Essays at the Interface of Finance and Operations Management

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There has been an urgent need, from both academics and practitioners, to find systematic approaches to strategic decision-making across business functions in the modern corporations. This dissertation aims to address issues at the interface of finance and operations management in particular. The first essay studies the interaction between equity markets and new product development and innovation in the context of green vehicles in the global automobile industry. We find that the investors embrace the green vehicle innovation positively, and specific operational decisions (e.g. technology and product segment choices) impose moderating effects on the associated value creation. These empirical findings put financial labels on the trade-offs between environmental and commercial benefits, which in return have strategic implications on the green product development in a low-carbon economy. In the second essay, we apply well-developed financial theory and tool to solving classic supply chain risk management problem. We use semi-variance to model the demand risk facing the supply chain and design an option contracting mechanism to help supply chain to manage the risk of uncertain demand and achieve a win-win outcome.

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Chapter 1

Overview

Both academics and practitioners have been looking for systematic approaches to strategic decision-making across business functions within the modern enterprizes in the past decade. This dissertation aims to address the issues at the interface of finance and operations in particular. In the first essay, we study the global green vehicle development and innovation in the past 15 years using the event study methodology. We also examine the implications of crucial new product development decisions such as technology choice and product segment choice on the wealth effects. A set of factors, which proxy for business and economic environment, are considered to explain the magnitude and direction of market value changes associated with this development. We find that investors in general positively embrace the idea of automakers' tackling environmental challenges through product innovation, as it leads to a significant 45 bps increase in market value. Automakers' fundamentals and financial health matter a great deal to generating those excessive returns; so does oil price. More importantly, the result indicates that, although they don't directly play a role, the choices of technology and product segment exert indirect influence on the market reaction. Our findings shed light on the ongoing phenomena in the field and put financial labels on trade-offs that automakers have to make, which help them gain more insights into the green vehicle development and innovation.

The second essay is focused on the problem of hedging supply chain risk under a buyback contract involving a risk-neutral supplier and a risk-averse retailer facing a single-period stochastic demand. Consistent with financial theory, we measure a retailer's downside risk by semi-variance. We design an optimal buyback contract where the buyback price is a function of the retailer's degree of risk aversion. The supply chain can be coordinated when the retailer's risk type is observable and discrimination of buyback price is also allowed. If the retailer's type is unobservable, the supplier can set a menu of buyback contracts as put options where the buyback prices are equivalent to the exercise prices and the retailer acquires the proper put option corresponding to her risk profile. We show how the supplier should compute the option's ask and exercise prices such that the retailer honestly reveals her type and the outcome is a "win-win" situation for both parties while the supply chain's profit is always optimized. Our analytical and numerical results demonstrate how the supplier's ability to identify a retailer's type affects the supply chain performance. Finally, we also show in which situations managing risk through linear pricing buyback contracts might be a better means than non-linear pricing contracts proposed in previous literature.

Chapter 2

Green Vehicle Innovation and its Impact on Market Value

2.1 Introduction

> *"The electrification of the automobile is inevitable." Bob Lutz, Vice Chairman, General Motors, January 2008.*

The quote from Mr. Bob Lutz reflects the urgent but optimistic sentiment of the global automobile industry towards green vehicles. Although the development is still nascent and subject to many uncertainties, automobile insiders believe the path to electrification will be fluid (Nesvold 2010). A confluence of economic, environmental, regulatory and technological forces has been fostering the rise of green vehicles: Deutsche Bank estimates that the global market for Electrified Vehicles (EV) will rise from approximately 1.0 million units in 2009 up to 17.3 million in 2020, which will account for 20% of global light vehicle volume (Lache et al. 2009). In his 2011 State of the Union address, President Obama stated that "[...] we can [..] become the first country to have a million electric vehicles on the road by 2015."

Looking back in history, this is not the first time the automobile industry tried to offer environment-friendly products. The last attempt was in the late 1980s but soon ceased unsuccessfully (a 2006 documentary film "Who Killed the Electric Car" explores the reasons of this failure in depth.) What could make things different this time? Many believe that regulations on fuel efficiency and CO_2 emissions, along with the momentum behind them, drive the automobile industry to push more green vehicles into the market.

Lawmakers worldwide have been rolling out increasingly stringent requirements for the automobile industry to become cleaner. In the U.S., the Energy Independence and Security Act of 2007 (EISA) tightened the corporate average fuel economy (CAFE) standard by 40%, a raise from 25 MPG in 2010 to 35 MPG by 2020. The European regulation imposes an average 130 grams CO_2/kilometer standard onto automakers in the region by 2012. These regulatory "sticks" drive the automobile industry to explore ways to make their products greener.

Rising oil prices and increasing environmental awareness among consumers also help move the trend forward. Although recent oil prices dropped back from their peak in 2008, analysts still believe that oil price could again rise to $150/barrel in the intermediate term (Lache et al. 2008). Individual consumers have expressed strong willingness to pay a premium for products that are good for the environment (Rosewicz 1990). Meanwhile, key technologies have drastically advanced, for example, cost effective, high energy and long lasting lithium ion and lithium-vanadium batteries have been adapted or come closer to reality (Gaines and Cuenca 2000, Electrification Coalition 2010). By and large, we have witnessed dramatic changes in vehicle technologies (towards electrification) on a global basis in the past ten years and expect to see more green vehicle innovations coming in the next decades.

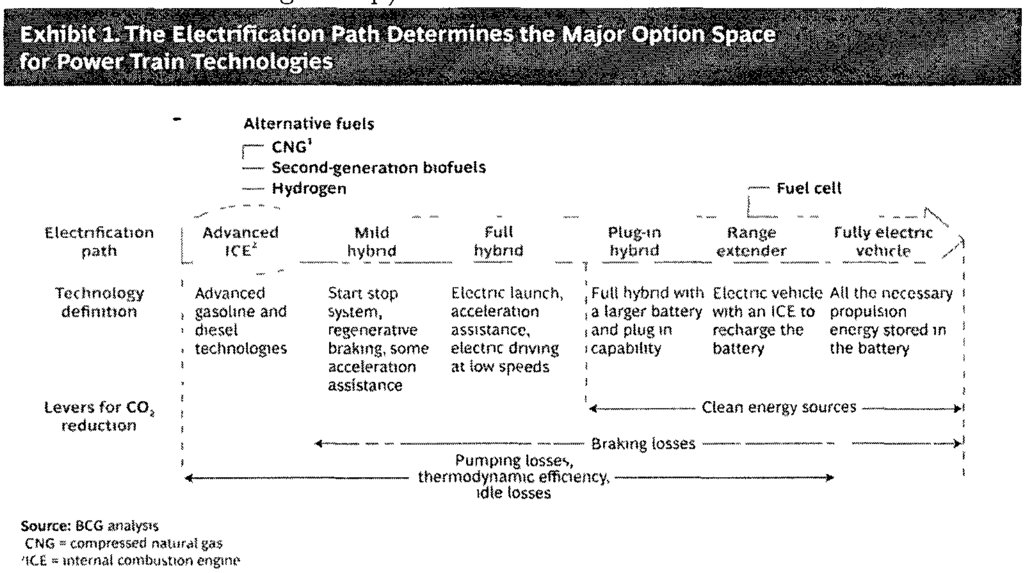
The fact that product innovations are the engine of a firm's growth and prosperity is extensively documented in the academic literature (e.g., Chaney et al. 1991, Kamien and Schwartz 1975, Mansfield et al. 1971). Kirshnan and Ulrich (2001) and Schmidt and Van Mieghem (2005) also suggest that specific product development/innovation decisions, such as which technologies will be employed or which market to enter, could substantially alter the path of product innovation's value creation. The Boston Consulting Group (BCG) emphatically raised these questions in their recent research on "the comeback of the electric car."

Figure 1 illustrates the major technological option space for green vehicle's power trains (courtesy of BCG). It also approximates the trade-offs between CO_2 emissions and development costs as well as risks. The "Advanced ICE" is the most cost-effective way to reduce carbon emissions. Less CO_2 is emitted along the path but at a higher development cost and technological risk (mainly long-lasting lithium ion batteries and propulsion system based on electricity). However, there is very little consensus on which technology is a winning solution; instead, there are many contradictory beliefs even within the automobile industry (Book et al. 2009).

We have observed that electrified power trains are put into not only compact economy cars (Honda Insight, Toyota Prius) but also full-size SUVs and luxury sedans (e.g., Chevrolet Tahoe, Lexus RX 400h). There isn't any product segment that has proved to be the dominating one for green vehicles as the industry still tries to figure out which consumers are willing to buy which green cars (Smith 2010, Book et al. 2009).

The development of green vehicles in the automobile industry provides a good opportunity for academicians to study management and business issues in the coming low-carbon economy. Pil and Rothenberg (2003) highlight that attaining

Figure 1: Major Green Vehicle Power Train Technologies (from "The Comeback of the Electric Car? How Real, How Soon, and What Must Happen Next" 2009, The Boston Consulting Group)



superior environmental performance can be a significant driver of other excellence in the automobile industry. The result of their research reinforces the perspective that the benefits of environmental efforts could go beyond compliance and encourages further research on the implications of firms' environmental efforts This paper is particularly interested in the following questions: First, what is the value of new product innovations that solve environmental problems to firms and shareholders? Second, what are the factors that could affect the value creation and how? How do new product development (NPD) decisions on trade-offs between environmental and commercial benefits (technology choice, product segment) influence the wealth effects for the firm?

This paper uses the event-study methodology to investigate the impacts of green vehicle innovations on the market value of 14 major public-listed automobile companies worldwide. The sample dataset consists of 261 announcements of green technology and vehicle innovations made by the automakers over a 15-year horizon A set of factors, which proxy for business and economic environments, are considered to explain the magnitude and direction of market value changes associated with green vehicle innovations More importantly, we also explore the implications of choices of product technology and segment on the wealth effects of those announcements

This research makes several important contributions First, There has been very limited empirical evidence on the economic impact of green product innovations We fill this gap by analyzing the impact of announcements of green vehicles on the firms' market value Second, this is the first empirical research that investigates the direct as well as indirect effects of trade-offs between environmental and financial considerations on the value creation of environmentally-oriented initiatives Third, the results could shed light on developing optimal green product innovation strategies, as it helps managers understand the influential factors and make the right trade-off decisions to maximize shareholder value

The rest of the paper is organized as follows Section 2 2 gives a comprehensive literature review Section 2 3 discusses the theory and hypotheses examined Section 2 4 reviews the research methodology, data collection and statistical methods used to test our hypotheses We present and discuss the empirical results and their implications in section 2 5 Section 2 6 summarizes the research and its contributions

2.2 Literature Review

Our study is related to two streams of research First, as we examine the effects on the market value of a car manufacturer when new green cars or technologies are announced, this research relates to the literature that studies the wealth effects of new product design and innovation in general Second, our research is related to a relatively new stream of research that studies the impact of corporate environmental initiatives on shareholder value

There is an abundance of studies of financing decisions on a firm's market value in the finance and accounting literature, but recently researchers in strategy management and marketing have studied the wealth effects of other decisions such as introduction of new products, announcements of R&D projects, etc , mainly using the event study methodology (MacKinlay 1997)

Chaney et al (1991), investigate the wealth effects of the introduction of new products and find significant positive excessive returns (0 75% cumulative abnormal return over a three-day event window) from those announcements The effects vary across industries as announcements in more technology-oriented industries generate higher value to shareholders They also find that factors such as whether the announcements are for original product introductions or multiple products, the frequency of firms' making announcements and even short-term interest rates could contribute to the value creation

Subsequent research studying the stock market reaction to events of new product development and innovation reinforces the findings of Chaney et al (1991) but discusses the issue from different angles Koku et al (1997) suggest that new product related event studies should distinguish between announcements and pre-announcements as they find only pre-announcements lead to significant effects (4 3%) Mishra and Bhabra (2001) take the issue a bit further they find that investors only react positively (0 44%) to pre-announcements of new products with credible evidence

Lee et al. (2000) reveal the relationship between the wealth effects and the timing of new product announcements. They show that a first mover would experience a positive reaction from investors (2.71%). However, the imitation from rivals is very likely to undercut the gains later on. In a similar research setup, Chen et al. (2005) find that rivals of firms announcing new products will experience small but negative wealth effects; however, those effects tend to be more favorable if the announced products are really new. Jones and Danbolt (2005) examine the difference in stock market reactions between new product announcements and new market entry announcements. Investors value new product related announcements more than announcements associated with new market entry.

Studies on the wealth effects of corporate environmental initiatives have been gaining momentum, although some studies have shown inconclusive or even conflicting results (Corbett and Klassen 2006). Klassen and McLaughlin (1996) examine the wealth effects of environmental awards and environmental crises from 1985 to 1991. They find significant positive effects for environmental awards and negative market reactions for environmental crises. In the case of environmental awards, the research also finds that investors react more positively to the announcement of a first-time award recipient in cleaner industries. Mathur and Mathur (2000) investigate the wealth effects of 73 corporate announcements of green marketing activities such as green products, recycling efforts and green promotional efforts. They find an overall negative effect, although green products and recycling efforts lead to insignificant market reactions. On the contrary, Shane and Spicer (1983) find that announcements on superior pollution control performance result in an increase of shareholder value based on a sample of 72 firms in traditionally dirty" industries such as petroleum and steel.

Recent research by Jacobs et al. (2010) of both corporate environmental initiatives (430 events) and environmental awards and certifications (381 events) finds no significant abnormal return due to the overall events. However, certain subcategories of events, such as voluntary emission reductions and ISO 14001 certifications, lead to significant abnormal returns (-0.90% and 0.65% respectively). The opposite direction of these effects shows that the market reacts very differently to self-reported corporate efforts and recognitions by third-parties.

Gilley (2000) looks into both process-driven and product-driven environmental initiatives based on a sample of 71 announcements from 1983 to 1996, which suggests that additional attention should be given to the difference in the types of environmental initiatives as they might affect the firm's value differently. The results indicate that, although the overall impact of the announcements is insignificant, the market reacts significantly better to product-driven initiatives than process-driven initiatives.

Very few research has focused on the value to shareholders of products designed to solve environmental problems (e.g., green vehicles). In addition, the implications of the trade-offs between environmental and financial benefits are absent in the literature. An understanding of the effects of new product design for green initiatives on the firm's market value is important for researchers as well as practitioners. Our research partially fills this gap.

2.3 Theory and Hypothesis

Green vehicle development and innovation have been gaining momentum in the automobile industry. The driving forces behind the new phenomenon are the pressing CO_2 emission/fuel efficiency regulations, growing demand for fuel-efficient vehicles, automakers' ambitions of building new competitive advantage as well as establishing good corporate citizenships (Lache et al. 2008).

As consumers become more and more environmentally conscious, they become more likely to buy environment-friendly vehicles. Surging oil prices provide another incentive to shift away from conventional cars to green vehicles. According to research by Lazard Asset Management (Nesvold 2010), electric miles cost substantially less than gasoline miles ($0.07/electric mile v.s. $.175/gasoline mile). They estimate the massive market demand for green vehicles might come faster than expected, and this will benefit automakers who have put significant efforts in green vehicle innovation.

In general, new product innovation is deemed as an essential activity for companies to build and sustain their competitive advantages (Souder 1987). Not only are innovating firms able to explore new market demands through new products, but also build technological barriers and best practices against competition. The story of Toyota Prius shows how much impact a successful green vehicle innovation could have on the automaker's leadership and market share in this particular space.

Previous research has also shown that good environmental management and corporate social responsibility performance are often perceived as positive signals and are therefore rewarded by the stock market (Klassen and McLaughlin 1996, Roy et al. 2001). Automobiles are a major source of CO_2 emissions, hence the efforts of car manufacturers to rein in environmental impacts shows the firms' determination for good corporate citizenships, which might be valued by investors.

Based on the above arguments, we believe that the market would value the industry's efforts in developing green technologies and vehicles. This leads to our first hypothesis.

