x_{SHP} + x^*_{WP}(x_{SHP})} m_S Z_H - c x_{SHP}\end{aligned}$$

and the preferred optimal pooling investment level for the low type and the high type are respectively $x^*_{SLP} = \frac{m_S^2 Z_L^2}{4cZ_\mu}$ and $x^*_{SHP} = \frac{m_S^2 Z_H^2}{4cZ_\mu}$.

We now show that any candidate investment level x_{SP} for a pooling equilibrium must satisfy: $x_{SP} \leq \min(x^*_{SLP}, x^*_{SHP}) = \frac{m_S^2 Z_L^2}{4cZ_\mu} = x_{(SP)\max}$, because the low type would never agree to pool at a level higher than x^*_{SLP} for any reasonable belief structure (where the uninformed firm ascribes a (weakly) higher probability to the high market size upon seeing a higher investment level by the informed firm). The proof is by contradiction. Suppose $\exists x_{SP} > x^*_{SLP}$. Then the low type informed firm can deviates to invest x^*_{SLP} and does strictly better as long as the uninformed firm assigns a probability of at most $1-p$ to $Z = Z_H$. ■

Lemma A.4 *The lowest investment level that the high type prefers to pool on is*

$$x_{(SP)\min} = \frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu}$$

Proof. The high type informed firm S prefers pooling as long as his pooling profit dominates his optimal separating profit. Hence, under any reasonable belief structure, there should exist a investment level threshold such that any investment level lower than that makes pooling unprofitable for the high type and induces him to separate out. Hence, a pooling investment level x_{SP} should satisfy

$$\frac{x_{SP}}{x_{SP} + x^*_{WP}(x_{SP})} m_S Z_H - c x_{SP} \geq \max_{x_{SH} > x_{SP}} \frac{x_{SH}}{x_{SH} + x^*_{WH}(x_{SH})} m_S Z_H - c x_{SH} = \frac{m_S^2 Z_H}{4}$$

where $x^*_{WP}(x_{SP}) = \sqrt{\dfrac{x_{SP} Z_\mu}{c}} - x_{SP}$

Solving the above inequality we get $x_{SP} \in \left[\frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu}, \frac{m_S^2(Z_H + \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu}\right]$.

Hence, the lowest pooling investment level for the high type is

$$x_{(SHP)\min} = \frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu}.$$

In other words, there is no pooling equilibria below $x_{(SP)\min} = x_{(SHP)\min}$. ■

Lemma A.5 *The pooling equilibrium exists for* $p \geq 1 - \frac{Z_L}{Z_H}$.

Proof. From Lemma A.3 and Lemma A.4, the pooling equilibrium exists if $x_{SP} \in \left[x_{(SP)\min}, x_{(SP)\max}\right]$. Hence, pooling exists whenever

$$x_{(SP)\min} \leq x_{(SP)\max}$$

Simplifying this condition, we get

$$\begin{aligned}
&\frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_\mu)})^2}{4cZ_\mu} \leq \frac{m_S^2 Z_L^2}{4cZ_\mu} \\
\Rightarrow\ & Z_H - \sqrt{Z_H(Z_H - Z_\mu)} \leq Z_L \\
\Rightarrow\ & p \geq 1 - \frac{Z_L}{Z_H}
\end{aligned}$$

■

Lemma A.6 *Both types prefer to pool at the* $x_{SP}^* = \frac{m_S^2 Z_L^2}{4cZ_\mu}$, *which is the Pareto-dominant pooling investment level.*

Proof. The low type's pooling profit is maximized at $x_{SLP}^* = \frac{m_S^2 Z_L^2}{4cZ_\mu} = x_{SP}^*$. For the high type, his pooling profit is concave in the pooling investment level with a maximum of $x_{SHP}^* = \frac{m_S^2 Z_H^2}{4cZ_\mu} > x_{SP}^*$. Therefore, the high type prefers pooling at a (feasible) investment level closest to x_{SHP}^*, which is x_{SP}^*. Hence, both types prefer to pool on $x_{SP}^* = \frac{m_S^2 Z_L^2}{4cZ_\mu}$, which Pareto-dominates all other possible pooling levels in the feasible interval $\left[x_{(SP)\min}, x_{SP}^*\right]$.

■

The profits expressions can be obtained fro the equilibrium investment levels after some tedious algebra.

- **The composite equilibrium.**

Lemma A.7 *These exists a pure strategy PBNE, composite of Lemmas A.1 and A.2, which parses to the separating equilibrium of Lemma A.1 when* $p \leq \overline{p} = \frac{3Z_H(Z_H - Z_L) - 2Z_L\sqrt{Z_H(Z_H - Z_L)}}{3Z_H^2 - 4Z_H Z_L}$ *and to the pooling equilibrium of Lemma A.2 otherwise.*

Proof. Separation is the only pure strategy equilibrium (and hence unique) for $p < 1 - \frac{Z_L}{Z_H}$.

For $p > 1 - \frac{Z_L}{Z_H}$, we need to compare the separating and the pooling profits in Lemmas A.1 and A.2. For the high type informed firm, it is readily shown in lemma A.4 that he always prefers pooling at the the Pareto-dominant pooling investment level x^*_{SP} whenever pooling equilibrium exists (i.e., for the entire region of $p > 1 - \frac{Z_L}{Z_H}$). While for the low-type informed firm, his profit is higher under pooling for $p > \overline{p} = \frac{3Z_H(Z_H - Z_L) - 2Z_L\sqrt{Z_H(Z_H - Z_L)}}{3Z_H^2 - 4Z_H Z_L} > 1 - \frac{Z_L}{Z_H}$, and under separating otherwise.

We then show that the strategies of both types of the informed firm will reduce to those under the separating equilibrium when $p \leq \overline{p}$, and to the pooling equilibrium otherwise. It is easy to see from the equilibrium lemmas that whenever pooling exists, the investment levels $x^*_{SL} < x_{(SP)\min} < x^*_{SP} < x^*_{SH}$. This means, if the low type chooses to separate at x^*_{SL}, the high type will also choose his optimal separation strategy because he never finds it profitable to mimic and pretend to be a low type at x^*_{SL}, nor can a pooling equilibrium be sustained at x^*_{SL}. Since the low type informed firm earns higher profit under separation when $p \leq \overline{p}$, he can always successfully do so simply by investing x^*_{SL}.

For $p > \overline{p}$, both types prefer the pooling equilibrium to the separation equilibrium. So they both will invest x^*_{SP}, and the pooling equilibrium of Lemma A.2 ensues. ■

The comparison of the three investment game configurations under

asymmetric market research structure.

To see which one of the three game configurations will be endogenously formed by the firms' CI and investment decisions, we need to compare the firms' equilibrium payoffs in these three game configurations.

Configuration I (Firm S observes x_W)

$$\pi^*_W = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{4m_S}$$
$$\pi^*_{SL} = \frac{\left(2m_S\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_S}$$
$$\pi^*_{SH} = \frac{\left(2m_S\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_S}$$

Configuration II (Firm W observes x_S)

If $p \leq \overline{p}$

$$\pi^*_W = p\frac{(2Z_L-m_S(Z_H-\sqrt{Z_H(Z_H-Z_L)}))^2}{4Z_L} + (1-p)\,\frac{(2-m_S)^2 Z_H}{4}$$
$$\pi^*_{SL} = \frac{m_S^2(Z_H-\sqrt{Z_H(Z_H-Z_L)})(2Z_L-(Z_H-\sqrt{Z_H(Z_H-Z_L)}))}{4Z_L}$$
$$\pi^*_{SH} = \frac{m_S^2 Z_H}{4}$$

If $p > \overline{p}$

$$\pi^*_W = \frac{(2Z_\mu-m_S Z_L)^2}{4Z_\mu}$$
$$\pi^*_{SL} = \frac{m_S^2 Z_L^2}{4Z_\mu}$$
$$\pi^*_{SH} = \frac{m_S^2 Z_L(2Z_H-Z_L)}{4Z_\mu}$$

Configuration III (Neither firm i observes x_j)

$$\pi^*_W = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{(1+m_S)^2}$$
$$\pi^*_{SL} = \frac{m_S\left((1+m_S)\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{(1+m_S)^2}$$
$$\pi^*_{SH} = \frac{m_S\left((1+m_S)\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{(1+m_S)^2}$$

First, because $m_S \geq 1$, it is easy to see that for all players (i.e., the low type informed firm, the high type informed firm, and the uninformed firm), configuration I (where firm S observes x_W) dominates configuration III (where neither firm observes the competitor's investment level). Hence, configuration III can never emerge as an equilibrium outcome in the CI-subgame.