Hypothesis 1: *The announcements of green vehicle innovations have a positive impact on the market value of the automakers.*

As Book et al. (2009) pointed out, the best choice of propulsion technology (the key technology of green vehicle innovation) that makes most commercial and technical sense still remains speculative and is open to debate, even within the automobile industry and experts. But, the present choice of technology will play a vital role in the success of the automakers' green vehicle strategy in the future. In other words, investors' opinions about the technology chosen by a car manufacturer today may be a major driver of the firm's market value.

We group the major technological options in the space as illustrated in Figure 1 into two categories: Conservative Innovation (CI), which includes advanced ICE (internal combustion engine), mild hybrid and full hybrid, and Radical Innovation (RI), which includes plug-in hybrid, range extender and full electric vehicle (Hoed 2007). CI represents the type of technologies that could achieve reasonable CO_2 emission reduction at a relatively low cost, which also requires less technology breakthroughs and therefore involves less R&D risks. On the other hand, RI aims at significantly reducing CO_2 emissions, even to the point of zero emission in the case of full electric vehicles However, it comes with significant extra costs: BCG estimates that EV costs an additional \$140 to \$280 per percentage point of CO_2 reduction versus \$70 to \$140 by advanced ICE (Book et al. 200). To make RI based vehicles a commercial reality, automakers not only have to achieve significant breakthroughs in key technologies (e.g., batteries), but also count on external support from government (tax incentives), power companies (charging infrastructure) and even new business models (e.g., Better Place provides a network of charge spots, battery switch stations and optimization systems to EV drivers), (Nesvold 2010, Lache et al. 2008, 2009).

Previous research supports the argument that more advanced innovations in technology are valued higher than the ones with a low degree of technological innovation (Garcia and Calantone, 2003). Does the theory still hold for the automakers' Radical Innovation in green vehicles? The answer is not obvious as the trade-offs between those two are beyond the technology itself because of the impact of other factors such as regulation.

CI-based vehicles and development projects might be favored due to its cost-effective CO_2 emission reduction, relatively more mature technology, and easier adoption by consumers on a large scale. However, many criticize CI-based green vehicles as a short-sighted solution since the vehicle still has to derive overwhelming majority of its propulsion from petroleum (Nesvold, 2010). As political entities clearly state their ambitions of reducing CO_2 emissions (e.g. European Union is targeting a 95 g/kilometer standard by 2020 vs. 130 g/kilometer by 2012), the automobile industry would "undoubtedly require meaningful electrification." CI-based vehicles might fall short from that perspective.

RI-based vehicles, on the other hand, are highly expected by many to come out stronger and faster to dramatically change the market and industry (Lache et al. 2009). Although many concerns, such as high production cost, immature technology, still remain unanswered, the industry experts are positive on the progress of solving those problems, and therefore the future of RI-based vehicles (Electrification Coalition, 2009). However, even those who are bullish on the long-term prospects of RI also caution that demand for RI-based vehicles might stay low in the near term as "automakers and suppliers are still validating products and gearing up for large scale production" (Lache et al 2008)

Simply put, although innovating in green vehicles seems the right strategy for automakers, different NPD decisions pertaining to technology choice may have different implications on earning forecasts, and therefore result in different impacts on an automaker's market value It is a critical decision to make, but there is very limited evidence to support either conclusion since most leading firms are still in the phase of validating products Each solution has its own merits and none is clearly superior to the other Therefore we postulate the following mutually exclusive hypotheses

Hypothesis 2a: *CI-based green vehicle innovations have a more positive impact on the market value of the automakers than RI-based innovations*

Hypothesis 2b: *RI-based green vehicle innovations have a more positive impact on the market value of the automakers than CI-based innovations*

Another important NPD decision is the choice of product segment should the car maker concentrate on small, economy cars, sedans or utility vehicles? Different vehicle segments are designed to meet different needs of certain consumer demographics The empirical observation is that automakers have been experimenting their green vehicles in different segments Toyota introduced its first hybrid product Prius as a 5-seat compact, Ford, on the other hand, targeted its first hybrid product, Escape Hybrid, in the SUV segment

Many factors would influence an automaker's choice of product segment for green vehicles such as technology feasibility, consumer adoption rate, etc (Book et al 2009) We would like to find out which segment investors perceive as contributing more to increasing a firm's value, since it potentially implies which consumer demographics are more likely to adopt green vehicles To simplify the analysis, we group the product segments into two classes: low-end class (LE) and high-end class (HE). LE refers to the segments of compacts and non-luxury sedans; HE refers to the segments of SUV and luxury sedans. The rationale behind this categorization is to be consistent with the traditional economics and marketing literature on the interaction between new product design and consumer behavior (Tirole 1997). Presumably, consumers shopping for LE vehicles might care less about non-essential features in a car, such as fast acceleration, passenger space, off-road performance. etc. of the product and are more price sensitive; whereas consumers of HE vehicles might value such non-essential features more and tend to be less price sensitive.

Which segment should the car manufacturer choose for a new green car? HE consumers might care less about the extra cost associated with green vehicles than LE consumers. However, they may not be very happy with the loss of driving performance, along with other inconveniences, in exchange for fuel efficiency. LE consumers, on the other hand, might not mind some loss of horsepower, shorter driving distance, etc., which are sacrificed for better fuel efficiency, but green vehicles' high price tag might turn them away. Also, the difference in production cost between LE and HE green vehicles could be substantial as HE requires much bigger batteries (the most costly component), which might be another challenge for automakers introducing a vehicle in the HE class. Therefore, the answer to the question is still ambiguous, which possibly explains why automakers act differently. This leads to our third set of mutually exclusive hypotheses.

Hypothesis 3a: *LE class green vehicle innovations have a more positive impact on the market value of the automakers than HE class innovations.*

Hypothesis 3b: *HE class green vehicle innovations have a more positive impact on the market value of the automakers than LE class innovations.*

Hypotheses 1 to 3 test the overall reactions of the stock markets to green vehicle innovations and product announcements as they relate to the direct impact of technology choice and product segment choice on value creation for the firm It is also interesting to discover factors which are exogenous to these decisions, but that could influence the magnitude and direction of changes in market value associated with those innovations This research particularly studies the most commonly used variables by academicians and industry analysts They include firm-level factors such as firm size, research and development expenditure, profitability, leverage and frequency of green innovation announcements, and economy-level factors such as oil price Together these variables proxy for business and economic environments We also examine how technology and segment choices moderate the impact of these variables on the market reactions

Firm size and R&D expenditure In general, both variables are regarded as proxies for a firm's capability of conducting innovations and ensuring the economic success of those activities (Chan et al 1990) Although some researchers believe that small firms might be able to benefit more from innovations as they could capture niche markets with positive outcomes of their innovations, others provide evidence that, in mature industries like the automobile industry, large firms are able to take advantage of their size to become the winners of innovations (Chaney et al 1991, Ettlie and Rubenstein 1987) Disruptive innovations, like green vehicles, require large investments in technical financial and human resources (Hoed 2007) Therefore, it may not be viable for smaller firms to undertake such projects, not to mention to bear significant risks associated with such innovations Similarly, large R&D expenditure is a well accepted indicator of a firm's strength in innovation and competence Firms with a significant R&D expenditure are believed to have better expertise, experience and execution in innovative R&D projects, and therefore are more likely to make innovations successful Thus we have the following hypotheses

Hypothesis 4: *Stock market reaction to the automakers' green vehicle innovations will be more positive for larger firms than for smaller firms*

Hypothesis 5: *Stock market reaction to the automakers' green vehicle innovations will be more positive for firms with a large R&D expenditure than firms with a small R&D expenditure*

Profitability Profitability reflects a company's operational and financial performance Thus it is widely used by investors to evaluate a company's fundamentals (Rosenbaum and Pearl 2008) Among comparable companies, higher profitability indicates that a firm runs its core business at a more efficient level, which potentially leads investors to believe that the firm is on the right track and might be better off sticking to the current core business strategy In this sense, the idea of deviating from core businesses and investing in green vehicles may not sound appealing to investors, especially when the market demand is unproven, the technical risk is high, and the required investment is huge The broad topic of whether successful companies should bother with radical innovation has been debated and studied by researchers and managers However, the findings are by no means conclusive (Christensen 1997) In our opinion, it might be reasonable for investors to cast doubts on carmakers' investment in green vehicles if they are obviously doing well in their conventional core businesses given the capital constraints, the firms will have to allocate capital resources to green vehicle projects which might be better used to further improve existing products and services Whether green vehicles would be as profitable as existing product lines is far from clear, and all the current evidence (e g , Inoue and Ueno 2009) points to a negative relationship between the introduction of green vehicles and profitability

Therefore, investors might value green vehicle innovations from less profitable carmakers more as they expect less profitable carmakers to find new breakthroughs in this potential market place This leads to the following hypothesis

Hypothesis 6: *The change in a firm's market value in response to automakers' green vehicle innovations will be lower for more profitable firms than less profitable firms*

Leverage This variable reveals a great deal about a firm's financial policy, risk profile and capacity for growth (Rosenbaum and Pearl 2008) Practically, investors perceive a firm with higher leverage as more vulnerable to financial stress due to greater associated interest expense and principal repayments Although Modigliani and Miller (1958) suggest that, in perfect capital markets, a firm's capital structure is irrelevant to its investments, other scholars show that, for numerous reasons, debt would actually inhibit a firm from engaging in productive R&D (Long and Ravenscraft 1993) Therefore, a highly leveraged automaker engaging in green vehicle innovations might not only be prone to financial risks, but also be unlikely to gain as much as less leveraged firms do from those R&D projects We test the following hypothesis

Hypothesis 7: *The change in a firm's market value in response to automakers' green vehicle innovations will be lower for firms with higher leverage than firms with lower leverage*

Oil price The consensus among managers, researchers and investors in the automobile industry is that oil price plays a critical role in shifting market demand from conventional to green vehicles or otherwise (Nesvold 2010) As long as oil prices keep rising as expected, consumers are very likely to seriously consider green vehicles and pay a premium for them This may not be the case if oil prices stay low in the long run (Lache et al 2008, 2009) Hence high oil prices help improve the earnings forecasts for green vehicles There are other external factors that could also stimulate market demand for green vehicles such as government incentives, the growing number of environmentally conscious consumers, etc High fuel prices give the most straightforward and financial incentives to consumers to go green Therefore we hypothesize

Hypothesis 8: *Stock market reaction to the automakers' green vehicle innovations will be positively related to oil prices*

Moderating effects of technology choice. The finance literature shows that stock markets respond to announcements only when they carry unanticipated information that could potentially affect future cash flows (Fama 1991) When automakers unveil their technology choices for green vehicles in the announcements, investors read into them and look for cash flow implications The decision of which technologies should be employed in the products is strategically important in the product development literature as it influences the success of the new products both technically and economically (Krishnan and Ulrich 2001) Investors evaluate the firm s choice to project whether the decision is likely to lead to incremental cash flow, and the stock price would react accordingly In the context of green vehicle innovations, the choice of technology, either CI or RI based, affects the success of the vehicles in two aspects First, RI-based innovations are featured with higher technical risks and require huge capital investments compared to CI-based innovations Therefore, for automakers who choose RI for green vehicles, investors have higher expectations in terms of resources and R&D capability than companies choosing otherwise More specifically, for RI-based vehicles, investors might weigh firm size and R&D expenditure much heavier than for CI-based innovations as these factors play a more important role in turning radical R&D projects into profits Second, another feature that distinguishes RI from CI is higher fuel efficiency In other words, RI-based green vehicles might give consumers better economic incentives to make a buying decision while oil prices are expected to rise Therefore investors might expect stronger positive influence of increasing oil prices on the demand for RI-based green vehicles Thus we hypothesize that

Hypothesis 9: *Automakers' technology choice moderates the effects of firm size, R&D expenditure and oil price on the stock market reaction to green vehicle innovations*

Moderating effects of product segment. In the same fashion, the choice of product segments for green vehicles might also alter the market valuation of automakers' innovations As we discussed previously, although HE consumers are less sensitive to prices, how much more they are willing to pay is still unclear (Smith 2010) Thus profits from HE green vehicles may not be able to justify the costs in quite a long time As a result, investors might be more critical of automakers' choice of the HE segment, especially when they are doing well with their existing product lines Simply put, investors may not respond well when a profitable automaker is to deviate from its core business Testing the innovations on its high end (and more profitable) consumers might just make it worse, not to mention that investors would scrutinize the automaker's financial health more severely while such commitments (choice of HE) are made Being vulnerable to financial stress might be less appreciated for the HE oriented green vehicle innovations, compared to LE oriented ones Therefore we have the following hypothesis

Hypothesis 10: *Automakers' product segment choice moderates the effects of profitability and leverage on the stock market reaction to green vehicle innovations*

2.4 Research Methodology

2.4.1 Data Collection

Two types of data were collected for this research. First, we collected a sample of announcements of automakers' green vehicle innovations and the corresponding stock returns for event study analysis. Second, the data for all the variables that would explain abnormal returns were also collected for the regression analysis. We constructed a sample of worldwide automakers who had officially invested in green technologies and vehicles. The sample of automakers include only publicly traded companies due to the nature of the study. Hence private companies such as Chrysler, etc., who have been committed to green vehicle innovations, were excluded from the sample. In total, there were 14 automobile companies in the initial sample. Then we searched the Dow Jones Factiva database for the announcements of green vehicle innovations made by those automakers from 1996 to 2009. The initial search generated 351 announcements during the sampling period. We looked into each announcement to make sure that, a) the announcement was concerned with green technology or product only, and also carried essential technology or product information; b) the announcement was the first news of the related technology or product disclosed to the public; and c) the time interval between two adjacent announcements of any firm was at least longer than one week (5 trading days). We dropped the announcements that did not meet the above criteria. The final sample consisted of 261 announcements.

The content of the 261 announcements were reviewed in detail to extract information on the date of the announcement, the type of the technology in use, and the product segment the announcement was concerned with. Panel A in Table 1 presents the distribution of announcements by year; whereas Panel B shows the number of the announcements associated with each technology We classify the announcements in light of the aforementioned technological categories Advanced ICE, mild hybrid and full hybrid are considered as Conservative Innovations (CI), plug-in hybrid, range extender and full electric are regarded as Radical Innovations (RI) The announcements that do not fall into either category are labeled as "Miscellaneous" Hence there were 148 CI-based and 91 RI-based announcements We also classified the announcements in terms of product segment (i e , HE and LE) 105 announcements pertained to low-end vehicles (LE) and 81 high-end vehicles (HE) Two independent coders and one of the authors classified the announcements The inter-rater reliability was over 95%, the disagreements were further resolved by discussions among the three coders

Table 1 Distribution of Announcements by Year and Technology

Panel A			
Year	No of Announcements	Year	No of Announcements
1996	3	2003	18
1997	6	2004	19
1998	2	2005	15
1999	6	2006	34
2000	13	2007	36
2001	12	2008	64
2002	11	2009*	22
Panel B			
CI Technology	No of Announcements	RI Technology	No of Announcements
Advanced ICE	14	Plug in Hybrid	21
Mild Hybrid	51	Range Extender	34
Full Hybrid	83	Full Electric	36
Miscellaneous	22		

*Announcements made before May 1st, 2009

Most of the automakers in the sample are foreign companies and not listed in major U S stock exchanges Some of them (e g Toyota) are cross listed in both U S stock exchanges (New York Stock Exchange) and their domestic stock exchanges (Tokyo Stock Exchange) When collecting the daily stock price data of the related automakers, we chose their prices on the primary listing exchanges and the corresponding value-weighted market index prices. All the daily stock prices and market index prices data are available in Thomson ONE Banker Database.

The measures for variables such as firm size, R&D expenditure, profitability and leverage were calculated based on the automakers' accounting and financial data that are available in Thomson ONE Banker Database. The operationalization of all the variables comes from previous literature. Table 2 summarizes the operationalization of the variables and the literature base of the operationalization. In addition, "Frequency" — the number of announcements an automaker made over the 15-year study period — was introduced as a control variable according to previous literature (Chaney et al. 1991).

Table 2: Variables and Operationalization

Variable	Operationalization	Literature Base
Firm Size ($FS_{i,t}$)	$\ln(TOTAL\_ASSETS_{i,t-1})^*$	Chen et al (2002)
R&D Expenditure ($RD_{i,t}$)	$\ln(R\&D\_EXPENDITURE_{i,t-1})$	Chaney et al (1991)
Profitability ($PR_{i,t}$)	$EBITDA_{i,t-1}/SALES_{i,t-1}$	Rosenbaum and Pearl (2008)
Leverage ($LEV_{i,t}$)	$DEBT_{i,t-1}/EBITDA_{i,t-1}$	Rosenbaum and Pearl (2008)
Oil Price (OP_t)	Monthly nominal crude oil prices change$^+$	Hamilton (1996)
Frequency (FRE_i)	Number of announcements over study period	Chaney et al (1991)

* $t-1$ represents the most recent fiscal year ending prior to the announcement

\+ West Texas Intermediate spot crude oil prices data

Table 3 presents the descriptive statistics of all the variables. The high correlation between firm size and R&D expenditure is noticeable. The sample of automakers are all large (on an absolute scale) global companies in a mature industry. Allocating R&D expenditure proportional to firm size is common industry practice, which explains the high correlation between these two variables. We subsequently discarded R&D expenditure and the associated hypotheses in our analysis.

Table 3: Descriptive Statistics

No	Var	Mean	Stdev	Min	Max	1	2	3	4	5	6
1	Firm Size	11 70	0 84	8 88	13 08	1 00					
2	R&D Expenditure	8 18	0 89	4 10	9 09	0 83	1 00				
3	Profitability	0 12	0 05	-0 07	0 34	0 37	0 19	1 00			
4	Leverage	4 99	3 68	-4 29	19 24	0 35	0 13	-0 22	1 00		
5	Oil Price	-0 01	0 11	-0 33	0 20	-0 03	-0 02	0 10	-0 01	1 00	
6	Frequency	26 83	11 76	5 00	41 00	0 45	0 63	-0 03	-0 06	0 00	1 00

2.4.2 Data Analysis

We use the event study methodology to estimate the changes in the automakers' market value associated with green vehicle development and innovation announcements. Based on the Efficient Market Hypothesis (Fama 1991), the event study measures the market reactions to unexpected firm-specific events, while adjusting stock returns for market-wide movements. The adjusted returns (often referred to as abnormal returns) reflect the effect of an economic event on the value of a firm given rationality in the marketplace (MacKinlay 1997). Therefore, we were able to measure the wealth effects of green vehicle development by observing stock price behavior over relatively short periods when the announcements were made.

Event study is a well accepted research methodology in many disciplines. Originated in the paper of Dolley (1933), the methodology has been well developed in two pioneering studies by Ball and Brown (1968) and Fama et al. (1969), and has been used by researchers in finance (Brown and Warner 1985, Fama 1991, etc.), strategic management (Woolbridge and Snow 1992), and marketing (Lane and Jacobson 1995). Recently researchers in Operations Management have also been adopting this methodology (e.g , Jacobs et al 2010, Singhal and Hendricks 2003). MacKinlay (1997) gives a comprehensive review of the methodology and its applications and summarizes major findings and caveats when using the methodology.

One of the major limitations of event study is the difficulty to precisely find out when the information has been incorporated into the stock prices. The problem could come in many forms, such as uncertain event date, information leakage prior to the announcement. MacKinlay (1997) has studied the issue and finds that simply extending the event window could lessen the problem. Ball and Torous (1988) investigate the issue in depth and find that there is very little to gain from the more elaborate estimation methods.

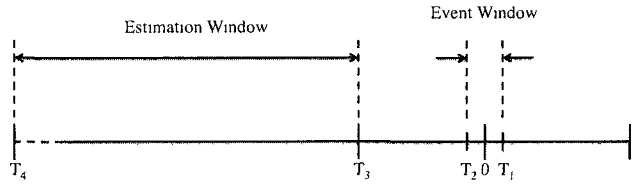
Different from corporate financing decisions (M&A, stock splits, etc.), events like new product innovation, R&D announcements, tend to evolve slowly so that they might be less surprising to the financial market and the value of these announcement events is also smaller. These challenges make it harder to use event study to measure the real value of the events as illustrated by Chaney et al. (1991) and many other related literature (Horsky and Swyngedouw 1987, Eddy and Saunders 1980, etc.). Chaney et al. (1991) conclude "the true importance of this methodology is not the magnitude of the excess return found but what that excess return is relating to and how this information can be integrated with other information to better understand the phenomenon being investigated."

In this paper, the Market Model (Brown and Warner 1980, 1985) is employed to measure abnormal returns. For any stock i we have

$$R_{it} = \alpha_i + \beta_i R_{mt} + \epsilon_{it} \tag{1}$$

with $E[\epsilon_{it}] = 0$ and $Var[\epsilon_{it}] = \sigma_\epsilon^2$, where R_{it} is the return of stock i on day t; R_{mt} is the return of market portfolio on day t; ϵ_{it} is the zero mean disturbance term; α_i, β_i and σ_ϵ^2 are the parameters of the model. In this study, the proxy for stock i's corresponding market portfolio is a value-weighted market index of all

Figure 2: Time Line for Event Study



securities traded in the country where the primary listing exchange of the stock i is located.

To measure and analyze abnormal returns, we first define the time frame for the event study. The initial announcement date is defined as the event date $t = 0$. The estimation window consists of 250 trading days, from Day $T_4 = -259$ to Day $T_3 = -10$. Ten trading days prior to the event date are excluded from the estimation window to limit any potential effects of the announcement (e.g. the market anticipates the event in the days prior to the formal announcement). Abnormal returns, the measure of stock market's reaction to the event, are calculated over an event window with 3 trading days (Day $T_2 = -1$ to Day $T_1 = +1$). Figure 2 illustrates the sequence on the time line (MacKinlay 1997).

We ran ordinary least squares (OLS) regression over the estimation period to estimate the parameters of the market model, $\hat{\alpha}$, $\hat{\beta}$ and $\hat{\sigma}^2_\epsilon$. Then we calculated the abnormal return of stock i on trading day t in the event window using the following formula:

$$AR_{it} = R_{it} - \hat{\alpha}_i - \hat{\beta}_i R_{mt} \tag{2}$$

for $t \in \{T_2, ..., T_1\}$, where AR_{it} is the abnormal return of stock i at day t. In total, there were $N = 261$ observations in the sample. As illustrated, the abnormal return is the <u>ex post</u> return of the stock over the event window minus the normal return, which is the expected return if the event did not take place. Under the null hypothesis that the event has no impact on returns, $AR_{it} \sim N(0, \sigma_\epsilon^2)$. The more detailed statistical properties of abnormal returns could be found in MacKinlay (1997).

To draw overall inferences, we first aggregate the abnormal returns across time for each event observation as follows,

$$CAR_j(T_2, T_1) = \sum_{t=T_2}^{T_1} AR_{jt} \tag{3}$$

for $j \in \{1, 2, ..., N\}$, where $N = 261$ and CAR_j represents the cumulative abnormal return of event j over the event window $[T_2, T_1]$. A test statistic is calculated to test if the average abnormal return for the stock associated with the event j is significantly different from zero. We have

$$t_j = \frac{CAR_j(T_2, T_1)}{\sqrt{T_1 - T_2}\hat{\sigma}_\epsilon^2} \tag{4}$$

for event j. This only studies the impact of one particular event on the value of the underlying stock. Then we aggregate abnormal returns across all event observations by

$$\overline{CAR}(T_2, T_1) = \frac{1}{N} \sum_{i=1}^{N} CAR_i(T_2, T_1) \tag{5}$$

where $\overline{CAR}(T_2, T_1)$ is the cumulative average abnormal return over N observations with $Var[\overline{CAR}(T_2, T_1)] = \frac{1}{N^2} \sum_{i=1}^{N} \sigma_i^2(T_2, T_1)$. Inferences about the cumulative abnormal returns could be drawn through

$$\overline{CAR}(T_2, T_1) \sim N(0, \frac{1}{N^2} \sum_{i=1}^{N} \sigma_i^2(T_2, T_1)), \tag{6}$$

as, under the null hypothesis, the expectation of the abnormal returns is zero. Therefore we could calculate another statistic to test the overall effects of N

events on the underlying stocks. The test statistic is given by

$$T = \frac{\overline{CAR}(T_2, T_1)}{N\sqrt{\sum_{i=1}^{N} \sigma_i^2(T_2, T_1)}} \tag{7}$$

To gain insights into the determinants of the abnormal returns, we develop a cross-sectional regression model to test the hypotheses.

$$\begin{aligned} CAR &= \beta_0 + \beta_1 \cdot FS + \beta_2 \cdot PR + \beta_3 \cdot LEV + \beta_4 \cdot OP + \beta_5 \cdot TC \\ &+ \beta_6 \cdot PS + \beta_7 \cdot FRE + \beta_8 \cdot TC \cdot FS + \beta_9 \cdot TC \cdot OP \\ &+ \beta_{10} \cdot PS \cdot PR + \beta_{11} \cdot PS \cdot LEV + \alpha + \epsilon, \end{aligned} \tag{8}$$

where CAR is the cumulative abnormal return from an announcement and the independent variables are Firm Size (FS), Profitability (PR), Leverage (LEV) and Oil Price (OP). FRE is the control variable Frequency, TC and PS represent the moderating variables Technology Choice and Product Segment, respectively. $TC = 0$ if the technology is Conservative Innovation; $TC = 1$ if the technology is Radical Innovation. Similarly, $PS = 0$ if the target segment is low-end Class; $PS = 1$ if the target segment is High-end Class. Finally α represents unobservable firm effects.

The rationale behind taking unobservable firm effect into account is that those firm-specific factors such as management, green innovation reputation, corporate culture, etc. might drive the excessive returns. For instance, investors might react to Toyota's announcements differently than to those of others simply because of Toyota's perceived leader status in the green vehicle space among the major car manufacturers. Therefore the fixed effect model is applied.

2.5 Empirical Results and Discussion

2.5.1 Event Study Results

Table 4 summarizes the results of the event study analysis of the green vehicle innovation announcements. Overall, the average CAR using the Market Model is 0.45% over the three-day event period (day −1 to day +1), which is statistically significant ($p \leq 0.05$). This result supports the Hypothesis 1 that the stock markets in general positively perceive the automaker's green vehicle innovations.

Table 4: Results of Event Study Analysis

		No of Events	Cumulative Abnormal Returns (%)	T-Statistic
Overall		261	0 45**	1 99
Technology Choice	CI	148	0 72***	2 95
	RI	91	0 45	0 96
Product Segment	LE	105	0 42	1 07
	HE	81	0 85**	2 03

* $p \leq 0\ 1$, ** $p \leq 0\ 05$, *** $p \leq 0\ 01$

To examine the direct impacts of technology choices on the market value, we separated the 261 announcements into two groups, CI and RI, as described in Section 4. The average CAR from CI-based announcements is a statistically significant increase of 0.72% over the three-day event period ($p \leq 0.01$). The average CAR from RI-based announcements is not statistically significant. These results indicate that CI-based green vehicle innovations have a positive impact on stock prices. However, it is not clear which technology choice is better in terms of leading to a higher average CAR, as the mean difference test is not significant ($t = 0\ 78$). In other words, neither Hypothesis 2a nor Hypothesis 2b is supported and the direct impact imposed by technology choice is not found.

Similarly, we separated all the announcements into two groups by product segment, LE and HE, to test the impact of product segments on the market value of automakers Although the average CAR from HE-oriented announcements is a statistically significant 0 85% over the three-day event period ($p \leq 0\ 05$), we did not find the direct impact of the choice of product segment proposed in Hypothesis 3a and 3b on stock prices, as the mean difference test is not significant ($t = -0\ 69$)

To give more perspectives on the magnitude of the stock markets' reaction to the automakers' green vehicle innovations, we briefly compare our results to the findings in previous research on the stock markets' reaction to relevant events Chaney et al (1991) finds that the average CAR of 1101 new product introduction announcements is a statistically significant increase of 0 75% over a three-day event period Kelm et al (1995), based on a sample of 501 R&D announcements, finds a statistically significant average excess return of 0 96% over a two-day event period In another stream of research, Klassen and McLaughlin (1996) finds that the average CAR of 140 positive environmental management announcements is 0 63%, which is also statistically significant Our findings (0 45% overall, 0 72% for CI, and 0 85% for LE) are comparable in magnitudes with previous results in the literature Furthermore, we explored the impacts of NPD-related decisions (technology choice, product segment) on the market value, which have not been done previously

2.5.2 Cross-sectional Regression Results

To examine the factors that could influence the magnitude and direction of the abnormal returns associated with green vehicle innovation announcements, we regressed CAR on the variables in question Eight observations were dropped due to missing data for the variables Table 5 presents the results

Table 5: Results of Cross-sectional Regression Analysis

Dependent variable $CAR(-1,+1)$

Independent Variables	Main Effects Model (I)	Main Effects Model (II)	Moderating Effects Model
Firm Size	0 0035	0 0017	0 1053
	(0 39)	(0 58)	(0 87)
Profitability	-0 1806**	-0 2585**	-0 1440
	(-2 25)	(-2 33)	(-1 13)
Oil Price	0 4606**	0 0450*	-0 0009
	(2 25)	(1 69)	(-0 03)
Leverage	−0 0025***	−0 0032**	-0 0012
	(-2 66)	(-2 49)	(-0 77)
Technology		-0 0087	-0 1143*
		(-1 28)	(-1 70)
Technology Firm Size			-0 0070
			(-0 88)
Technology Oil Price			0 1321**
			(2 49)
Product Segment		0 0016	0 0004
		(0 24)	(0 06)
Product Segment Profitability			-0 2514*
			(-1 79)
Product Segment Leverage			-0 0037**
			(-2 18)
Fixed Effect			
No of Categories	14	13	13
F Statistic	0 832	1 112	1 220
No of observations	253	176	176
F Statistic	3 93***	2 22**	2 74***
R^2	0 0944	0 1314	0 2007
Adjusted R^2	0 0289	0 0318	0 0858

t statistics are in parentheses

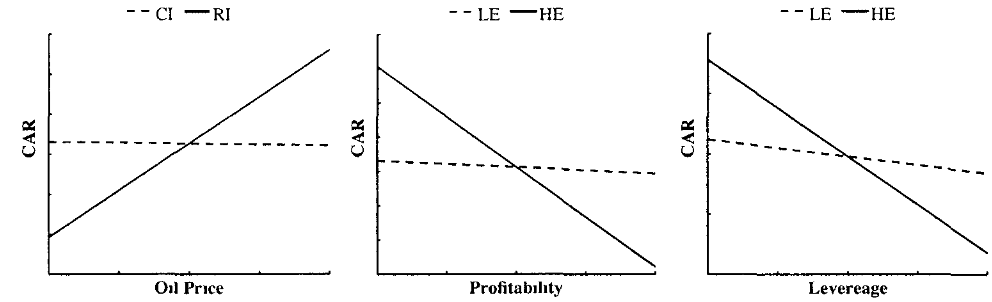
* $p \leq 0$ 1, ** $p \leq 0$ 05, *** $p \leq 0$ 01

The main effects model explains a significant amount of variation in the wealth effects of green vehicle innovation announcements ($Adj.\ R^2 = 0.03, F = 3.93$). The moderating effects model analyzes the interaction effects. The sample size of the moderating effects model (176) is much smaller because some announcements do not fall into either category of Technology Choice (Product Segment). Therefore they are dropped in the analysis. The F statistics of testing the null hypothesis that all the fixed effects (unobservable firm effects) are zero in both models are only 0 832 and 1 220, respectively. It proves that the firm effects are insignificant in explaining differences in CAR.

The results of the main effects model suggest both automakers' profitability and leverage are negatively related to the abnormal returns of green vehicle innovation announcements. Oil price, on the other hand, has a significant positive relationship with the value creation. Therefore, our Hypothesis 6 to 8 are supported. Contrary to previous findings, we don't find any significant relationship between firm size and the abnormal returns, although Fama and French (1992), Chaney et al. (1991) and others all document that smaller firms might benefit more from innovation related announcements. Also, the frequency of announcements is found to be not significant, which is different from the conclusions drawn by previous research that both negative and positive relationship exist (Chaney et al. 1991 and Kelm et al. 1995).