Between the configurations I (where firm S observes x_W) and II (where firm W observes x_S), it can be observed from the numerical results that there exist a $\beta^* > 1$ such that for $m_S < \beta^*$ both the low type informed firm and the uninformed firm prefer configuration II where a signaling game is played. Hence, for $m_S < \beta^*$, the low type informed firm has incentive to invest early and do not conceal his investment, while for $m_S > \beta^*$, the low type informed firm has incentive to do competitive intelligence and invest late.

A.3 Proof of Proposition 2.3

There are four possible market research structures. As per proposition 2.1, the two firms' expected payoffs under the two symmetric market research structures are respectively:

$$\pi_S\left(M_S, M_W\right) = \frac{(2m_S - m_W)^2 Z_\mu}{4m_S}; \pi_W\left(M_S, M_W\right) = \frac{m_W^2 Z_\mu}{4m_S}$$
$$\pi_S(\overline{M}_S, \overline{M}_W) = \frac{Z_\mu}{4}; \pi_W(\overline{M}_S, \overline{M}_W) = \frac{Z_\mu}{4}$$

As per proposition 2.2, the expected payoffs under the two asymmetric market research structures depends on the parameter values:

If $m_i \leq \beta^*$ and $p \leq \overline{p}$:

$$\pi_S\left(M_S, \overline{M}_W\right) = p\frac{m_S^2(Z_H-\sqrt{Z_H(Z_H-Z_L)})(2Z_L-(Z_H-\sqrt{Z_H(Z_H-Z_L)}))}{4Z_L} + (1-p)\frac{m_S^2 Z_H}{4}$$
$$\pi_W\left(M_S, \overline{M}_W\right) = p\frac{(2Z_L-m_S(Z_H-\sqrt{Z_H(Z_H-Z_L)}))^2}{4Z_L} + (1-p)\frac{(2-m_S)^2 Z_H}{4}$$
$$\pi_S\left(\overline{M}_S, M_W\right) = p\frac{(2Z_L-m_W(Z_H-\sqrt{Z_H(Z_H-Z_L)}))^2}{4Z_L} + (1-p)\frac{(2-m_W)^2 Z_H}{4}$$
$$\pi_W\left(\overline{M}_S, M_W\right) = p\frac{m_W^2(Z_H-\sqrt{Z_H(Z_H-Z_L)})(2Z_L-(Z_H-\sqrt{Z_H(Z_H-Z_L)}))}{4Z_L} + (1-p)\frac{m_W^2 Z_H}{4}$$

If $\mathrm{m}_i \leq \beta^*$ and $p > \overline{p}$:

$$\pi_S\left(M_S, \overline{M}_W\right) = p\frac{m_S^2 Z_L^2}{4Z_\mu} + (1-p)\frac{m_S^2 Z_L(2Z_H-Z_L)}{4Z_\mu}$$
$$\pi_W\left(M_S, \overline{M}_W\right) = \frac{(2Z_\mu-m_S Z_L)^2}{4Z_\mu}$$
$$\pi_S\left(\overline{M}_S, M_W\right) = \frac{(2Z_\mu-m_W Z_L)^2}{4Z_\mu}$$
$$\pi_W\left(\overline{M}_S, M_W\right) = p\frac{m_W^2 Z_L^2}{4Z_\mu} + (1-p)\frac{m_W^2 Z_L(2Z_H-Z_L)}{4Z_\mu}$$

If $\mathrm{m}_i > \beta^*$:

$$\pi_S\left(M_S, \overline{M}_W\right) = p\frac{\left(2m_S\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_S} + (1-p)\frac{\left(2m_S\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_S}$$
$$\pi_W\left(M_S, \overline{M}_W\right) = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{4m_S}$$
$$\pi_S\left(\overline{M}_S, M_W\right) = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{4m_W}$$
$$\pi_W\left(\overline{M}_S, M_W\right) = p\frac{\left(2m_W\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_W} + (1-p)\frac{\left(2m_W\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_W}$$

The comparison of the firms' payoffs determine which market research structure will emerge in the equilibrium. In specific, we have to do the following four groups of payoffs comparisons.

- $\pi_S(\overline{M}_S, \overline{M}_W)$ and $\pi_S\left(M_S, \overline{M}_W\right)$.

  Using the payoff functions above, we have $\pi_S(\overline{M}_S, \overline{M}_S) \geq \pi_S\left(M_S, \overline{M}_W\right)$ iff either of the following condition is satisfied:

  (i) $p \leq \overline{p}$ and $m_S \leq \sqrt{\frac{Z_L Z_\mu}{Z_H Z_L - 2p(Z_H-Z_L)\left(Z_H-\sqrt{Z_H(Z_H-Z_L)}\right)}} < \beta^*$; or,

  (ii) $p > \overline{p}$ and $m_S \leq \sqrt{\frac{Z_\mu^2}{2(1-p)Z_H Z_L + (2p-1)Z_L^2}} < \beta^*$.

- $\pi_W(\overline{M}_S, \overline{M}_W)$ and $\pi_W\left(\overline{M}_S, M_W\right)$.

  The analysis is parallel to above as the payoff functions are the same. $\pi_W(\overline{M}_S, \overline{M}_W) \geq \pi_W\left(\overline{M}_S, M_W\right)$ iff either of the following condition is satisfied:

  (i) $p \leq \overline{p}$ and $m_W \leq \sqrt{\frac{Z_L Z_\mu}{Z_H Z_L - 2p(Z_H-Z_L)\left(Z_H-\sqrt{Z_H(Z_H-Z_L)}\right)}} < \beta^*$; or,

  (ii) $p > \overline{p}$ and $m_W \leq \sqrt{\frac{Z_\mu^2}{2(1-p)Z_H Z_L + (2p-1)Z_L^2}} < \beta^*$.

- $\pi_S(\overline{M}_S, M_W)$ and $\pi_S\left(M_S, M_W\right)$.

  $\pi_S(\overline{M}_S, M_W) \geq \pi_S\left(M_S, M_W\right)$ holds if either of the following two conditions is satisfied:

  (i) $p \leq \overline{p}$ and $m_W < \beta^*$ and $m_W \leq m_S \leq \frac{m_W Z_\mu + A + \sqrt{A^2 + 2m_W Z_\mu A}}{2Z_\mu}$ (where $A = p\frac{(2Z_L - m_W(Z_H - \sqrt{Z_H(Z_H - Z_L)}))^2}{4Z_L} + (1-p)\frac{(2-m_W)^2 Z_H}{4}$), or,

  (ii) $p > \overline{p}$ and $m_W < \beta^*$ and $m_W \leq m_S \leq \left(\frac{2Z_\mu - m_W Z_L + \sqrt{8m_W Z_\mu^2 + (2Z_\mu - m_W Z_L)^2}}{4Z_\mu}\right)^2$.

- $\pi_W(M_S, \overline{M}_W)$ and $\pi_W\left(M_S, M_W\right)$.

  $\pi_W(M_S, \overline{M}_W) \geq \pi_W\left(M_S, M_W\right)$ if either of the following conditions is satisfied:

  (i) $p \leq \overline{p}$ and $m_S \leq \beta^*$ and $m_W \leq \sqrt{\frac{m_S\left(p\left(2Z_L - m_S\left(Z_H - \sqrt{Z_H(Z_H - Z_L)}\right)\right)^2 + (1-p)(2-m_S)^2 Z_L Z_H\right)}{Z_\mu Z_L}}$, or,

  (ii) $p > \overline{p}$ and $m_S \leq \beta^*$ and $m_W \leq \frac{\sqrt{m_S}(2Z_\mu - m_S V_L)}{Z_\mu}$.

  We then use the following rules to determine the Nash equilibrium outcome in the market research stage:

  $(\overline{M}_S, \overline{M}_W)$ is an equilibrium iff $\pi_S(\overline{M}_S, \overline{M}_W) \geq \pi_S\left(M_S, \overline{M}_W\right)$ and $\pi_W(\overline{M}_S, \overline{M}_W) \geq \pi_W\left(\overline{M}_S, M_W\right)$.

  $\left(\overline{M}_S, M_W\right)$ is an equilibrium iff $\pi_S(\overline{M}_S, M_W) \geq \pi_S\left(M_S, M_W\right)$ and $\pi_W(\overline{M}_S, M_W) \geq \pi_W\left(\overline{M}_S, \overline{M}_W\right)$.

  $\left(M_S, \overline{M}_W\right)$ is an equilibrium iff $\pi_S(M_S, \overline{M}_W) \geq \pi_S\left(\overline{M}_S, \overline{M}_W\right)$ and $\pi_W(M_S, \overline{M}_W) \geq \pi_W\left(M_S, M_W\right)$.

  (M_S, M_W) is an equilibrium iff $\pi_S(M_S, M_W) \geq \pi_S\left(\overline{M}_S, M_W\right)$ and $\pi_W(M_S, M_W) \geq \pi_W\left(M_S, \overline{M}_W\right)$.

  And the result in proposition 2.3 follows with β_0, m_S^* and m_W^* defined below.

$$\beta_0 = \begin{cases} \sqrt{\frac{Z_L Z_\mu}{Z_H Z_L - 2p(Z_H - Z_L)\left(Z_H - \sqrt{Z_H(Z_H - Z_L)}\right)}} & \text{for } p \leq \overline{p} \\ \sqrt{\frac{Z_\mu^2}{2(1-p)Z_H Z_L + (2p-1)Z_L^2}} & \text{for } p > \overline{p} \end{cases}$$

$$m_W^* = \begin{cases} \sqrt{\frac{m_S\left(p\left(2Z_L - m_S\left(Z_H - \sqrt{Z_H(Z_H - Z_L)}\right)\right)^2 + (1-p)(2-m_S)^2 Z_L Z_H\right)}{Z_\mu Z_L}} & \text{for } p \leq \overline{p} \\ \frac{\sqrt{m_S}(2Z_\mu - m_S V_L)}{Z_\mu} & \text{for } p > \overline{p} \end{cases}$$

$$m_S^* = \begin{cases} \frac{m_W Z_\mu + A + \sqrt{A^2 + 2m_W Z_\mu A}}{2Z_\mu} & \text{for } p \leq \overline{p} \\ \left(\frac{2Z_\mu - m_W Z_L + \sqrt{8m_W Z_\mu^2 + (2Z_\mu - m_W Z_L)^2}}{4Z_\mu}\right)^2 & \text{for } p > \overline{p} \end{cases}$$

(where $A = p\frac{(2Z_L - m_W(Z_H - \sqrt{Z_H(Z_H - Z_L)}))^2}{4Z_L} + (1-p)\frac{(2-m_W)^2 Z_H}{4}$.)

A.4 Proof of Lemma 2.1

When CI is not possible, in the CI subgame, the only configuration in play is the case where neither firm observes the competitor's investment level before choosing his own x. Hence, we only need to compare the firms' payoffs of configuration III under each of the market research structure.

For (M_S, M_W) :

$\pi^*_{S0} = \frac{m_S^3 Z_\mu}{(m_S+m_W)^2}$; $\pi^*_{W0} = \frac{m_W^3 Z_\mu}{(m_S+m_W)^2}$

For $(\overline{M}_S, \overline{M}_W)$:

$\pi^*_{S0} = \frac{Z_\mu}{4}$; $\pi^*_{W0} = \frac{Z_\mu}{4}$

For $(M_S, \overline{M}_W)$:

$\pi^*_{S0} = p\frac{m_S\left((1+m_S)\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{(1+m_S)^2} + (1-p)\frac{m_S\left((1+m_S)\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{(1+m_S)^2}$;

$\pi^*_{W0} = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{(1+m_S)^2}$

For $(\overline{M}_S, M_W)$:

$\pi^*_{S0} = \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{(1+m_W)^2}$;

$\pi^*_{W0} = p\frac{m_W\left((1+m_W)\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{(1+m_W)^2} + (1-p)\frac{m_W\left((1+m_W)\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{(1+m_W)^2}$

Because $m_i \geq 1$, it can be readily shown that it is a dominant strategy for both firms to conduct market research (i.e., (M_S, M_W)), and the equilibrium investment levels are

$$\begin{aligned} x^*_{S0} &= \frac{m_S^2 m_W Z}{c(m_S+m_W)^2}; x^*_{W0} = \frac{m_S m_W^2 Z}{c(m_S+m_W)^2} \\ \pi^*_{S0} &= \frac{m_S^3 Z_\mu}{(m_S+m_W)^2}; \pi^*_{W0} = \frac{m_W^3 Z_\mu}{(m_S+m_W)^2} \end{aligned}$$

A.5 Proof of Proposition 2.4

The conclusion in proposition 2.4 can be seen by directly comparing the equilibrium results when CI is available (as per proposition 2.3) and the equilibrium results when CI is not available (as per lemma 2.1).

A.6 Proof of Proposition 2.5

In region D when $\{(M_S, C_S), (M_W, \overline{C}_W)\}$ is played in the equilibrium, firm W gets higher payoff when the rival firm S conducts CI:

$$\pi_W(M_S, M_W) = \frac{m_W^2 Z_\mu}{4m_S} > \frac{m_W^3 Z_\mu}{(m_S+m_W)^2} = \pi^*_{W0}$$

Even in the regions B and C where a firm doing MR and investing early is vulnerable to the competitor's CI and needs to strategically manage its superior market knowledge, it can earn higher payoff than that in the benchmark case without CI when m_i is large enough.

As per lemma 1, when CI is not available, the two firms' total payoff is

$$\Pi_0 = \pi^*_{S0} + \pi^*_{W0} = \frac{m_S^3 Z_\mu}{(m_S + m_W)^2} + \frac{m_W^3 Z_\mu}{(m_S + m_W)^2} = \frac{m_S^2 - m_S m_W + m_W^2}{m_S + m_W} Z_\mu$$

We then compare this total payoff Π_0 to the equilibrium total payoffs for the two firms in our original model.

$$\begin{aligned}
\Pi\left(\overline{M}_S, \overline{M}_W\right) &= \frac{Z_\mu}{4} + \frac{Z_\mu}{4} < \Pi_0 = \frac{\left(m_S^3 + m_W^3\right) Z_\mu}{(m_S + m_W)^2} \\
\Pi\left(M_S, M_W\right) &= \frac{\left(2m_S - m_W\right)^2 Z_\mu}{4m_S} + \frac{m_W^2 Z_\mu}{4m_S} > \Pi_0 = \frac{\left(m_S^3 + m_W^3\right) Z_\mu}{(m_S + m_W)^2}
\end{aligned}$$

Clearly, because both firms refrain from conducting market research in the presence of CI in region A when $\left(\overline{M}_S, \overline{M}_W\right)$ emerges as the unique equilibrium, the total payoffs for the two firms are lower with CI than that in the benchmark case without CI. However, in region D when (M_S, M_W) emerges as the unique equilibrium, the presence of CI benefits the industry as the total expected payoffs for the two firms are higher than that in the benchmark case without CI.