The results from the moderating effects model show that technology choice significantly moderates the relationship between oil price and abnormal returns ($p \leq 0.05$), product segment significantly moderates the relationship between value creation and two predictors: profitability ($p \leq 0.1$) and leverage ($p \leq 0.05$). More specifically, the moderating effect between technology and oil price, with its positive sign, indicates that the stock markets respond more positively to RI-based innovation announcements when oil price is expected to rise. Similarly, with both negative signs, the moderating effects between product segment and profitability as well as leverage suggest that investors react more positively to HE-based innovation announcements made by less profitable and less leveraged automakers. Figure 3 gives a visual illustration of these moderating effects.

Figure 3 Moderating Effects of Technology and Product Segment



2.5.3 Sensitivity Analysis

We checked the robustness of the results of our analysis Two scenarios to which our findings are potentially sensitive are identified and considered as follows

Year Effect. We have observed that, in certain years, sentiments towards tackling climate change among public and politicians were stronger than that in other years At the same time, car manufacturers may be more or less inclined to announce new initiatives based on such external factors Therefore equity markets might react differently to green vehicle announcements in those years and then the so-called "year effect" could play a role in explaining abnormal returns We utilize the fixed-effects model to examine whether year effect exists and how it affects our findings Table 6 presents the results

The results show that the year effect does not exist as the year dummy variables prove to be insignificant in explaining differences in CAR in both models (F statistics are 0 673 and 0 588, respectively) Meanwhile, our previous findings remain the same

Financial Crisis Effect. The study covers the period when the financial crisis hit the global economy and equity markets collapsed worldwide Take Dow Jones Industrial Average for example, the Index went into turmoil after reaching

Table 6: Year Effect Analysis

Dependent variable $CAR(-1,+1)$

Independent Variables	Main Effects Model (I)	Main Effects Model (II)	Moderating Effects Model
Firm Size	0 0044	0 0061	0 0070
	(1 34)	(1 20)	(1 08)
Profitability	-0 0921*	-0 1200	-0 0187
	(-1 66)	(-1 47)	(-0 17)
Oil Price	0 0429*	0 0317	-0 0223
	(1 96)	(1 09)	-0 59
Leverage	-0 0022***	-0 0024**	-0 0004
	(-3 00)	(-2 34)	-0 31
Technology		-0 0051	-0 0060
		(-0 76)	(-0 88)
Technology Firm Size			-0 0052
			(-0 68)
Technology Oil Price			0 1414**
			(2 51)
Product Segment		0 0030	0 0015
		(0 46)	(0 22)
Product Segment Profitability			-0 2915**
			(-2 04)
Product Segment Leverage			-0 0036**
			(-2 15)
Fixed Effect			
No of Categories	14	14	14
F Statistic	0 673	0 463	0 588
No of observations	253	176	176
F Statistic	3 13**	1 27	2 13**
R^2	0 0867	0 0926	0 1655
Adjusted R^2	0 0207	-0 0179	0 0392

t statistics are in parentheses

* $p \leq 0$ 1, ** $p \leq 0$ 05, *** $p \leq 0$ 01

a historical high in October 2007 and tumbled throughout 2008. In the mean time, oil price increased at an accelerating pace until peaked in June 2008, and then suddenly dropped until the year end of 2008. Neither equity market nor oil market seemed to behave rationally during the period. Therefore, it would be interesting to investigate how it affects our results.

To examine the financial crisis effect, we excluded announcements in a 12-month period (November 2007 to October 2008) from the original data set and re-ran the analysis The time frame is chosen such that it is long enough to cover major chaos in both equity and crude oil markets, but also short enough to not lose too many observations. In total, 57 announcements were dropped. It turns out that CAR of green vehicle announcements excluding the above mentioned period is still positive (43 bps) and significant (T statistic: 1.78). Then we ran the cross-sectional regression analysis on the smaller data set and the results are presented in Table 7.

Table 7: Results of Cross-sectional Regression Analysis Excluding Financial Crisis

Dependent variable $CAR(-1,+1)$

Independent Variables	Main Effects Model (I)	Main Effects Model (II)	Moderating Effects Model
Firm Size	0 0050	0 0039	0 0064
	(0 48)	(0 30)	(0 51)
Profitability	-0 1800**	-0 2395***	-0 0774
	(-2 07)	(-2 02)	(-0 55)
Oil Price	0 0613***	0 0753***	0 0522
	(2 74)	(2 57)	(1 36)
Leverage	-0 0022**	-0 0024*	-0 0003
	(-2 31)	(-1 85)	(-0.8)
Technology		-0 0029	-0 0086
		(-0 38)	(-1 11)
Technology Firm Size			-0 0061
			(-0 77)
Technology Oil Price			0 0766
			(1 32)
Product Segment		-0 0007	0 0015
		(-0 10)	(0 21)
Product Segment Profitability			-0 3417**
			(-2 03)
Product Segment Leverage			-0 0040**
			(-2 29)
Fixed Effect			
No of Categories	14	13	13
F Statistic	0 562	0 983	0 937
No of observations	197	139	139
F Statistic	3 59***	1 92*	2 26**
R^2	0 1108	0 1610	0 2304
Adjusted R^2	0 0263	0 0352	0 0845

t statistics are in parentheses.
$^{*}\ p \leq 0\ 1$, $^{**}\ p \leq 0\ 05$, $^{***}\ p \leq 0\ 01$

The factors that have direct impact on CAR are still significant and retain the same signs after we take the financial crisis effect into account, such as profitability, oil price and leverage. For this trimmed data set, product segment remains to be a significant moderator of the relationships between CAR and profitability as well as leverage, shown in the moderating effects model. However, the moderating effect between technology and oil price became insignificant (T statistic: 1.32).

This result suggests that the moderating effect between technology and oil price might be driven by the financial crisis when the oil price was believed to change more dramatically than usual. During the time, the marginal benefit of having greener technology to help save on gas is so significant that it could explain the excessive returns, and this effect may be weaker during normal times. Nonetheless, the relationship between the abnormal returns and oil prices stays significant in both cases.

2.5.4 Discussion of Results

The results of our analysis help answer the previously raised research questions. As expected, in general, investors positively embrace the idea of green vehicle innovations with a significant 0.45% increase in market value. This is encouraging news for the automobile industry to carry on the development of green vehicles, especially at a moment when market demand for green vehicles does not have a material positive impact on the automakers' economy yet (the global market share of EVs was less than 2% in 2008). To a large extent, it suggests that strategic initiatives of solving environmental problems through "greener products" could positively influence investors' valuation of the companies. To the best of our knowledge, this is the first research that documents the financially positive impact of green products.

When investors evaluate green vehicle innovations, the results suggest that the automaker's fundamentals and financial health matter a great deal. Seemingly surprising, the stock market responds more positively to the announcements made by less profitable automakers. We argue that investors expect automakers who are doing well with existing business to concentrate on their existing business and less profitable automakers to find a competitive edge through green vehicle innovations This might be the case especially in the early days of green vehicles when Toyota first announced its plan of Prius in the late 90s, investors cast a great deal of doubt on it and suggested the automaker not to deviate from its core business Further, the value creation is also higher for firms who are financially healthier, that is, less leveraged Since green vehicle innovations require huge upfront investment and the product development cycle usually takes up to 6 or 7 years in the automobile industry, investors might appreciate more if the automakers are financially capable and less vulnerable to make such a commitment

Another influential factor is the oil price, which is always taken for granted as the most important economic variable for the massive adoption of EVs among industry insiders but never verified (Lache et al 2008) Our results indicate that the wealth effects are positively related to oil prices indeed When oil prices are expected to rise, investors might respond to the green vehicle innovations more positively The simple implication for managers in the automobile industry is the timing to announce green vehicle innovations Our data shows that managers actually did it right in 2008 when oil prices rose up to an all time high of \$147/barrel, global automakers made totally 64 green vehicle innovation announcements, which is significantly more than any other years (the second highest is 36 announcements in 2007)

Previous studies (Chaney et al 1991, Kelm et al 1995, etc) examine the overall wealth effects of corporate strategic decisions of introducing new products or conducting innovations etc , while this paper goes deeper to investigate both the direct and indirect implications of NPD decisions involved We find that although automakers' choices of technology/product segment do not directly affect the market values, they play an implicit role in value creation The results are interesting and informative from the following perspectives. First, the evidence that investors do not directly differentiate between CI(LE) and RI(HE)-based innovation announcements shows the difficulty in truly understanding product development and strategies of applying green technology and also illustrates the uncertainties in the outlook of green vehicle market. However, it doesn't mean this information is worthless; on the contrary, both technology and product segment choices carry great value as long as investors put them into specific context. For example, RI-based innovation might contribute more to market value when oil price is expected to rise; less profitable automakers might receive better market response if working on HE-oriented green vehicle projects; HE-oriented projects could also help financially healthier automakers create more value in the stock market. These empirical evidences put financial labels on trade-offs that automakers have to make, therefore help them gain more insights and make better decisions.

2.6 Conclusion

We study the global green vehicle development and innovation in the past 15 years using the event study methodology. Different from previous research, we are interested in not only the overall wealth effects of these development/innovation events, but also the explicit and implicit implications of specific NPD related decisions, such as technology choice and product segment choice.

Our results indicate that these decisions are actually read carefully by investors so that they affect the value creation of the events in a sophisticated manner. In other words, there doesn't exist a one-size-fits-all winning strategy when it comes to green vehicle development. Choosing conservative (or aggressive) technology is not always optimal for everybody at any situation. Neither is focusing on high-end segment (or low-end). This may sound obvious but actually states the essence and complexity of developing green vehicles. Although the technology itself is already complex enough, the automakers need to be more careful when deciding which technology to use and which product segment to put the technology onto. Both internal corporate factors (profitability and leverage) and external economic environment (oil price) should be taken into account. Furthermore, NPD decisions, coupled with the above factors, are found to be able to explain the value creation of green vehicle development and innovation for shareholders.

We acknowledge that there is more work to do to truly understand what are the keys to the success of green vehicle development and innovation as the whole idea is still in the stage of infancy. As the development evolves, business researchers/industry practitioners should be able to collect more facts and data to look at the problem from different angles and go deeper. However, we believe this study sheds light on the ongoing effort in green vehicles development by the global automobile industry and builds a solid foundation for future research.

Chapter 3

Hedging Supply Chain Risk through Buyback Contracts with Linear Prices

3.1 Introduction

This paper deals with the problem of hedging supply chain risk under a buyback contract involving a risk-neutral supplier and a risk-averse retailer facing a single-period stochastic demand. Consistent with financial theory, we measure a retailer's downside risk by semi-variance. We design an optimal buyback contract where the buyback price is a function of the retailer's degree of risk aversion. The supply chain can be coordinated when the retailer's risk type is observable and discrimination of buyback price is also allowed. If the retailer's type is unobservable, the supplier can set a menu of buyback contracts as put options where the buyback prices are equivalent to the exercise prices and the retailer acquires the proper put option corresponding to her risk profile. We show how the supplier should compute the option's ask and exercise prices such that the retailer honestly reveals her type and the outcome is a "win-win" situation for both parties while the supply chain's profit is always optimal.

We model the risk of a retailer by its semi-variance. Semi-variance is a special case of "lower partial moments" and was pioneered by Markowitz (1952) as an alternative to variance to measure the risk of returns in equities. The underlying intuition is that variance as a measure of risk penalizes both big positive outcomes as well as undesirably small (or negative) ones. In the finance literature the importance of semi-variance for measuring risk has decreased somewhat as of late — as being evidenced by the complete omission of semi-variance in Markowitz' 2nd edition of his book "Portfolio Selection" Markowitz (1991). The main reason is that the distribution of equity returns are approximately symmetric, in which case variance and semi-variance produce similar outcomes and the additional difficulty in computing semi-variance does not offset its advantages. Semi-variance is still widely used when the distribution is fairly asymmetric: e.g., oil exploration companies prefer the use of semi-variance, as variance would penalize the low-probability event of a gigantic oil find (Hightower et al. 1997).

When the supplier does not know the retailer's type, our set-up becomes a screening game (Cachon and Netessine 2004). We view a buyback contract as a put option—where the buyback price is in effect the put option's exercise price—and where contracts with different buyback prices can be obtained by "buying" a different put option. The option prices are computed such that a retailer will reveal her risk type by choosing contract designed for her to achieve optimal supply chain performance. Hence, a truth-revealing contract will assign *information rent* to certain types of retailers. Such information rent is a cost to the supplier and we investigate the economic dynamics between supplier and retailer under such a mechanism.

This paper contributes to the supply chain management literature by presenting a buyback contract with linear prices when a supplier is risk neutral and a retailer is risk averse. The paper derives the supply chain coordinating contract when the risk type is observable or unobservable and we characterize the properties of such contracts. Our computational results demonstrate the value of risk management and the dynamics of economic allocation (such as information rent) under such a hedging mechanism.

The following section contains the pertinent literature and previous results in this area. Section 3.3 formulates our model and assumptions. Section 3.4 derives the optimal contract when a retailer's type is observable, whereas section 3.5 describes the optimal contract when types are unobservable. Section 3.6 displays computational results and section 3.7 concludes.

3.2 Literature Review

There is an extensive literature studying the coordination of the supply chain through contracts in both risk-neutral and risk-averse cases. Cachon (2003) gives a comprehensive review of recent literature about coordinating supply chain involving risk-neutral agents through contracts. He defines a supply chain as being coordinated if the set of supply chain optimal actions is a Nash equilibrium and each firm's objective is aligned with the supply chain's objective. Krishnan et al. (2004) considers using a buy back contract to coordinate the supply chain when a retailer could make inventory decisions ex ante and promotional efforts ex post. However, when a supply chain consists of one or more risk-averse agents, it is known that standard buyback contracts and revenue-sharing contracts no longer coordinate the supply chain and that a risk-averse retailer's optimal order quantity will be lower than the one for a risk-neutral agent (see, e.g., Gan et al. 2005). Agrawal and Seshadri (2000b) show optimal order quantity decreases with increasing risk aversion.

Although there is consensus that "risk" should be related to the uncertainty of outcomes, there is no universal consensus on how it should be measured. Risk measures generally seem to fall into one of two categories. In the first category, risk is a function of the *variability* of returns, and two common measures in this category are variance and mean absolute deviation. Another set of risk measures define risk as to be only concerned with *outcomes below a target*, the lower partial moments as defined by Markowitz (1952) belong to this class of risk measures. The supply chain literature with risk-averse agents has used both measures of risk.

Chen and Federgruen (2000) take a mean-variance approach to analyze some basic inventory models and demonstrate a way of conducting a systematic mean-variance trade-off analysis. They also show how the strategies under risk aversion differ from those derived in the standard, risk-neutral cases. Agrawal and Seshadri (2000b) show that in a supply chain with multiple risk-averse retailers, a risk-neutral (or less risk-averse) intermediary can help increase retailer's order quantity to the expected value maximizing quantity by offering a menu of mutually beneficial contracts that could induce every retailer to select an exclusive contract and maximize the intermediary's profit simultaneously. They use variance to measure risk, justified by the fact that variance appears in a second order Taylor expansion of a general utility function. Tsay (2002) studies the impact of risk aversion on both supplier and retailer in a partnership and show how a return policy can manage the effects and also finds that risk-averse agents behave fairly different from those in risk-neutral case—using variance as the measure of risk—and the penalty for neglecting an agent's risk aversion could be substantial.