If $p \leq \overline{p}$:

$$\begin{aligned}
\Pi\left(M_S, \overline{M}_W\right) &= p\frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_L)})(2Z_L - (Z_H - \sqrt{Z_H(Z_H - Z_L)}))}{4Z_L} + (1-p)\frac{m_S^2 Z_H}{4} \\
&\quad + p\frac{(2Z_L - m_S(Z_H - \sqrt{Z_H(Z_H - Z_L)}))^2}{4Z_L} + (1-p)\frac{(2 - m_S)^2 Z_H}{4}
\end{aligned}$$

$$\begin{aligned}
\Pi\left(M_S, \overline{M}_W\right) &= p\frac{m_S^2(Z_H - \sqrt{Z_H(Z_H - Z_L)})(2Z_L - (Z_H - \sqrt{Z_H(Z_H - Z_L)}))}{4Z_L} + (1-p)\frac{m_S^2 Z_H}{4} \\
&\quad + p\frac{(2Z_L - m_S(Z_H - \sqrt{Z_H(Z_H - Z_L)}))^2}{4Z_L} + (1-p)\frac{(2 - m_S)^2 Z_H}{4}
\end{aligned}$$

$$\begin{aligned}
\Pi\left(\overline{M}_S, M_W\right) &= p\frac{(2Z_L - m_W(Z_H - \sqrt{Z_H(Z_H - Z_L)}))^2}{4Z_L} + (1-p)\frac{(2 - m_W)^2 Z_H}{4} \\
&\quad + p\frac{m_W^2(Z_H - \sqrt{Z_H(Z_H - Z_L)})(2Z_L - (Z_H - \sqrt{Z_H(Z_H - Z_L)}))}{4Z_L} + (1-p)\frac{m_W^2 Z_H}{4}
\end{aligned}$$

If $p > \overline{p}$:

$$\begin{aligned}
\Pi\left(M_S, \overline{M}_W\right) &= p\frac{\left(2m_S\sqrt{Z_L} - (1-p)\sqrt{Z_H} - p\sqrt{Z_L}\right)^2}{4m_S} \\
&\quad + (1-p)\frac{\left(2m_S\sqrt{Z_H} - (1-p)\sqrt{Z_H} - p\sqrt{Z_L}\right)^2}{4m_S} \\
&\quad + \frac{\left((1-p)\sqrt{Z_H} + p\sqrt{Z_L}\right)^2}{4m_S}
\end{aligned}$$

$$
\begin{aligned}
\Pi\left(\overline{M}_S, M_W\right) &= \frac{\left((1-p)\sqrt{Z_H}+p\sqrt{Z_L}\right)^2}{4m_W} \\
&\quad + p\frac{\left(2m_W\sqrt{Z_L}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_W} \\
&\quad + (1-p)\frac{\left(2m_W\sqrt{Z_H}-(1-p)\sqrt{Z_H}-p\sqrt{Z_L}\right)^2}{4m_W}
\end{aligned}
$$

Through numerical analysis, it can be shown that in these two regions when $\left(M_S, \overline{M}_W\right)$ and/or $\left(\overline{M}_S, M_W\right)$ are the equilibrium, the total expected payoff for the two firms can still be higher than in the benchmark case without CI.

Appendix B

Technical Appendix to Chapter 3

B.1 Proof of Lemma 3.1

This is a dynamic game with complete information. Consider the last period of the n-period relationship. By definition, the honest manufacturer honors the contract at Stage 4. Hence, at Stage 2, the supplier chooses his effort level to maximize his expected payment as follows,

$$
\begin{aligned}
e_h^*(\alpha_h) &= \arg\max_{e_h} \begin{cases} \alpha_h pV - c, & \text{if } e_h = 1 \\ 0, & \text{if } e_h = 0 \end{cases} \\
\Longrightarrow \quad e_h^*(\alpha_h) &= \begin{cases} 1, & \text{if } \alpha_h \geq \dfrac{c}{pV} \\ 0, & \text{otherwise} \end{cases}
\end{aligned}
$$

That is, the supplier invests if and only if his share of the project value is large enough.

At Stage 1, the honest manufacturer solves for

$$
\begin{aligned}
\alpha_h^* &= \arg\max_{\alpha_h} (1-\alpha_h) e_h^*(\alpha_h) pV \\
\Longrightarrow \quad \alpha_h^* &= \begin{cases} \dfrac{c}{pV}, & \text{if } \dfrac{c}{pV} \leq 1 \\ \emptyset, & \text{otherwise} \end{cases}
\end{aligned}
$$

When $\frac{c}{pV} > 1$, the honest manufacturer has to pay the supplier from his own pocket in order to induce investment, so he is better off not offering any contract at all.

Since the last period has a unique equilibrium, which is equivalent to the equilibrium of a one-shot (single period) game, the unique equilibrium of any period in a finitely repeated relationship with complete information is identical to the equilibrium of the terminal period, and the result follows.

B.2 Proof of Lemma 3.2

Consider again the last period in a n-period relationship. At Stage 4, because there is no future interactions with the supplier whatsoever, it is the dominant strategy for the rational manufacturer and the only strategy (by definition) for the cheat manufacturer to take the entire project value and pay the supplier nothing. That is, when the realized value is V, the manufacturer (either type) renegotiates $V_n^R = 0$. When the realized value is 0, renegotiation is pointless since the contractual payment to the supplier is anyway zero. Anticipating zero payment from the manufacturer even when the project succeeds, the supplier will not invest in Stage 2 of the last period, i.e., $e_n^* = 0$. As a result, both the supplier and the manufacturer earns zero payoff in the last period.

Again, this is the unique equilibrium to a single period game, and hence it is also the unique equilibrium of any period in a finitely repeated relationship, i.e., $V_i^R = 0$ iff $V_i = V$, and $e_i^* = 0 \ \forall \alpha_i$.

B.3 Proof of Proposition 3.1

The supplier's beliefs over the buyer's type are $\overrightarrow{q}_{21} = (q_{21}^r, q_{21}^h, q_{21}^c)$ at the beginning of the last period. We solve the multi-stage last period game backward.

At Stage 4, the honest manufacturer will honor the contract. And as discussed earlier, because there is no future considerations, both the rational manufacturer and the cheat manufacturer will renegotiate $V_2^R = 0$ iff $V_2 = V$.

Anticipating the manufacturer's strategy in the payment stage, the supplier knows that he will only get paid if the project succeeds and the manufacturer is honest, so the supplier chooses his effort at Stage 2 to maximize his expected payment as follows,

$$e_2^*(\alpha_2) = \arg\max_{e_2} \begin{cases} \alpha_2 q_{22}^h pV - c, \text{ if } e_2 = 1 \\ 0, \text{ if } e_2 = 0 \end{cases}$$
$$\Longrightarrow \quad e_2^*(\alpha_2) = \begin{cases} 1, \text{ if } \alpha_2 \geq \dfrac{c}{q_{22}^h pV} \\ \emptyset, \text{ otherwise} \end{cases}$$

Clearly, if $q_{22}^h = 0$, i.e., if the supplier is convinced that the manufacturer is not the honest type by the beginning of Stage 2, the supplier will not invest at all, which is consistent with lemma 3.2.

With an contract α_2, and the three types of manufacturer's payoff are respectively,

$$\begin{aligned} \pi_{h2} &= (1-\alpha_2)e_2^*(\alpha_2)pV \\ \pi_{r2} &= \pi_{c2} = e_2^*(\alpha_2)pV \end{aligned}$$

Clearly, the honest manufacturer's payoff is decreasing in α_2; thus, from the honest manufacturer's perspective, an α_2^* that leaves the supplier with exactly zero surplus in expectation is optimal. The rational and the cheat manufacturer, on the other hand, always get $\pi_{r2} = \pi_{c2} = e_2^*(\alpha_2)pV$ for any α_2; therefore, they can promise any α_2 (even an $\alpha_2 > 1$) to induce the supplier to invest because they always renegotiate zero payment to the supplier in Stage 4. The supplier is certainly aware of these incentives. As a result, any α_2 different from the one that the honest manufacturer finds optimal convinces the supplier that the manufacturer is not honest ($q_{22}^h = 0$), leading to zero investment by the supplier. On the equilibrium path, both the rational type and the cheat type pool with the honest manufacturer, and offer the same α_2 to the supplier, so the supplier's beliefs are unchanged after Stage 1 (i.e., $q^h_{22} = q^h_{21}$). Equation (3.1) details the supplier's beliefs update structure.

Hence, in Stage 1 the honest manufacturer solves,

$$\alpha_2^* = \arg\max_{\alpha_0}(1-\alpha_2)e_2^*(\alpha_2)pV;\ \text{while}\ q^h_{22} = q^h_{21}$$

$$\implies \alpha_2^* = \begin{cases} \dfrac{c}{q^h_2 pV},\ \text{if}\ q^h_2 \geq \dfrac{c}{pV} \\ 0,\ \text{otherwise} \end{cases}$$

And the result follows.

B.4 Proof of Propositions 3.2 and 3.3

Below we prove the first period equilibrium in a two period game with trembles. The one without trembles is a special case with $m = 0$.

The second period equilibrium is identical to the one specified in proposition 3.1, excepting by replacing $\overrightarrow{q}_0$ with the supplier's updated beliefs at the beginning of the second period $\overrightarrow{q}^m_{21}$ (detailed discussed below).

(i) The payment stage of period 1 and the supplier's belief updates across periods.

At the Stage 4 of the first period, when the realized value is 0, all types of manufacturer honor the contract. When the realized value is V, by definition, the honest type honors the contract and the cheat type renegotiates with $V^R = 0$; both are identical to their myopic strategy. The rational type can either renegotiate or honor the contract: by renegotiating, the rational type gets the entire V in period which then reveals his type to be not honest (i.e., $q^{hm}_{21} = 0$), resulting in zero investment by the supplier in period 2; by honoring the contract, the rational manufacturer needs to pay the supplier $\alpha^m_1 V$ in period 1, which allows him to hide his type and gives the supplier incentive to invest again in period 2 (and he can renegotiate then to get the entire value). Because the strategy of honoring the contract contradicts with the rational type's myopic strategy of renegotiating, he also needs to take into consideration that he may tremble into renegotiation with probability m. In summary, the rational type's trade-off is as follows.

Renegotiate: $V + 0$
Honor the contract: $m[(1-\alpha^m_1)V + pV] + (1-m)V$

Clearly, the rational type's dynamically optimal strategy is to renegotiate when $\alpha^m_1 \geq p$, and to honor the contract when $\alpha^m_1 < p$.

Hence, after Stage 4, the supplier updates his beliefs into $\overrightarrow{q}^m_{21} = (q^{rm}_{21}, q^{hm}_{21}, q^{cm}_{21})$ in the following way:

(a) $\overrightarrow{q}^m_{21} = (q^{rm}_{12}, q^{hm}_{12}, q^{cm}_{12})$, if $\tilde{V}_1 = 0$
(b) $\overrightarrow{q}^m_{21} = (\frac{q^{rm}_{12}}{q^{rm}_{12}+q^{cm}_{12}}, 0, \frac{q^{rm}_{12}}{q^{rm}_{12}+q^{cm}_{12}})$, if $\tilde{V}_1 = V, \alpha^m_1 \geq p$, and manufacturer renegotiates
(c) $\overrightarrow{q}^m_{21} = (0, 1, 0)$,if $\tilde{V}_1 = V, \alpha^m_1 \geq p$, and manufacturer honors contract

(d) $\overrightarrow{q}^{m}_{21} = (\frac{mq^{rm}_{12}}{mq^{rm}_{12}+q^{hm}_{12}}, 0, \frac{q^{cm}_{12}}{mq^{rm}_{12}+q^{hm}_{12}})$,if $\tilde{V}_1 = V, \alpha^m_1 < p$, and manufacturer renegotiates

(e) $\overrightarrow{q}^{m}_{21} = (\frac{(1-m)q^{rm}_{12}}{(1-m)q^{r}_{12}+q^{hm}_{12}}, \frac{q^{hm}_{12}}{(1-m)q^{r}_{12}+q^{hm}_{12}}, 0)$,if $\tilde{V}_1 = V, \alpha^m_1 < p$, and manufacturer honors contract

(ii) The effort stage of period 1.

Because the supplier gets zero expected payoff in the terminal period 2 (as per proposition 3.1), the supplier only needs to consider his first period payoff at this stage. Based on the manufacturer's strategy in the payment stage above, the supplier solves,

$$e^{m*}_1(\alpha^m_1) = \arg\max_{e^m_1} \begin{cases} \alpha^m_1(1 - q^{rm}_{12} - q^{cm}_{12})pV - c, \text{ if } e^m_1 = 1, \alpha^m_1 \geq p \\ \alpha^m_1(1 - mq^{rm}_{12} - q^{cm}_{12})pV - c, \text{ if } e^m_1 = 1, \alpha^m_1 < p \\ 0, \text{ if } e^m_1 = 0 \end{cases}$$

and the optimal strategy is

$$e^{m*}_1(\alpha^m_1) = \begin{cases} 1, \text{ if } \alpha^m_1 \geq \max(\frac{c}{(1-q^{rm}_{12}-q^{cm}_{12})pV}, p), \text{ or } p > \alpha^m_1 \geq \frac{c}{(1-mq^{rm}_{12}-q^{cm}_{12})pV} \\ 0, \text{ otherwise} \end{cases}$$

(iii)Contract stage of the period 1.

For the same reason discussed above, both the rational type and the cheat type mimic the honest type in the contract stage and offer the same contract, otherwise they will reveal their types to be not honest and get no investment from the supplier.

To maximize his total payoff across two periods Π_h, the honest type solves,

$$\max_{\alpha^m_1} \begin{cases} p[(1-\alpha^m_1)V + \pi^*_{h2}(\overrightarrow{q}^{m}_{21})] + (1-p)\pi^*_{h2}(\overrightarrow{q}^{m}_{21}), \text{ if } e^{m*}_1(\alpha^m_1) = 1 \\ 0 + \pi^*_{h2}(\overrightarrow{q}_{21}), \text{ if } e^{m*}_1(\alpha^m_1) = 0 \end{cases}$$

or

$$\max_{\alpha^m_1} \begin{cases} p[(1-\alpha^m_1)V + pV - c] + (1-p)(pV - \frac{c}{q^h_{11}}), \text{ if } \alpha_1 \geq \max(\frac{c}{(1-q^r_{11}-q^c_{11})pV}, p) \\ p[(1-\alpha^m_1)V + pV - \frac{\frac{c}{q^h_{11}}}{(1-m)q^r_{11}+q^h_{11}}] + (1-p)(pV - \frac{c}{q^h_{11}}), \text{ if } p > \alpha_1 \geq \frac{c}{(1-mq^r_{11}-q^c_{11})pV} \\ pV - \frac{c}{q^h_{11}}, \text{ otherwise} \end{cases}$$

hence, the optimal strategy is

$$\alpha^*_1 = \begin{cases} \frac{c}{(1-mq^r_{11}-q^c_{11})pV} = \alpha^{m*Pool}_1, \text{ if } (1 - mq^r_{11} - q^c_{11}) > \frac{c}{p^2V} \\ \frac{c}{(1-q^r_{11}-q^c_{11})pV} = \alpha^{m*Sep}_1, \text{ if } (1 - mq^r_{11} - q^c_{11}) \leq \frac{c}{p^2V} \end{cases}$$

where the α^{m*Pool}_1 and α^{m*Sep}_1 denote that, with such an contract, the rational manufacturer's dynamically optimal strategy in the payment stage of period 1 is to *pool* with the honest type and honor the contract, and to *separate* from the honest type and renegotiate.