Gan et al. (2005) design a new risk-sharing contract to provide downside risk protection so as to coordinate a supply chain with a risk-neutral supplier and a downside risk-averse retailer, whose risk is measured by the zero-th partial moment Their setup is similar to ours, however their contract involves non-linear pricing not only are the wholesale and buyback prices adjusted, but the contract requires the supplier to use quantity adjustments (in the form of quantity rationing and discounts) as well Deng and Yano (2005) study how different contracts ought to be modified to improve the supply chain performance and induce truth telling Similar to Gan et al (2005) the risk measure used is zero-th partial moment

Gan et al (2004) define the coordination of a supply chain with risk-averse agents and examine how to construct contracts to coordinate a supply chain They consider three modeling paradigms the first two include risk as measured by respective zero-th partial moment and variance and the third model assuming general concave utility functions Fishburn (1977) derives a congruence between risk as related to below-target returns and expected utility theory More specifically, if an agent's target outcome is τ, and the set of outcomes x is distributed as $F(x)$, then a model using a measure of risk as defined by

$$\int_{-\infty}^{\tau} (\tau - x)^{\kappa} dF(x)$$

is congruent with using a model using a von Neumann–Morgenstern expected utility model with utility function $u(\,)$ as follows

$$u(x) = \begin{cases} x & \text{for } x \geq \tau \\ x - \alpha(\tau - x)^{\kappa} & \text{for } x < \tau \end{cases}$$

The parameter κ is the order of the lower partial moment and the α measures the local degree of risk aversion When $\kappa = 2$ and $\tau = \mathbb{E}[x]$, the lower partial moment becomes the semi-variance proposed by Markowitz (1952) Harlow (1991) and Fishburn (1977) note that $\kappa < 1$ can be used for modeling risk-seeking behavior, whereas functions with $\kappa > 1$ are appropriate for risk-averse agents. Criticisms against using variance as a measure of risk have been reported in numerous works and it is outside the scope of this paper to give an overview of such. Semi-variance and variance yield the same outcomes only in the case of symmetric distributions. Despite being less tractable than variance, we have chosen to use semi-variance as a measure of risk in our paper since in our opinion its advantages outweigh its disadvantages.

We view a buyback contract as a put option, i.e., it gives the retailer the right to sell his goods to the supplier at the preset buyback price. The use of "options" in the supply chain literature is not new. Donohue (2006) presents a model with uncertain demand where the retailer can "reserve" manufacturing capacity at a certain price. Barnes-Shuster et al. (2001) shows how in a two-period model with correlated demand, option prices should be calculated to obtain a coordinated supply chain. Although related to our work, the "options" in those papers are call options: they give the right to the retailer to purchase goods at a preset price. Similar to our work, Chen and Parlar (2007) use put options to mitigate a newsvendor's risk.

3.3 Model Formulation

A risk-neutral supplier intends to use a buyback contract to coordinate a supply chain with a retailer. The product has one selling season only (such as a fashion good or a good with very short life cycle) and demand D is stochastic with distribution function $G(\cdot)$. To simplify further analysis we assume that $G(\cdot)$ is continuous. The supplier's unit product cost is c and he sells to the retailer at the wholesale price w. The retailer orders q units up front and sells each in the market for a retailing price p. If there are any leftovers at the end of the selling season, she can sell them back to the supplier at a unit buyback price b. We assume that c and p are exogenously given and we assume $p > w > c$ and $b < w$. We assume that the supplier is risk-neutral and that he maximizes the supply chain's expected profit. When the retailer's reservation utility is independent of the supply chain's profit, we follow Tirole (1997) who shows that maximizing the supplier's profit is equivalent to maximizing the expected profit of the total supply chain. That is, if the retailer's minimum share of the profit consists of a fixed slice of the total "profit pie," then maximizing the size of the pie yields the maximum profit for the supplier. Hence, the optimal supply chain quantity q^c is given by the familiar formula $q^c = G^{-1}(\frac{p-c}{p})$. It is known that a risk-neutral retailer will order the supply chain's optimal order quantity q^c as long as the supplier sets w and b such that $\frac{p-w}{p-b} = \frac{p-c}{p}$ (Pasternack 1985). As can be seen below, this is no longer the case when the retailer is risk averse.

3.3.1 Profit Allocation

Under a buyback contract, the retailer's profit is $R(q, D) = p\min(q, D) + b \times (q - D)^+ - wq$. Then, the distribution of her profit is

$$F(R) = \text{Prob}(R(q, D) \leq u) = \begin{cases} 1, & \text{if } u \geq (p-w)q, \\ G(\frac{u+(w-b)q}{p-b}), & \text{if } -(w-b)q \leq u < (p-w)q, \\ 0, & \text{if } u < -(w-b)q \end{cases} \tag{9}$$

Then expected profit for the retailer becomes

$$\Pi(q) \stackrel{\text{def}}{=} \mathbb{E}_D R(q, D) = (p-w)q - (p-b)\int_0^q G(x)\, dx \tag{10}$$

Likewise, the supplier's expected profit is (here as well as in the rest of the paper, we use boldface for the supplier):

$$\mathbf{\Pi}(q) = (w - c)q - b\int_0^q G(x)\,dx. \tag{11}$$

3.3.2 Risk Aversion

The retailer is risk-averse with respect to the uncertainty of her profit. She measures risk using semi-variance, defined as $S = \mathbb{E}[\min(0, R - \tau)^2]$ where $\tau = \mathbb{E}(R)$. With expected profit $\Pi(q)$ as target the semi-variance then becomes:

$$S(q) \stackrel{\text{def}}{=} \int_{-\infty}^{\Pi(q)} (\Pi(q) - R)^2\, dF(R)$$

and, using integration by parts, we obtain:

$$S(q) = 2\int_{-\infty}^{\Pi(q)} (\Pi(q) - R)\, F(R)\, dR \tag{12}$$

Following Fishburn (1977) using semi-variance as a measure of risk is congruent with the expected mean-semi-variance utility function:

$$U(q) = \Pi(q) - \alpha S(q). \tag{13}$$

The constant $\alpha \geq 0$ is the retailer's degree of risk aversion, which stands for her inherent attitude towards profit uncertainty. The larger the value of α, the more risk averse the retailer is, while $\alpha = 0$ represents the special case where the agent is risk neutral.

An alternative to using a utility function is to impose a risk constraint for the retailer, $S(q) \leq \bar{S}$ where $\bar{S}$ is the maximum risk level that the retailer is willing to tolerate. However, it does not seem realistic that such a risk constraint is an accurate representation of an economic agent's choice: it implies that a retailer would always prefer a quantity q_1 over q_2 when $S(q_1) \leq \bar{S}$ and $S(q_2) = \bar{S} + \varepsilon$ and $\Pi(q_1) + M \leq \Pi(q_2)$ even when $\varepsilon \to 0$ and $M \to \infty$.

3.4 Contract Design

The supplier's objective is to maximize the expected profit of the supply chain by offering an appropriately designed buyback contract (w, b). It has been observed that maximizing the expected profit of the supply chain is also in the supplier's best interest, the wholesale price w then plays the role of allocating the profit to the different parties. This usually depends on the bargaining power of the supplier versus the retailer, and we capture this by the retailer's reservation utility. Hence it is known (Pasternack 1985) that the supply chain's optimal order quantity is given by $q^c = G^{-1}(\frac{p-c}{p})$. Unless noted otherwise, we assume that the demand distribution is common knowledge within the supply chain. So, the supplier's problem is to find the right pair of a wholesale price w and a buyback price b such that the retailer's expected utility maximizing order quantity is q^c. However, the retailer's expected-utility-maximizing order quantity depends not only on the contract terms (such as w, b), but also on her own attitude towards risk (α in our model). Hence, as we will show shortly, whether the supplier knows the retailer's degree of risk aversion and the risk-aversion-related information (such as the retailer's reservation utility) makes a difference in deciding the optimal buyback contract. In the following, we use the term "type" to mean the retailer's degree of risk aversion. Therefore we have to distinguish between two cases: in the first scenario we assume the retailer's type is "observable" and in the second scenario we assume the retailer's type to be "unobservable," i.e., it is part of the retailer's private information. First we study the situation where the retailer's type is observable. Next, we discuss the problems when using this contract in a situation where types are unobservable and then present a contract specifically designed for the latter case.

3.4.1 Retailer's Type Observable

We study how the supplier designs the contract under the assumption that he knows the retailer's type. Given a buyback contract, the retailer makes a decision of q to maximize her expected utility, which is described as

$$\max_{q\geq 0} \quad U(q; w, b), \tag{14}$$

$$\text{s.t.} \quad U(q) \geq \underline{\text{U}}(\alpha). \tag{15}$$

The expression of U is given by (13) and $\underline{\text{U}}(\alpha)$ is the retailer α's reservation utility. (15) is her individual rationality (IR) constraint which says that the retailer enters the contract if and only if she can gain at least her reservation utility. This reservation utility can be interpreted as the availability of an outside alternative for the retailer, e.g., the existence of another supplier or other opportunity. It can be easily shown that the utility function $U(q; w, b)$ is strictly concave and hence has a unique maximum. Through solving this optimization problem, the retailer finds that her expected-utility-maximizing order quantity q^* has to satisfy

$$(p-w)-(p-b)G(q^*)-2\alpha(p-b)[1-G(q^*)]\int_{-\infty}^{\Pi(q^*)} F(R)\,dR = 0.\text{[1]} \tag{16}$$

The first two terms represent the change in expected profit as the order quantity increases, whereas the last term expresses the change in risk as the order quantity increases. In other words, the retailer orders the quantity q^* where the marginal expected profit equals the marginal risk. From the above equation, we see that q^* is determined by the buyback price b, the wholesale price w, the retail price p, the retailer's risk aversion α and the distribution of demand $G(\cdot)$, or formally: $q^*(b, w, p, \alpha, G)$.

[1] All mathematical derivations are provided in the Appendix.

Since the equation (16) will be used frequently in the remainder, it is useful to define the function:

$$
\begin{aligned}
\Gamma(q, w, b, \alpha) &\stackrel{\text{def}}{=} \frac{\partial U(q; w, b)}{\partial q} \\
&= (p - w) - (p - b)G(q) \\
&\quad -2\alpha(p - b)[1 - G(q)] \int_{-\infty}^{\Pi(q)} F(R)\, dR
\end{aligned}
\tag{17}
$$

We could not find a closed-form solution for q^* from condition (16), but the function Γ can be used by a software package such as Maple or Mathematica to obtain numerical solutions for q^*. The condition $\Gamma(q^*, w, b, \alpha) = 0$ conveys the relationship of a retailer's expected-utility-maximizing order quantity q^* as a function of her type α and the buyback contract (w, b) she faces. Thus, in order to coordinate the supply chain, the supplier will set up the contract (w^c_α, b^c_α) such that the retailer's q^* is equal to q^c, i.e., such that $\Gamma(q^c, w^c_\alpha, b^c_\alpha, \alpha) = 0$. Because we have only one equation with two unknowns, there are an infinite number of pairs (w^c_α, b^c_α) which satisfy the equation, each yielding a different utility. Without closed-form solution, we can still prove the following properties for the coordinating contracts.

Lemma 1: *Let the pairs (w^c_α, b^c_α) be coordinating contracts, i.e., $\Gamma(q^c, w^c_\alpha, b^c_\alpha, \alpha) = 0$ Then, for such coordinating buyback contracts, we have:*

(i) The change of the wholesale price w^c_α with respect to the buyback price b^c_α is positive as $\frac{\mathrm{d}w^c_\alpha}{\mathrm{d}b^c_\alpha} > 0$;

(ii) Let $(w^c_\alpha(U_0), b^c_\alpha(U_0))$ be the buyback contract that yields the retailer a utility of U_0. For the retailers of type $\alpha \leq \bar{\alpha} \stackrel{def}{=} \frac{\Pi(q^c, \alpha, w^c_\alpha(U_0), b^c_\alpha(U_0))}{2S(\alpha, w^c_\alpha(U_0), b^c_\alpha(U_0))}$ we have the following:

- $\frac{\mathrm{d}w^c_\alpha(U_0)}{\mathrm{d}U_0} < 0$; *and*
- $\frac{\mathrm{d}b^c_\alpha(U_0)}{\mathrm{d}U_0} < 0$

The first part generalizes the result from Pasternack (1985): there may be an infinite number of pairs (w_α^c, b_α^c) that coordinate the supply chain, and a higher w_α^c is paired with a higher b_α^c in the optimal contract. Higher values of (w_α^c, b_α^c) correspond to higher profits for the supplier, and the second part of the result shows that the retailer's utility goes down for higher values of (w_α^c, b_α^c). That is, when $\underline{\mathrm{U}}(\alpha)$ is relatively low, the supplier will offer a contract with high values for (w_α^c, b_α^c), in case $\underline{\mathrm{U}}(\alpha)$ is high, a contract with a lower (w_α^c, b_α^c) will be offered. The monotonicity of $U(\cdot)$ with respect to b is only guaranteed where the value of α is not extraordinarily high; the condition on α in part (ii) of the lemma states that the risk premium for a retailer should not exceed more than half its profit. It is easy to see that for extremely risk averse retailers, a coordinating contract with positive supplier profits may not exist.

Theorem 1: *The optimal buyback contract for retailers of type $\alpha \in [0, \bar{\alpha}]$ that coordinates the supply chain (w_α^c, b_α^c) always exists when $\underline{\mathrm{U}}(\alpha) = 0$ and is unique. When $\underline{\mathrm{U}}(\alpha) > 0$, coordinating contract exists if and only if there is a solution to the following equations:*

$$\Gamma(q^c, w_\alpha^c, b_\alpha^c, \alpha) = 0, \tag{18}$$

$$U(q^c; w_\alpha^c, b_\alpha^c) = \underline{\mathrm{U}}(\alpha). \tag{19}$$

Among all contracts (w_α^c, b_α^c) that coordinate the supply chain, the contract that maximizes the supplier's expected profit is $(w_\alpha^*, b_\alpha^*) = \max\{(w_\alpha^c, b_\alpha^c)\}$.

In case the retailer's type is observable, it is easy to see that the IR constraint (15) binds at the optimal solution. That is, the supplier is able to extract all the surplus by giving the appropriate w_α^c and b_α^c such that the retailer only makes as much as her reservation utility.

Thus, in the supply chain where there exist a number of independent retailers, if the supplier is able to identify each retailer's real type α, he can suitably offer a coordinating buyback contract (w_α^c, b_α^c) based on Theorem 1. However, this approach makes practical sense only when, in addition to the observability of the retailer's type, we assume that the discrimination of buyback contracts with regard to the retailer's types permitted under the law.

3.4.2 Retailer's Type Unobservable

When the retailer's type is not observable the approach described above may no longer result in an optimal supply chain, and may be detrimental to the supplier. We demonstrate this by means of a simple example. Suppose there are two retailer types, α_1 and α_2, with $\alpha_1 < \alpha_2$. For ease of exposition, assume that both have the same reservation utility, i.e., $\underline{U}(\alpha_1) = \underline{U}(\alpha_2)$ and the supplier designs two contracts $(w_{\alpha_1}, b_{\alpha_1})$ and $(w_{\alpha_2}, b_{\alpha_2})$ accordingly. So, we have

$$\Pi(q^c; w_{\alpha_1}^c, b_{\alpha_1}^c) - \alpha_1 S(q^c; w_{\alpha_1}^c, b_{\alpha_1}^c) = \Pi(q^c; w_{\alpha_2}, b_{\alpha_2}) - \alpha_2 S(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c).$$

Now, if α_1 enters the contract $(w_{\alpha_2}^c, b_{\alpha_2}^c)$ and orders q^c, her expected utility will be $\Pi(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c) - \alpha_1 S(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c)$. Since $\alpha_1 < \alpha_2$, we now have:

$$\begin{aligned}\Pi(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c) - \alpha_1 S(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c) &> \Pi(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c) - \alpha_2 S(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c) \\ &= \Pi(q^c; w_{\alpha_1}^c, b_{\alpha_1}^c) - \alpha_1 S(q^c; w_{\alpha_1}^c, b_{\alpha_1}^c).\end{aligned}$$

This means that α_1 finds it beneficial to enter the contract for α_2 by simply ordering q^c. [2] More generally, the following result follows.

Proposition 1: *A retailer's optimal order quantity $q^*(b_{\alpha_2}^c, w_{\alpha_2}^c, p, \alpha_1, G)$ may differ from the optimal supply chain coordinating order quantity q^c when she enters buyback contracts for other types.*

[2] Note, however, that there may exist a quantity $q^* \neq q^c$ that maximizes her expected utility and yields a utility over $\Pi(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c) - \alpha_1 S(q^c; w_{\alpha_2}^c, b_{\alpha_2}^c)$.

As has been discussed, the retailer's order quantity q^* equals q^c only when she enters the buyback contract designed for her type. However, by Proposition 1, $q^* = q^c$ is no longer guaranteed when entering a buyback contract designed for another type. Since we assume that the retailer's type α is unobservable, it seems intuitive that the retailer will strategically lie about her type to obtain a buyback contract that makes her better off than the contract specifically dedicated to her type α. The following theorem derives the retailer's optimal strategy when she can freely enter a contract for any type. We derive the retailer's *marginal expected utility* with respect to the buyback price, which we write as $U_b(q^*; w, b, \alpha)$.

Theorem 2: *Let (w^c_α, b^c_α) be the contract designed for a retailer of type α, according to Theorem 1. The retailer's marginal expected utility with respect to buyback price is:*

$$U_b(q^*; w, b, \alpha) \stackrel{def}{=} \frac{\mathrm{d}U(q^*; w, b, \alpha)}{\mathrm{d}b} = -q^* \frac{\mathrm{d}w}{\mathrm{d}b} + \frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\, dx. \qquad (20)$$

and hence a type-α retailer will enter a contract $(w^c_{\alpha'}, b^c_{\alpha'})$ designed for type α' where

(i) $b^c_{\alpha'} > b^c_\alpha$ whenever $\frac{\mathrm{d}w}{\mathrm{d}b} < \frac{\frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\, dx}{q^*}$; and

(ii) $b^c_{\alpha'} < b^c_\alpha$ whenever $\frac{\mathrm{d}w}{\mathrm{d}b} > \frac{\frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\, dx}{q^*}$.

Whenever the retailer chooses a contract $(w^c_{\alpha'}, b^c_{\alpha'}) \neq (w^c_\alpha, b^c_\alpha)$, there is no guarantee that the supply chain remains coordinated. The result of the theorem hinges upon the function $\frac{\mathrm{d}w}{\mathrm{d}b}$ which measures how the wholesale price changes with the buyback price. This function is determined by how the retailer's reservation utility changes with respect to α. Therefore, when the supplier is not able to identify the retailer's type α, the retailer's best strategy is to pretend being more risk-averse or less risk-averse. Economically speaking, the agent (retailer) who has private information possesses a potential strategic advantage in dealing with the other agent (supplier) who does not, which exactly happens in our problem: the retailer can capture some surplus from the supplier by using the superior knowledge of her type. When the retailer enters a contract designed for another type, there is no guarantee that the supply chain is coordinated. From the supplier's perspective, the information of the retailer's type disclosed by herself is no longer credible under the current contract scheme.

The proposition below characterizes the change in retailer's utility as a function of her type. The second part shows how a retailer's marginal utility changes with type, i.e., it shows that the Spence-Mirrlees condition is satisfied in our setup.

Proposition 2: *Under a buyback contract, the retailer's optimal expected utility decreases with her degree of risk aversion since*

$$\frac{\mathrm{d}U(q^*; w, b, \alpha)}{\mathrm{d}\alpha} = -S(q^*) < 0. \tag{21}$$

But the retailer's marginal optimal expected utility with respect to buyback price increases with her degree of risk aversion since

$$\frac{\mathrm{d}U_b(q^*, w, b, \alpha)}{\mathrm{d}\alpha} = \frac{2S(q^*)}{p-b} > 0. \tag{22}$$

Before we present our linear price option buyback contract, we note that there is a rather straight-forward way to design contracts where the retailer orders the optimal supply chain quantity q^c by using non-linear prices. That is, a retailer can be dissuaded from ordering a quantity over q^c, e.g. by refusing any returns for the units ordered above q^c. Likewise, the supplier can offer incentives to make the retailer order up to q^c units, e.g., by offering a buyback price equal to the wholesale price, as is done in Gan et al. (2005); or by giving quantity discounts up to q^c. An extreme example of such non-linear contract is a take-it-or-leave-it contract, where the supplier only sells a batch consisting of exactly q^c units. Using standard economic arguments from second degree price discrimination (see, e.g., Tirole 1997), this contract can be designed such that the retailer will reveal her true type. An example with just two types of retailers will clarify.

Let there be two types of retailers α_1 and α_2, $\alpha_1 < \alpha_2$, with reservation utilities $\underline{U}(\alpha_1)$ and $\underline{U}(\alpha_2)$. Suppose the supplier creates two contracts with buyback prices b_1 and b_2 with $b_1 < b_2$, and contract j is designed for retailer α_j. We use the shorthand notation $U_{\alpha_j}(b_i)$, $i, j = 1, 2$ to refer to retailer's α_j's utility derived from the contract b_i. Then, the problem for the supplier becomes to compute the respective prices for the contracts, which we call W_1 and W_2. The standard model in second degree price discrimination then sets up the problem consisting of the *individual rationality constraints*

$$U_{\alpha_j}(b_j) - W_j \geq \underline{U}(\alpha_j) \tag{23}$$

for $j = 1, 2$ together with the *incentive compatibility constraints*:

$$U_{\alpha_1}(b_1) - W_1 \geq U_{\alpha_1}(b_2) - W_2 \tag{24}$$

$$U_{\alpha_2}(b_2) - W_2 \geq U_{\alpha_2}(b_1) - W_1 \tag{25}$$

The standard result from economics will apply: one retailer gets *information rent* whereas the other does not.

We did not pursue this type of contract with non-linear prices for the following reasons. Non-linear price contracts such as these give the retailer very little incentive to order a quantity other than q^c. In other words, such contracts are highly sensitive to the supplier's knowledge of the demand distribution to derive the supply chain's optimal order quantity. Pasternack (1985) shows that one of the big advantages of buyback contracts is that the supplier need not know the demand distribution; whenever he sets $\frac{p-w}{p-b} = \frac{p-c}{p}$ the retailer will order the optimal quantity. It is common to assume that the retailer's local knowledge about demand is superior to the supplier's and hence we would like to have a flexible contract where the retailer's order quantity is sensitive to changes in the demand distribution Hence, we stick with linear price contracts and, although the supplier in our contract still needs to have some knowledge about the demand distribution $G(\,)$ to design the contract, the retailer will no longer order $q^c = G^{-1}(\frac{p-c}{p})$ when her knowledge of demand $G'(\,)$ deviates from the supplier's, resulting in higher total supply chain profits

3.5 Option Buyback Contract

Inspired by the fact that the buyback contract is a special put option with zero cost, the supplier could charge the retailer a buyback premium (ask price) for the desired buyback price (exercise price) such that the retailer will optimally choose the buyback contract that maximizes the profit of the supply chain We name this new form of buyback contract the *option buyback contract*, or OB contract in short

Our OB contract shares some properties with the classical buyback contract as in Pasternack (1985) There is no limit on the quantity of goods that can be returned after the selling season is over, and our contract is a linear price contract there are no quantity discounts or premiums As in the scenario where the retailer's type is unobservable, we will design a menu of contracts each with different buyback and wholesale price targeted each to one specific retailer type α The total wholesale price now consists of two components the price to compensate the supplier for the good itself (common to all retailers) plus the "put option" price, i e , the premium paid by a retailer to (partially) offset her risk for receiving a better buyback price We introduce the function $o(b)$ to capture the the option's price to obtain a buyback of value b The retailer then faces a unit cost of $w + o(b)$ which is paid before the selling season starts. As in the financial literature, the retailer who is more risk averse will be willing to pay more (i.e., a higher $o(b)$) to receive a higher buyback price b. Padmanabhan and Png (1997) give some industry examples where such a menu of contracts is offered.

We first present the model under the OB contract, and then show how to compute the menu of the OB contracts. In the end, we demonstrate that the OB contract comes out with a "win-win" outcome for both the supplier and the retailer.

3.5.1 Option Buyback Contract Model

The retailer's profit under the OB contract is $R^{OB}(q, D) = p\min(q, D) + b^{OB} \times (q - D)^+ - (w + o)q$, where b^{OB} denotes the buyback price. Thus the distribution of her profit is

$$
\begin{aligned}
F^{OB}(u) &= \text{Prob}(R^{OB}(q, D) \le u) \qquad (26)\\
&= \begin{cases} 1, & \text{if } u \ge (p - w - o)q; \\ G(\frac{u + (w + o - b^{OB})q}{p - b^{OB}}), & \text{if } -(w + o - b^{OB})q \le u < (p - w - o)q; \\ 0, & \text{if } u < -(w + o - b^{OB})q. \end{cases}
\end{aligned}
$$

The expected profit of the retailer is

$$
\Pi^{OB}(q) = (p - w - o)q - (p - b^{OB}) \int_0^q G(x)\, dx. \qquad (27)
$$

Consistent with the risk measure in subsection 3.3 2, the retailer's downside risk is described as

$$\begin{aligned} S^{OB}(q) &= \int_{-\infty}^{\Pi^{OB}(q)} (\Pi^{OB}(q) - R)^2 \, dF^{OB}(R) \\ &= 2\int_{-\infty}^{\Pi^{OB}(q)} (\Pi^{OB}(q) - R) F^{OB}(R) \, dR \end{aligned} \tag{28}$$

Similarly we can define $\Gamma^{OB}(q, b^{OB}, o, \alpha) = (p - w - o) - (p - b^{OB})G(q) - 2\alpha \times (p - b^{OB})[1 - G(q)] \int_{-\infty}^{\Pi^{OB}(q)} F^{OB}(R) \, dR$ and conclude that $\Gamma^{OB}(q^*, b^{OB}, o, \alpha) = 0$ is the necessary and sufficient condition for the retailer α to maximize her expected utility by ordering q^* under the OB contract (b^{OB}, o).

We suppose the supplier cannot exactly identify the retailer's type α but he knows it follows a certain distribution over $[0, \bar{\alpha}]$. [3] The supplier's objective is to maximize the supply chain's expected profit by offering a menu of OB contracts, from which any retailer α will find a proper (b^{OB}, o) corresponding to her type. Therefore, the supplier's problem is to come up with the menu of OB contracts such that

$$\Gamma^{OB}(q^c, b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i) = 0 \ \forall i, \tag{29}$$

$$U^{OB}(q^c; b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i) > U^{OB}(q^*; b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_i), \ \forall i \neq j, \tag{30}$$

$$U^{OB}(q^c; b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i) \geq \underline{U}(\alpha_i) \ \forall i, \tag{31}$$

Constraint (29) enforces that the retailer's optimal quantity is equal to q^c, the optimal order quantity for the supply chain. Inequality (30) is the incentive compatibility constraint which indicates that the retailer prefers the OB contract designed for her to any others in the menu and (31) is the retailer's IR constraint. Similar to Proposition 2, we obtain the following results for the OB contract

[3] We assume that the lower bound for the risk aversion is the risk neutral retailer All subsequent results will still hold if we were to change the range of types to $[\underline{\alpha}, \bar{alpha}]$ with $\underline{\alpha} > 0$

Proposition 3: *Under an OB contract (o, b^{OB}), the retailer's optimal expected utility decreases with her degree of risk aversion since*

$$\frac{\mathrm{d}U^{OB}(q^*; b^{OB}, o, \alpha)}{\mathrm{d}\alpha} = -S^{OB}(q^*) < 0. \tag{32}$$

Define U_b^{OB} as the retailer's marginal optimal expected utility with respect to buyback price. U_b^{OB} increases with her degree of risk aversion since

$$\frac{\mathrm{d}U_b^{OB}(q^*; b^{OB}, o, \alpha)}{\mathrm{d}\alpha} = \frac{2S^{OB}(q^*)}{p - b^{OB}} > 0. \tag{33}$$

3.5.2 Retailer With Continuum of Types

In this section we study the situation in which the retailer's type is continuously distributed over $[0, \bar{\alpha}]$. We can obtain the conditions for deriving a menu of OB contracts to enforce the coordination constraint (29) and the self-selection constraint (30).

Proposition 4: *In order to ensure the constraints of (29) and (30) binding, the OB contract $(o_{\alpha_i}, b_{\alpha_i}^{OB})$ for the retailer α_i has to satisfy the following condition:*

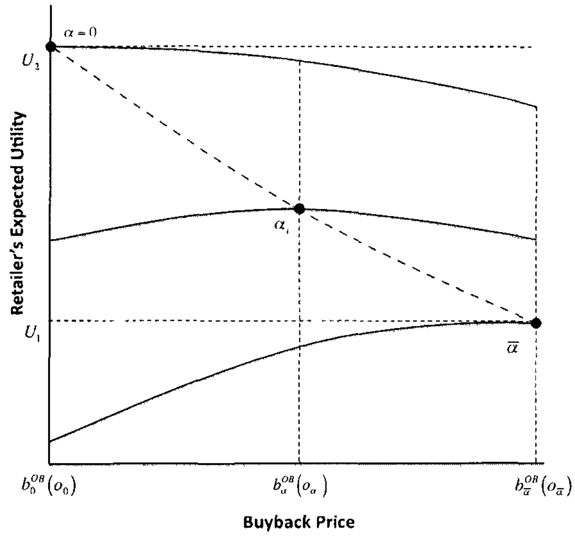
$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b_{\alpha_i}^{OB}, o_{\alpha_i}, \alpha_i)=0} = 0, \ \forall \alpha_i \in [0, \bar{\alpha}]. \tag{34}$$

Thus we can obtain

$$\left.\frac{\mathrm{d}o}{\mathrm{d}b^{OB}}\right|_{(o_{\alpha_i}, b_{\alpha_i}^{OB})} = \frac{\frac{2\alpha_i S^{OB}(q^c)}{p - b_{\alpha_i}^{OB}} + \int_0^{q^c} G(x)\,dx}{q^c}, \ \forall \alpha_i \in [0, \bar{\alpha}]. \tag{35}$$

The derived menu of OB contracts based on Proposition 4 has more properties as follows.

Figure 4: Retailer's optimal utility for different buyback prices



Corollary *In the menu of OB contracts, the buyback price of the contract designed for a more risk-averse retailer is higher than the one for a less risk-averse retailer and so is the option cost as*

$$\alpha_i < \alpha_j \Leftrightarrow (o_{\alpha_i}, b_{\alpha_i}^{OB}) < (o_{\alpha_j}, b_{\alpha_j}^{OB})$$

However, the less risk-averse retailer obtains a higher optimal expected utility as

$$U^{OB}(q^c; b_{\alpha_i}^{OB}, o_{\alpha_i}, \alpha_i) > U^{OB}(q^c; b_{\alpha_j}^{OB}, o_{\alpha_j}, \alpha_j), \ \forall \alpha_i < \alpha_j.$$

Proposition 4 reflects the necessary changes of the option cost and the buyback price to achieve price discrimination as well as the optimization of the supply chain. Corollary 1 focuses on the changes of the OB contract and the corresponding optimal expected utility with respect to the retailer's type α. Based on the above results, the supplier is able to construct a menu of OB contracts. One such menu is represented in figure 4: the three solid lines correspond to the expected utility of three different retailers with different attitude towards risk when they enter the contract with buyback price displayed on the horizontal axis As desired, their expected utility is maximized when they enter the contract designed for her type The curve with the long dashes shows the expected utility when each retailer enters the contract designed for her type From Corollary 1, we know that this function is downward sloping If all retailers have the same reservation utility equal to U_1, this menu of OB contracts satisfies the retailers' individual rationality constraints (31) since all the optimal expected utility of all types is greater than their reservation utility In this example, all retailer types except $\bar{\alpha}$ earn information rent the difference between their expected utility and reservation utility Note that although the slope of the optimal expected utility curve is unique, dictated by equation 34, the location is not That is, we can change, e g , w and move this curve up or down, increasing or decreasing the retailer's utility for the contract It is clear that shifting the curve down will violate $\bar{\alpha}$'s individual rationality constraint and this retailer will not enter the contract Shifting the curve up would give all retailers additional surplus at the expense of the supplier's whose expected profit will suffer Hence, the curve displayed is "optimal" in the sense that the supplier earns the highest expected profit while all retailers participate in the contract and the supply chain's profit is maximized

3.5.3 Individual Rationality and Information Rent

As mentioned before, the slope of the optimal expected utility curve is unique, however its location is not This implies that there exist more than one menu of contracts that maximizes the supply chain's profit, induces the retailer to reveal her type and is individually rational Hence, we can arbitrarily pick $s \in [0, \bar{\alpha}]$, and an arbitrary $w \in (c, p)$ and compute the optimal supply chain coordinating buyback price b_s using the techniques in section 3.4.1. The rest of the menu $(o_{\alpha_i}, b^{OB}_{\alpha_i})$ is then computed as follows.