B.5 Proof of Theorem 3.1

This theorem is an immediate results by comparing the three types of manufacturer's expected payoffs in a two-period relationship, as detailed in proposition 3.3).

When $m \geq m^{Pool} = \frac{1-q_{11}^c-c/(p^2V)}{q_{11}^r}$, i.e., $1-mq_{11}^r-q_{11}^c \leq \frac{c}{p^2V}$ (part II of proposition 3.3), the three types of manufacturer's payoffs are

$$\begin{aligned} \Pi_r^m &= 2pV - p^2V \\ \Pi_h^m &= 2pV - \frac{2-p(q_{11}^r+q_{11}^c)}{1-q_{11}^r-q_{11}^c}c \\ \Pi_c^m &= 2pV - p^2V \end{aligned}$$

Because $\frac{1-q_{11}^c-c/(p^2V)}{q_{11}^r} \leq m < 1$, $1-q_{11}^r-q_{11}^c > 0$ and $p < 1$,

$$\frac{2-p(q_{11}^r+q_{11}^c)}{1-q_{11}^r-q_{11}^c}c > \frac{2-p(q_{11}^r+q_{11}^c)}{1-mq_{11}^r-q_{11}^c}c \geq [2-p(q_{11}^r+q_{11}^c)]p^2V > p^2V$$

thus,

$$\Pi_h^m = 2pV - \frac{2-p(q_{11}^r+q_{11}^c)}{1-q_{11}^r-q_{11}^c}c < 2pV - p^2V = \Pi_r^m = \Pi_c^m$$

In other words, when $m \geq m^{Pool}$, the rational type and the cheat type get the same payoff, which is higher than the honest type.

When $m < m^{Pool}$, i.e., $1-mq_{11}^r-q_{11}^c > \frac{c}{p^2V}$, the three types of manufacturer's payoffs are

$$\begin{aligned} \Pi_r^m &= (2-mp)pV - \frac{c(1-m)}{1-mq_{11}^r-q_{11}^c} \\ \Pi_h^m &= 2pV - \frac{c}{1-mq_{11}^r-q_{11}^c} - \frac{(1-p(mq_{11}^r+q_{11}^c))c}{1-q_{11}^r-q_{11}^c} \\ \Pi_c^m &= 2pV - p^2V \end{aligned}$$

Because $m < m^{Pool} = \frac{1-q_{11}^c-c/(p^2V)}{q_{11}^r}$,

$$\Pi_r^m = (2-mp)pV - \frac{c(1-m)}{1-mq_{11}^r-q_{11}^c} > (2-mp)pV - (1-m)p^2V = 2pV - p^2V = \Pi_c^m$$

that is, when $m < \frac{1-q_{11}^c-c/(p^2V)}{q_{11}^r}$, the rational type always gets higher payoff than the cheat type in a two-period relationship.

For the honest type to gets higher payoff than the rational type (and thereby also the cheat type), we need

$$\begin{aligned} & 2pV - \frac{c}{1-mq_{11}^r-q_{11}^c} - \frac{(1-p(mq_{11}^r+q_{11}^c))c}{1-q_{11}^r-q_{11}^c} > (2-mp)pV - \frac{c(1-m)}{1-mq_{11}^r-q_{11}^c} \\ \Longrightarrow \quad & \frac{p^2V}{c} > \frac{1}{1-mq_{11}^r-q_{11}^c} + \frac{1-mpq_{11}^r-pq_{11}^c}{m(1-q_{11}^r-q_{11}^c)} \end{aligned}$$

Appendix C

Appendix to Chapter 4

C.1 Proof of Theorem 4.1

Lemma C.1 will be used in the proof of Theorem 1.

Lemma C.1 (i) *The dominant strategy for the unconstrained type of principal is to renegotiate in stage 4 of the terminal period* N*.*

(ii) *If* $q_i = 0$*, then* $e_j = 0 \; \forall j \in \{i, i+1, ..., N\}$ *.*

Proof. (i) Profit by renegotiating in the terminal period N is $\tilde{V}_N(e_N)$, which is greater than $(1-\alpha_N^u)\tilde{V}_N(e_N)$, the profit without renegotiating, since $\alpha_N^u \geq 0$.

(ii) If $q_i = 0$, then $q_j = 0 \; \forall j \in \{i, i+1, ..., N\}$. By part (i), the unconstrained type of principal renegotiates in stage 4 of the terminal period N; and since $q_N = 0$, the agent's best-response is $e_N^* = 0$ in stage 2. Hence, the unconstrained principal renegotiates in stage 4 of period $N-1$, the agent responds with $e_{N-1}^* = 0$ since $q_{N-1} = 0$, and the result unravels by backward induction.

■

To prove Theorem 1, we proceed for now with the assumption that the equilibrium strategy of the unconstrained type of principal is to not renegotiate in stage 4 of the non-terminal periods. We will prove that the assumption holds under our proposed equilibrium. The honest principal never renegotiates and Lemma C.1 has established the unconstrained principal's strategy in the terminal period. With the principal's equilibrium strategy in stage 4 thus settled, we derive a Perfect Bayesian Nash equilibrium in terms of (i) the contract offered by the principal in stage 1; (ii) the agent's beliefs after stage 1; and (iii) the agent's investment strategy in stage 2.

Consider stage 1 of any period $i \in \{1, ..., N\}$: A pure strategy (separating) equilibrium where $\alpha_i^u \neq \alpha_i^h$ is easily ruled out since the agent *must* assign a belief $\hat{q}_i = 0$ after stage 1 upon observing $\alpha_i^u \left(\neq \alpha_i^h\right)$, resulting in 0 continuation payoff for the unconstrained principal in periods $j \in \{i, i+1, ..., N\}$ per Lemma C.1. Consider, therefore, a pooling equilibrium in stage 1 where $\alpha_i^u = \alpha_i^h = \alpha_i^* \; \forall i \in \{1, ..., N\}$ and the agent's belief after stage 1 of period $i \in \{1, ..., N\}$ is:

$$\hat{q}_i = \begin{cases} q_i \text{ if } \alpha_i^x = \alpha_i^* \text{ where } x \in \{u, h\} \\ 0 \text{ otherwise} \end{cases} \tag{C.1}$$

The agent's belief of equation $(C.1)$ satisfies the Intuitive Criterion of Cho and Kreps (1987). Moreover, $q_i > 0$ for any $i \in \{1, ..., N\}$ or the game never proceeds to period i.

Define $I_{\{e_i=1\}} = 1$ if $e_i = 1$ and 0 otherwise. Also, $\Pi^x(K, \cdot)$ is the expected continuation payoff of the Principal of type x where $x \in \{h, u\}$ with $K \leq N$ periods to go, and π_i^A is the agent's expected payoff in period $i \in \{1, ..., N\}$. In stage 1 of period $i \in \{1, ..., N-1\}$, i.e., with $N-i+1$ periods to go including the i^{th} period, the honest type of principal solves the following program which maximizes his expected continuation payoff subject to the individual rationality constraint (IRC) of the agent (the unconstrained type of principal mimics and solves an identical program in the pooling equilibrium):

$$\begin{aligned}
&\Pi^h(N-i+1, q_i) = \max_{0 \leq \alpha_i \leq 1} \left((1-\alpha_i)\tilde{V}_i(e_i) + \Pi^h(N-i, q_{i+1})\right) \\
&s.t. \\
&0 \leq \pi_i^A = \max_{e_i \in \{0,1\}} \left((1 - m(1-q_i))\alpha_i pV - c\right) I_{\{e_i=1\}}, \\
&\text{where } q_{i+1} = \frac{q_i}{q_i + (1-m)(1-q_i)}, \text{ and} \\
&\Pi^h(1) = \max_{0 \leq \alpha_N \leq 1} (1-\alpha_N)\tilde{V}_N(e_N) \\
&s.t. \\
&0 \leq \pi_N^A = \max_{e_N \in \{0,1\}} (q_N \alpha_N pV - c) I_{\{e_i=1\}}
\end{aligned}$$

$\Pi^h(1)$ is the honest principal's expected payoff in the terminal period. Since the unconstrained principal always renegotiates in the terminal period per Lemma C.1, the agent is paid only when $\tilde{V}_N(1) = V$ and the principal is of the honest type (the probabilities of which are p and q_N respectively). The agent invests, i.e., $e_N = 1$, whenever $\alpha_N \geq \frac{c}{q_N pV} = \alpha_N^*$. Hence, in equilibrium, the principal optimally offers $\alpha_N = \alpha_N^*$ (< 1 under our technical condition) so that $e_N^* = 1$ and the IRC binds for the agent. In the non-terminal period i, $m(1-q_i)$ is the probability of renegotiation through trembles by the unconstrained principal, and hence, $(1 - m(1-q_i))$ is the probability that the agent is paid his contractual share in the event $\tilde{V}_i(1) = V$. The agent invests, i.e., $e_i = 1$ $\forall i \in \{1, ..., N-1\}$ whenever $\alpha_i \geq \frac{c}{(1-m(1-q_i))pV} = \alpha_i^* (< 1)$. In equilibrium, both types of principal optimally offer $\alpha_i = \alpha_i^*$ $\forall i \in \{1, ..., N-1\}$ so that $e_i^* = 1$ and IRC binds for the agent.

Finally, we prove that the unconstrained type of principal has no profitable deviation under the proposed equilibrium from his (assumed) strategy of not renegotiating in the non-terminal periods. Consider $N = 2$ first. On the equilibrium path, it is optimal for the unconstrained principal to not renegotiate in stage 4 of period 1 because the incremental gain from renegotiation $(\alpha_1^* V)$ is less than the expected future payoff (pV) under our technical condition, i.e., $\alpha_1^* < p$ whenever $\frac{pV}{c} > \frac{2-p(1-q_1)}{pq_1}$. Observe that q_i is non-decreasing in i, hence $\alpha_i^* \leq \alpha_1^* < p$ $\forall i \in \{2, ..., N-1\}$, which completes the proof of Theorem 1 for all $N \geq 2$.

C.2 Proof of Theorem 4.2

The readers can read next section (Proofs of Theorem 4.3) first, as the proof below will use the result in Theorem 4.3.

We first prove that $\Delta\Pi\left(N,q_1\right)$ is strictly increasing in N.

Note that:

$$\begin{aligned}\Delta\Pi(N+1,q_1) &\equiv \Delta\Pi(N+1,q_{(0)}) \\ &= (1-p)\Delta\Pi(N,q_{(0)}) \\ &\quad +p\left(m\left(-\alpha^*_{(0),NT}V+\Pi^h(N,q_{(1)})\right)+(1-m)\,\Delta\Pi(N,q_{(1)})\right),\end{aligned}$$

where $q_{(k)}$ is given by equation $(C.3)$. Rearranging terms and noting that $\Delta\Pi(N,q_{(0)}) = \Pi^h(N,q_{(0)}) - \Pi^u(N,q_{(0)})$, we get:

$$\Delta\Pi(N+1,q_{(0)}) = (1-p)\Delta\Pi(N,q_{(0)})+p\left(\Pi^h(N,q_{(1)}) - m\alpha^*_{(0),NT}V - (1-m)\Pi^u(N,q_{(1)})\right). \tag{C.2}$$

Since it is suboptimal for the unconstrained type to renegotiate in the first period, $\alpha^*_{(0),NT}V < \Pi^u(N,q_{(1)})$. Thus,

$$\Delta\Pi(N+1,q_{(0)}) > (1-p)\Delta\Pi(N,q_{(0)}) + p\Delta\Pi(N,q_{(1)}) > \Delta\Pi(N,q_{(0)})$$

The last inequality follows from: (i) $q_{(1)} > q_{(0)}$ from equation $(C.3)$, and (ii) $\Delta\Pi(N,q_{(0)})$ is increasing in $q_{(0)}$, straightforward to prove from equations $(C.4)$, $(C.5)$, $(C.7)$ and $(C.9)$.

We now formally prove Theorem 2.

Proof of parts (i) **and** (ii).

Consider $N = 2$ first. From equation $(C.9)$, $\Delta\Pi(2) = mp^2V - \frac{m}{1-m(1-q_1)} - \frac{(1-pm(1-q_1))c}{q_1}$. Hence, $\Delta\Pi(2) > 0 \iff \frac{p^2V}{c} > \frac{1}{1-m(1-q_1)} + \frac{1-pm(1-q_1)}{mq_1}$. Define $f(m) = \frac{1}{1-m(1-q_1)}+\frac{1-pm(1-q_1)}{mq_1}$, which is a convex function of m because $\frac{\partial f^2(m)}{\partial m^2} = \frac{2}{m^3q_1}+\frac{2(1-q_1)^2}{(1-m(1-q_1))^3} > 0$ for $q_1, m \in (0,1)$. Since $\lim_{m\to 0^+} f(m) = +\infty > \frac{p^2V}{c} > \frac{2-p(1-q_1)}{q_1}$ (by assumption) $= f(1)$, and $f(m)$ is convex and continuous, there exists $m_2^* \in (0,1)$ that is the smaller root of the quadratic equation $\frac{p^2V}{c} = f(m)$, such that $\frac{p^2V}{c} < f(m)$ for $m \in (0, m_2^*)$ and $\frac{p^2V}{c} > f(m)$ for $m \in (m_2^*, 1)$. It follows that $\Delta\Pi(2) > 0$ or $\Pi^h(2) > \Pi^u(2)$ iff $m \in (m_2^*, 1)$.

Now consider $N = 3$. Because $\Delta\Pi(N)$ is strictly increasing in N, $\Delta\Pi\left(3\right) > \Delta\Pi(2) > 0$ for $m \in (m_2^*, 1)$. Moreover, it can easily be shown $\forall N \geq 2$ that: (i) $\Delta\Pi(N)$ is continuous in m and (ii) $\Delta\Pi(N) < 0$ for $m = 0$. Hence, there must exist $0 < m_3^* < m_2^*$, such that $\Delta\Pi(3) > 0$ for all $m \in (m_3^*, 1)$. By extension, there exists a strictly decreasing sequence $m_2^* > m_3^* > ... > m^*_{(N-1)} > m_N^* > 0$ for all $N \geq 2$, such that $\Delta\Pi(N) > 0$ or $\Pi^h(N) > \Pi^u(N)$.

Proof of part (iii).

We prove part (iii) by contradiction. Suppose $\lim_{N\longrightarrow\infty} m_N^* = \epsilon > 0$. (The limit exists from the Monotone Convergence Theorem, *cf.* Abbott 2001[1].) Then, $\exists m \in (0,\epsilon)$ which contradicts part (i) of Theorem 3. Hence, $\epsilon = 0$, i.e., $\lim_{N\longrightarrow\infty} m_N^* = 0$.

[1] Abbott, Stephen. 2001. Understanding Analysis. Springer.

Proof of part (iv).