Theorem 3: *Starting from an arbitrary type $s \in [0, \bar{\alpha}]$ with buyback price b_s, the menu of OB contracts $(o_{\alpha_i}, b^{OB}_{\alpha_i})$ is computed as:*

$$\begin{aligned} o_{\alpha_i} &= \int_{b_s}^{b^{OB}_{\alpha_i}} \frac{\mathrm{d}o}{\mathrm{d}b^{OB}}(r)\, dr, \\ \textit{under } \Gamma^{OB}(q^c, b^{OB}_{\alpha_i}, o_{\alpha_i}. \alpha_i) &= 0, \\ \alpha_i &\in [0, \bar{\alpha}]. \end{aligned} \tag{36}$$

When this menu of contracts satisfies the individual rationality constraints, every retailer will participate in the contract. In the previous example, the OB contracts in the solid lines were computed with $s = \bar{\alpha}$. When the reservation utility is independent of type, i.e., $\underline{\mathrm{U}}(\alpha)$ is constant, it is easy to see that choosing $s = \bar{\alpha}$ always satisfies the individual rationality constraints. For example, if the reservation utility were changed to U_2 and we take $s = 0$, our menu of contracts would be identical, but except for the risk neutral retailer, none of the individual rationality constraints would be satisfied. The following proposition states how the retailer's utility and the supplier's profit are affected by choosing s.

Proposition 5: *The retailer's optimal expected utility increases with respect to the value of s and the change rate increases with the retailer's risk aversion degree α as*

$$\begin{aligned} \frac{\mathrm{d}U^{OB}(q^c; s, \alpha)}{\mathrm{d}s} &> 0, \\ \frac{\mathrm{d}^2U^{OB}(q^c; s, \alpha)}{\mathrm{d}s\mathrm{d}\alpha} &> 0. \end{aligned}$$

The supplier's optimal expected profit decreases with respect to the value of s and the change rate decreases with the retailer's risk aversion degree α as

$$\frac{\mathrm{d}\Pi^{OB}(q^c, s, \alpha)}{\mathrm{d}s} < 0,$$
$$\frac{\mathrm{d}^2\Pi^{OB}(q^c, s, \alpha)}{\mathrm{d}s\mathrm{d}\alpha} < 0$$

Proposition 5 states that increasing s lifts every retailer's optimal expected utility, although the more risk-averse retailer's optimal expected utility goes up faster than the less risk-averse retailer's As a result, the curve of the retailer's optimal expected utility becomes flatter but still remains downward as Corollary 1 indicates Increasing s is at the cost of the supplier his expected profit declines and at an increasing rate

As discussed before, when the reservation utility is constant for all types, the most risk averse retailer does not earn information rent and the less risk averse the retailer, the more information rent she earns The presence of a reservation utility other than zero can be thought of as an outside alternative for the retailer, e g , by stocking another product, or (in the extreme case) by selling her store When the reservation utility is constant over types, this means that the outside alternative is risk-free If the outside alternative is risky, then the reservation utility is no longer constant and according to Agrawal and Seshadri (2000b) the reservation utility is downward sloping with type, i e , $\frac{\partial \underline{U}(\alpha)}{\partial \alpha} < 0$ According to economic theory, there will be at least one retailer who does not have valuable type information For example if the outside alternative is much riskier than entering the proposed contract, a retailer will have incentive to pretend to be less risk averse than she really is This would lead to the situation that the most risk averse retailer will earn information rent to truthfully reveal her type In fact, which retailer earns information rent and how much, depends on the shape of the reservation utility function vis-a-vis the shape of the optimal expected utility function The following proposition identifies which retailer will not earn information rent and once she is identified, how to construct the rest of the contract menu

Proposition 6: *While calculating the menu of OB contracts, the supplier choses the optimal value of s such that*

$$U^{OB}(q^c, b_s, o_s, s) = \underline{U}(s) \quad s \in [0, \bar{\alpha}], \tag{37}$$

where s is the least risk-averse among the retailers who have no type information advantage Therefore, the OB contract for s is

$$\begin{aligned} w &= w_s, \\ b_s^{OB} &= b_s, \\ o_s &= 0, \end{aligned}$$

where (w_s, b_s) is the coordinating buyback contract constructed according to Theorem 1 Other OB contracts in the menu are calculated through Theorem 3

Proposition 6 shows how to design a menu of contracts where every retailer participates and that is optimal for the supply chain This menu is unique other than information rent, the retailers do not extract any more surplus, all other supply chain coordinating contracts that induce truth-telling and satisfy the retailers' individual rationality constraints will leave some "money on the table" for the supplier However, this comes at a cost the information rent that the supplier has to give up may be too high and therefore offering such a hedging mechanism may leave the supplier worse off

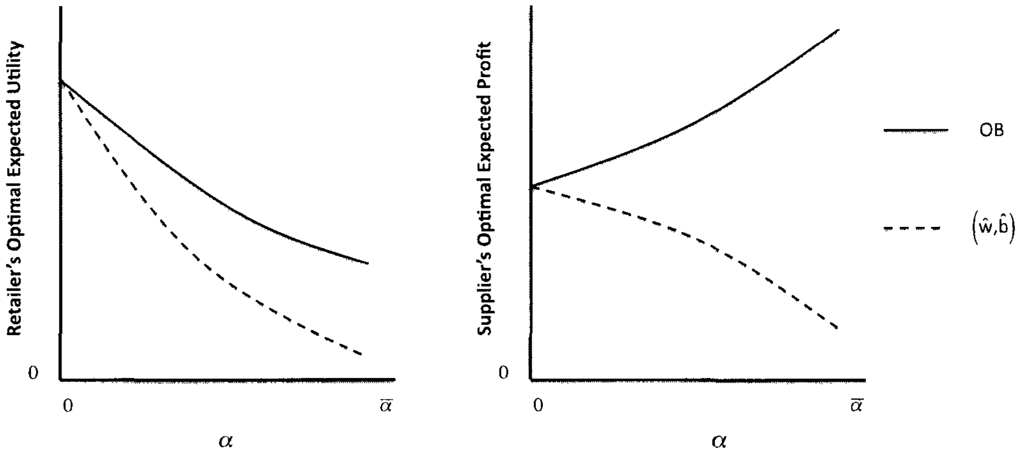
When the retailer's type is observable, the derived buyback contract is also optimal for the supplier as the retailer only captures the reservation utility and the total profit of the supply chain is maximized However, when the retailer's type is unobservable, maximizing the supply chain's profit is not equal to maximizing the supplier's profit since the supplier has to give enough incentives to retailers to self-select. From the supplier's standpoint, it's a battle between the gain from hedging the supply chain risk and the cost to induce the retailer to tell the truth. It's interesting to investigate the economic dynamics under such a hedging mechanism. Since we don't make any assumptions on the retailers' reservation utility, we demonstrate the results through numerical study in later section. It's also natural to ask whether the supplier will have incentives to hedge the supply chain risks through the proposed OB contracts. This is the subject in the next section.

3.5.4 Value of Risk Management

In this subsection we show the value of hedging the supply chain risk by comparing the OB contracts to a standard buyback contract designed for a risk-neutral retailer, but where all retailers participate. Comparing to the benchmark case of the standard contract, the OB contract scheme could lead to a "win-win" outcome for both supplier and retailer.

Suppose the retailer's type α is distributed on the interval of $[0, \bar{\alpha}]$ and all types have the same reservation utility, for simplicity assume $\underline{U}(\alpha) = 0$. Without managing risk (i.e., by assuming that retailers are risk neutral) the supplier will offer a standard buyback contract as in Pasternack (1985). When presented with this contract, risk-averse retailers order a quantity q^* with $0 < q^* < q^c$. The more risk averse the retailer, the less she orders and the less expected utility she earns. This is similar to the "deadweight loss" in the economic literature, e.g., where a monopoly produces less than the optimal (with respect to social welfare) output and a welfare loss (equal to the 'deadweight loss") results, see, e.g., Tirole

Figure 5: Comparison between OB contract scheme and $(\hat{w}, \hat{b})$



(1997). In our case, the presence of the retailer's risk aversion creates a similar deadweight loss: she orders less than the optimal order quantity and a welfare loss (for the supply chain) occurs. We assume that all retailers participate, hence the supplier offers a buyback contract $(\hat{w}, \hat{b})$ and our buyback contract then needs to meet the following conditions:

$$\Gamma(q^c, \hat{w}, \hat{b}, 0) = 0, \tag{38}$$

$$U(q^*, \hat{w}, \hat{b}, \bar{\alpha}) \geq 0. \tag{39}$$

Condition (38) ensures that the risk-neutral retailer will order q^c given $(\hat{w}, \hat{b})$, while condition (39) states that every retailer's type and thus also says $\bar{\alpha}$'s IR constraint should be satisfied. According to Proposition 2, the less risk averse the retailer is, the more expected utility she will gain from the contract. Therefore, if the most risk-averse retailer stays in the game as the condition (39) holds, so do any other types.

The OB contract scheme eliminates the deadweight loss by offering a menu of contracts. In order to guarantee a "win-win," the expected utility for the retailers under the OB contract needs to be at least as high as under the benchmark contract Since the risk does not concern the risk-neutral retailer, her outcome in terms of order quantity and expected utility will not be different from the benchmark case Thus we design a menu of OB contracts such that the risk-neutral retailer earns as much surplus as before The "surplus" a retailer earns under the OB contract can be interpreted as information rent, as it is the surplus required for a retailer to reveal her true type In this sense, the OB contract for the risk neutral retailer $\alpha = 0$ should be $(w = \hat{w}, b_0^{OB} = \hat{b}, o_0 = 0)$ and those for other types can be calculated through Theorem 3 with $b_s = \hat{b}$ From an economic interpretation, under the OB contract scheme the supplier "pays" information rent so that the retailer will reveal her true type and enter the supply chain coordinating contract The "gain" for the supplier is the additional profit he earns from having the supply chain coordinated As the next theorem shows, this trade-off is in the supplier's best interest the information rent is less than the gain from coordinating the supply chain

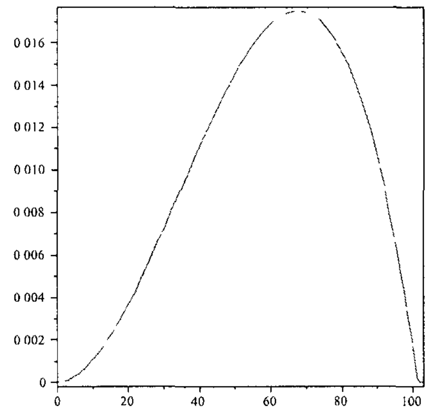
Theorem 4: *In the benchmark case, the supplier can design a menu of OB contracts under which the risk-neutral retailer captures as much surplus as under* $(\hat{w}, \hat{b})$ *Under the proposed OB contract scheme,*

- *any retailer type is better off except the risk-neutral one who gains as much as under* $(\hat{w}, \hat{b})$
- *the supplier is better off except when the retailer is risk neutral, where he captures as much surplus as under* $(\hat{w}, \hat{b})$

In addition, the supply chain is always coordinated regardless of the retailer type

Again, the formal proof can be found in Appendix, but its intuition is shown in figure 5 Dashed lines are used for the benchmark contract, solid lines are for

Figure 6: Probability Density Function of Demand.



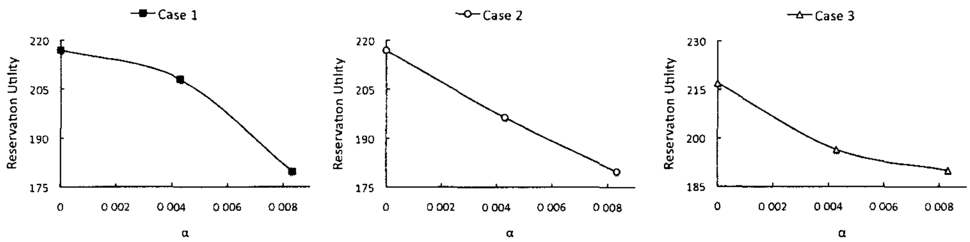
the OB contract. We can see that the OB strategy becomes better when the risk aversion is higher, but in any case leads to a "win-win" situation. The retailer's higher expected utility under the OB contract is paid for by the higher expected supply chain profit from offering the OB contract. Note also that the more risk-averse retailer gains more from the OB contract as compared to the benchmark contract. However, in this case when $\underline{U}(\alpha) = 0$ the less risk averse retailers earn a higher information rent.

3.6 Numerical Study

We demonstrate the contracting strategies in various situations through a numerical study. Consider a market demand $D = l * B + m$, where B is a random variable following a Beta(3,2) distribution, as shown in figure 6. The unit retailing price $p = 10$ and the unit product cost $c = 2$. Then, with $(l = 101.56, m = 0)$, we are able to calculate $q^c = G_D^{-1}(\frac{p-c}{p}) = 80$.

The supply chain consists of a risk-neutral supplier and risk-averse retailers. For the sake of simplicity, we assume the retailer could be one of three types: α_0, α_1 and α_2, where $\alpha_2 > \alpha_1 > \alpha_0 = 0$; α_0 represents the special risk-neutral

Figure 7: Retailer Reservation Utility.



type. As many results hinge upon the retailer's reservation utility, we consider three cases as shown in figure 7. Note that all reservation utility functions are downward sloping which means that the outside alternative opportunity for the retailers is not risk-free.

3.6.1 Observable Retailer

We first derive the coordinating contracts for each reservation utility in figure 7 when the retailer's type is observable. In this case, the supplier is able to extract the most profit and the retailer has zero surplus. Tables 1, 2 and 3 display the optimal order quantity and utility for the reservation utilities in cases 1, 2 and 3. Only the coordinating contracts for the three types are displayed as the rows in the table, and the optimal order quantity and utility are shown in bold face. The other numbers illustrate the findings of Proposition 1: if the retailers could self-select, they might prefer a contract designed for another type. For example, in table 1, α_0 will be better off if she enters $(w^c_{\alpha_1}, b^c_{\alpha_1})$, or say, pretends to be as risk averse as α_1 and orders $q^* = 84.20 > q^c$. At the same time, α_2 would gain by entering the contract designed for α_1 and she would order $q^* = 73.60 < q^c$. In this example, α_0 and α_2 are the types holding valuable information—guaranteeing information rent to enforce revelation of their type—while α_1 is not.

Coordinating Contract		α_0		α_1		α_2	
w_α^c	b_α^c	q^*	U	q^*	U	q^*	U
6.00	5.00	**80.00**	**216.90**	74.60	196.44	67.60	179.77
5.96	5.31	84.20	227.43	**80.00**	**208.00**	73.60	191.16
6.39	6.00	87.30	207.80	84.46	193.12	**80.00**	**179.76**

Table 8: Coordinating Buyback Contracts, Retailer q^* and U in Case 1

Coordinating Contract		α_0		α_1		α_2	
w_α^c	b_α^c	q^*	U	q^*	U	q^*	U
6.00	5.00	**80.00**	**216.90**	74.60	196.44	67.60	179.77
6.19	5.56	83.95	213.78	**80.00**	**196.43**	74.12	181.31
6.39	6.00	87.30	207.80	84.46	193.12	**80.00**	**179.76**

Table 9: Coordinating Buyback Contracts, Retailer q^* and U in Case 2

3.6.2 Discriminatory Pricing Strategy: the OB contract

For the same parameters as before, we now construct the menu of OB contracts when the retailer's type is unobservable. That is, the retailer knows the range of types $[0, \bar{\alpha}]$ and their reservation utilities, but is not able to identify a retailer's α. By applying Proposition 6, the supplier is able to construct the menu of OB contracts. For instance, given $\underline{U}(\alpha)$ in case 1, we know that α_1 is the retailer who has no information advantage. Hence the supplier can come up with the menu of OB contracts as in table 11.