We prove part (iv) only for q_1. (Proof for other parameters is analogous and available from the authors.) It is straightforward to show, from equations $(C.4)$, $(C.5)$, $(C.7)$ and $(C.9)$, that $\Delta\Pi(N)$ is strictly increasing in q_1 $\forall m \in (0,1)$. Hence, for any $q_1' > q_1$, $\Delta\Pi(N, q_1') > \Delta\Pi(N, q_1) > 0$ $\forall m \in (m_N^*, 1)$. Moreover, since $\forall N \geq 2$, $\Delta\Pi(N, q_1)$ is continuous and $\Delta\Pi(N, q_1)|_{m=0} < 0$ $\forall q_1 \in (0,1)$, there must exist $0 < m_N'^* < m_N^*$ such that $\Delta\Pi(N, q_1') > 0$ for all $m \in (m_N'^*, 1)$.

C.3 Proof of Theorem 4.3

Proof of part (i).

We construct a lower bound $G(N)$ for $\Delta\Pi(N) = \Pi^h(N) - \Pi^u(N)$ so that $\Delta\Pi(N) > 0$ whenever $G(N) > 0$. Towards this end, first note that the agent updates his belief only when $\tilde{V}_i(1) = V$. Hence, consider only the 'successful' periods (where $\tilde{V}_i(1) = V$). Denote by $q_{(k)}$ the agent's belief in a period when there have been $k \geq 0$ successful investments in prior periods. Denote by $\alpha^*_{(k),T}$ and $\alpha^*_{(k),NT}$ the equilibrium contractual shares in the terminal (T) and non-terminal (NT) periods respectively when there have been $k \geq 0$ successful investments in prior periods. Then,

$$q_{(k)} = \begin{cases} q_1 \text{ for } k = 0, \text{ and} \\ \frac{q_{(k-1)}}{q_{(k-1)} + \left(1 - q_{(k-1)}\right)(1-m)} = \frac{q_{(0)}}{q_{(0)} + \left(1 - q_{(0)}\right)(1-m)^k} \text{for } 1 \leq k \leq N. \end{cases} \tag{C.3}$$

(Note that $q_{(0)} \equiv q_1$.) From Theorem 1 and equation $(C.3)$, the equilibrium contractual payoffs in the non-terminal and terminal periods respectively are:

$$\alpha^*_{(k),NT} = \frac{c}{(1 - m(1 - q_{(k)}))pV} = \frac{c}{pV}\left(\frac{q_{(0)} + (1 - q_{(0)})(1-m)^k}{q_{(0)} + (1 - q_{(0)})(1-m)^{k+1}}\right), \text{ and} \tag{C.4}$$

$$\alpha^*_{(k),T} = \frac{c}{q_{(k)}pV} = \frac{c}{pV}\left(\frac{q_{(0)} + \left(1 - q_{(0)}\right)(1-m)^k}{q_{(0)}}\right). \tag{C.5}$$

Since $\alpha^*_{(k),NT}$ and $\alpha^*_{(k),T}$ are decreasing in k, and since $\alpha^*_{(k),T} > \alpha^*_{(k),NT}$ from equations $(C.4)$ and $(C.5)$, it follows that

$$\alpha^*_{(0),T} \geq \max\left(\alpha^*_{(k),NT}, \alpha^*_{(k),T}\right) \ \forall k \geq 0. \tag{C.6}$$

Let s_N be the number of successful investments prior to period N. The honest principal's total expected payoff over N periods is:

$$\Pi^h(N) = \Pi^h(N\,|s_N = 0)\Pr(s_N = 0) + \sum_{j=1}^{N-1} \Pi^h(N\,|s_N = j)\Pr(s_N = j)$$

Thus,

$$\begin{aligned}\Pi^h(N) &= (1-p)^{N-1} p\left(1 - \alpha^*_{(0),T}\right)V \\ &+ \sum_{s_N=1}^{N-1}\left[\binom{N-1}{s_N} p^{s_N}(1-p)^{N-1-s_N}\left(\sum_{k=0}^{s_N-1}\left(1 - \alpha^*_{(k),NT}\right)V + p\left(1 - \alpha^*_{(s_N),T}\right)V\right)\right]\end{aligned} \tag{C.7}$$

From equation $(C.7)$ and inequality $(C.6)$:

$$\Pi^h(N) > Np\left(1-\alpha^*_{(0),T}\right)V \tag{C.8}$$

Finally, note that:

$$\begin{aligned}\Delta\Pi(N) &= \sum_{T=1}^{N-1}\sum_{s_T=0}^{T-1}\left[\begin{array}{c}\binom{T-1}{s_T}p^{s_T+1}(1-p)^{T-1-s_T}(1-m)^{s_T}m\\ \left(-\alpha^*_{(s_T),NT}V+\Pi^h(N-T,q_{(s_T+1)})\right)\end{array}\right]\\ &\quad+\sum_{s_N=0}^{N-1}\left[\binom{N-1}{s_N}p^{s_N+1}(1-p)^{N-1-s_N}(1-m)^{s_N}\left(-\alpha^*_{(s_N),T}V\right)\right]\end{aligned} \tag{C.9}$$

where s_T are the number of successful investments prior to period T. The first term is the expected difference in payoffs between the two types when the unconstrained type trembles in a period $T \leq N-1$, and the second term is the expected difference in payoffs when the unconstrained type does not tremble. Bounding equation $(C.9)$ by using inequalities $(C.6)$ and $(C.8)$, we get:

$$\begin{aligned}\Delta\Pi(N) &> \sum_{T=1}^{N-1}\sum_{s_T=0}^{T-1}\left\{\begin{array}{c}\binom{T-1}{s_T}p^{s_T+1}(1-p)^{T-1-s_T}(1-m)^{s_T}m\\ \left(-\alpha^*_{(0),T}V+(N-T)p\left(1-\alpha^*_{(0),T}\right)V\right)\end{array}\right\}\\ &\quad+\sum_{s_N=0}^{N-1}\left\{\binom{N-1}{s_N}p^{s_N+1}(1-p)^{N-1-s_N}(1-m)^{s_N}\left(-\alpha^*_{(0),T}V\right)\right\}\\ &> \left(1-(1-mp)^{N-1}\right)\left(-\alpha^*_{(0),T}\right)V+\left(\frac{Nmp-1+(1-mp)^N}{m}\right)\left(1-\alpha^*_{(0),T}\right)V\\ &\quad+p(1-mp)^{N-1}\left(-\alpha^*_{(0),T}V\right)\\ &> -\alpha^*_{(0),T}V+\left(\frac{Nmp-1}{m}\right)\left(1-\alpha^*_{(0),T}\right)V-\alpha^*_{(0),T}V=G(N)\end{aligned}$$

Thus, $G(N) > 0 \Rightarrow \Delta\Pi(N) > 0$. And $G(N) > 0$ iff $N > \frac{2\alpha^*_{(0),T}}{p\left(1-\alpha^*_{(0),T}\right)}+\frac{1}{mp} = \frac{2c}{p(pq_1V-c)}+\frac{1}{mp}$ (since $\alpha^*_{(0),T}=\frac{c}{pq_1V}$ from Theorem 1). It therefore follows that $\Delta\Pi(N) > 0$ for all $N > \lceil\frac{2c}{p(pq_1V-c)}+\frac{1}{mp}\rceil$.

Proof of part (ii).

It can be shown that $\Delta\Pi(N)$ of equation $(C.9)$ is strictly increasing in p, V, q_1, and decreasing in c. (The proofs are technical in nature and are omitted.) Hence, the threshold value of N above which $\Delta\Pi(N) > 0$ must be decreasing in p, V, q_1, and increasing in c. (That such a threshold exists is proved in part (i).) Finally, that this threshold value of N decreases in m follows from parts (i), (ii) and (iii) of Theorem 2.

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