Consistent with our analysis, given the menu of OB contracts shown in table 11, the retailer will always pick the contract in which she orders q^c. Comparing this situation with the one where the retailer's type is observable, we see that α_1's utility remains the same; she is the only retailer not capturing any information rent, while the other retailer's expected utility is now higher than when their type is observable. The optimal expected utility of the retailers and their reservation

Coordinating Contract		α_0		α_1		α_2	
w^c_α	b^c_α	q^*	U	q^*	U	q^*	U
6.00	5.00	**80.00**	**216.90**	74.60	196.44	67.60	179.77
6.19	5.56	83.95	213.78	**80.00**	**196.43**	74.12	181.31
6.17	5.78	87.77	221.29	84.82	204.89	**80.00**	**190.00**

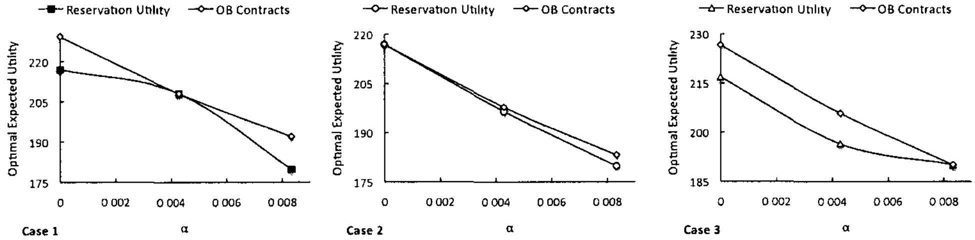
Table 10: Coordinating Buyback Contracts, Retailer q^* and U in Case 3

Coordinating Contract		α_0		α_1		α_2	
$w + o_\alpha$	b^{OB}_α	q^*	U^{OB}	q^*	U^{OB}	q^*	U^{OB}
5.77	4.71	**80.00**	**229.29**	74.22	206.50	66.75	188.20
5.96	5.31	84.20	227.43	**80.00**	**208.00**	73.60	191.16
6.13	5.74	87.86	223.85	84.90	207.11	**80.00**	**191.92**

Table 11: OB Contracts, Retailer q^* and U^{OB} in Case 1, $w = w^c_{\alpha_1} = 5.96$

utilities are shown in figure 8. In case 2, it is the risk-neutral retailer who does not capture information rent: in this case the outside alternative used to calculate the reservation utility is more risky than the OB contract and hence retailers would like to pretend to be less risk-averse than they really are, hence retailer α_2 captures the most information rent. The opposite is true in case 3: the outside alternative is less risky than the OB contract and the risk-neutral retailer gains the highest information rent.

Figure 8: OB Contracts v.s. Reservation Utility.



Coordinating Contract		α_0		α_1		α_2	
$w + o_\alpha$	b_α^{OB}	q^*	U^{OB}	q^*	U^{OB}	q^*	U^{OB}
6 00	5 00	**80.00**	**216.90**	74 60	196 44	67 60	179 77
6 16	5 53	83 98	215 34	**80.00**	**197.77**	74 06	182 44
6 32	5 93	87 46	212 22	84 58	196 98	**80.00**	**183.13**

Table 12 OB Contracts, Retailer q^* and U^{OB} in Case 2, $w = w^c_{\alpha_0} = 6$

Coordinating Contract		α_0		α_1		α_2	
$w + o_\alpha$	b_α^{OB}	q^*	U^{OB}	q^*	U^{OB}	q^*	U^{OB}
5 82	4 78	**80.00**	**226.57**	74 31	204 30	66 93	186 37
6 00	5 36	84 15	224 78	**80.00**	**205.76**	73 70	182 26
6 17	5 78	87 77	221 29	84 82	204 89	**80.00**	**190.00**

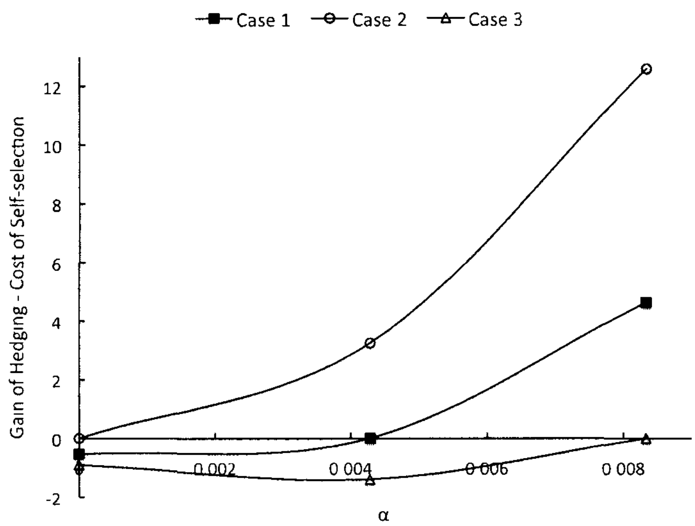
Table 13 OB Contracts, Retailer q^* and U^{OB} in Case 3, $w = w^c_{\alpha_2} = 6$ 17

3.6.3 Risk Hedging v.s. Truth Telling

As discussed previously, when the retailer's type is unobservable, offering OB contracts might leave the supplier worse off From the supplier's standpoint, it's a battle between the gain from hedging the supply chain risk and the cost to induce the retailers to tell the truth We investigate the economic dynamics under such a hedging mechanism based on the three cases above We calculate the difference between the supplier's gain from hedging the supply chain risk and the cost of inducing the retailers to self-select The results are illustrated in Figure 9

In Case 1 and Case 2, the supplier's overall gain from hedging the supply chain risk is more than that he pays the retailers to reveal their types since the areas between each curve and x-axis are both positive On the contrary, in Case 3, the area is negative indicating it's not in the supplier s interest to offer the OB contracts Depending on the shape of the retailers' reservation utility, the area

Figure 9: OB Contracts v.s. Reservation Utility.



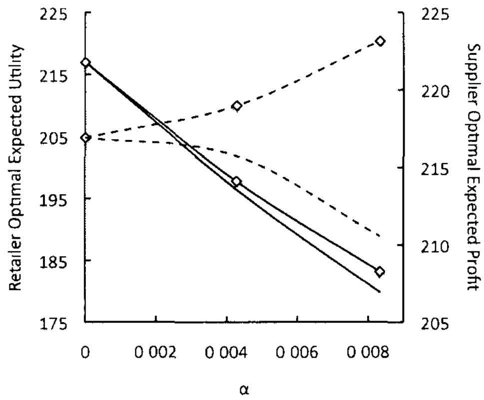
will vary from positive to negative. Thus the supplier could decide whether he will be better off to propose the OB contracts.

3.6.4 Value of Risk Management

Without taking into account the retailer's risk aversion, the supplier fails to give the risk-averse retailer right incentives to order an amount up to q^c. Therefore, a deadweight loss occurs and both suffer. On the other hand, the proposed OB contract scheme is able to align the retailer with the supply chain by giving her appropriate incentives, which does not only consider the retailer's risk aversion but also acknowledges the heterogeneity in her type. More important, both the supplier and the retailer can benefit. In a sense, implementing the risk management through the OB contract scheme can guarantee a win-win outcome.

Now suppose the benchmark case is that three retailer types have the same reservation utility, equal to zero and ($\hat{w} = 6.00, \hat{b} = 5.00$) is the standard buyback contract for which only the risk-neutral type has $q^* = q^c$. The expected utility of

Figure 10: Value of Risk Management.

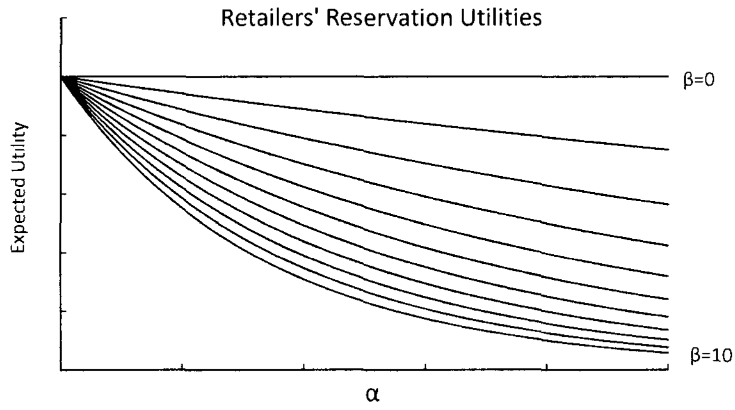


each type under ($\hat{w} = 6.00, \hat{b} = 5.00$) and the corresponding expected profit of the supplier are shown in figure 10. As has been discussed, both the supplier and the retailer suffer from the deadweight loss caused by the risk aversion. As Theorem 4 suggests, we appropriately design a menu of OB contracts under which the risk-neutral retailer can earn as much surplus as before but the other two types will be able to capture more surplus since the supply chain's profit is maximized. Moreover, the supplier is also able to capture more profit under the OB contract scheme as shown in the figure. Managing risk results in a "win-win" situation, and, in addition, the value of risk management increases as the retailer becomes more risk averse.

3.6.5 Comparison between Linear and Non-Linear Contract

In subsection 3.4.2, we discussed non-linear pricing contracts which are able to coordinate the supply chain. For example, a risk-averse retailer could be induced to order up to q^c by giving quantity discounts and could be discouraged from ordering over q^c by, e.g., refusing returns for the units above q^c. The Risk-Sharing Contract (RSC) presented by Gan et al. (2005) is one of the kind. When the

Figure 11: Retailers' Reservation Utility

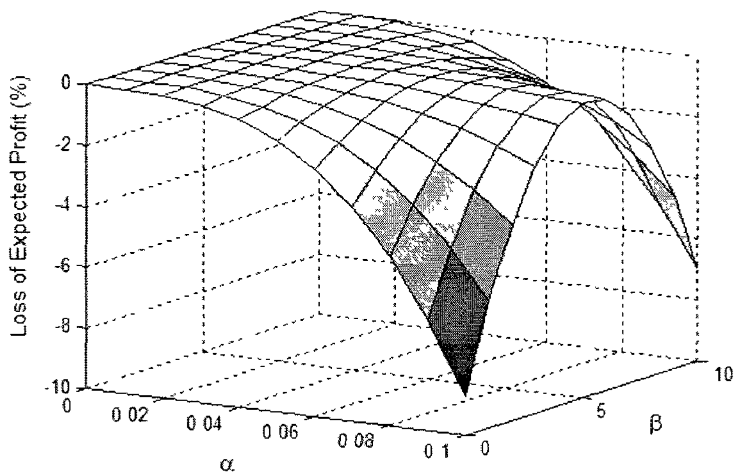


retailer's type is unknown, RSC is proved to be able to induce the retailer to enter the contract designed for her type and order q^c. At the same time, RSC allows the retailer only to earn as much as her reservation utility. In other words, no retailer could enjoy information rent under the non-linear pricing scheme. As such, the supplier is almost always better off to offer the contract since his expected profit is also optimized while the total pie of the supply chain is maximized.

As illustrated earlier, the OB contract is not always in the supplier's best interest. The proposed linear pricing scheme is lack of the tools to induce every retailer to order q^c without giving out information rent. In other words, OB contract will have to underperform the non-linear pricing contract such as RSC in terms of the supplier's expected profit. Before even articulating the advantages of the OB contract scheme, it makes more sense to know, comparing to RSC, how much worse the OB contract could be, which we investigate as follows.

Figure 11 shows a set of retailers' reservation utility curves. α indicates the degree of the retailer's risk aversion. The higher α, the more risk-averse the retailer is. β represents how risky the outside alternative is. The higher β, the more risky the alternative is. Based on this set of retailers' reservation utility, we

Figure 12: Comparison between OB Contract and RSC



calculate the supplier's expected profit under OB contract and RSC respectively. As we expected, OB contract underperforms RSC most of the time. Figure 12 illustrates how the extent of "underperformance" with respect to α and β.

In a special case where $\beta = 0$, the retailer's reservation utility curve appears to be flat along with α, under which the type of the retailer who has no information advantage is the most risk-averse one. The derived OB contract will have to offer incentives to all types of retailers but her. The more risk averse she is, the more incentives the supplier has to offer to others. Therefore, comparing to non-linear pricing RSC, the loss of the supplier's expected profit becomes more and more while the degree of risk aversion of the most risk-averse retailer increases. In our simulation, the loss could be as high as 9% of the expected profit under RSC.

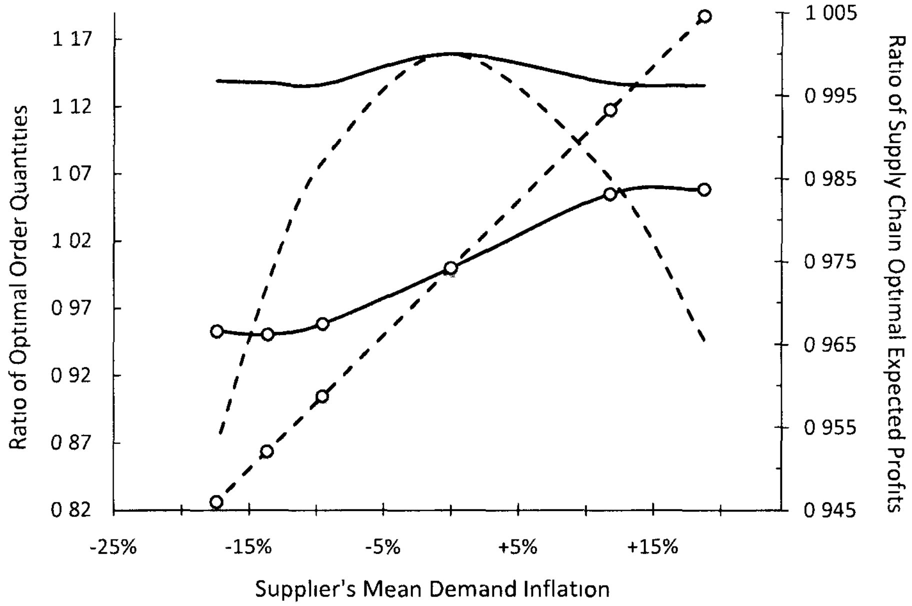
However, when β increases, although the type of retailer who has no information advantage is still the most risk-averse one, the information rent that the supplier has to offer under OB contract becomes less and less until it reaches at a point where the OB contract does not give any information rent. This is a very special case as the reservation utility curve happens to be the one on which nobody has information advantage Unfortunately, there is no such a curve in the set of reservation utility curves our simulation is based on In our computation, the minimum information rent is obtained while the type of the retailer who has no information advantage shifts from the most risk-averse on to the risk-neutral one Then, when β keeps increasing, under the derived OB contract, the supplier has to give more incentives to ensure the risk-averse retailers to tell the truth As a result, the performance of the OB contract becomes worse and worse Figure 12 clearly demonstrates this dynamic

3.6.6 Demand Distortion

Although it seems that non-linear pricing contract is in the supplier's favor as it outperforms the proposed linear pricing OB contract, we demonstrate the advantages of linear pricing OB contracts in this subsection Similar to RSC derived by Gan et al (2005), one extreme example of non-linear pricing contract is a simple take-it-or-leave it (TOL) contract The retailer can only order in batches of q^c for a fixed price This implies that the supplier has perfect knowledge of the demand distribution needed to compute the optimal value q^c However, it may be that the local information about the demand distribution obtained by the retailer is more accurate than the supplier's In a TOL contract, however, the retailer is not able to exploit this information since she is forced to order q^c Since the OB contract is a linear price contract, the retailer's optimal order quantity q^* will deviate from the q^c computed by the supplier Hence, we would like to compare how the OB contract and TOL contract adapt when the retailer's information about demand differs from the supplier's

We expect the OB contract scheme to be more flexible and adjustable under the distortion of demand information than a TOL contract We study this

Figure 13 Comparison of TOL and OB when supplier's demand is inflated



problem through a numerical example Using the same Beta(3,2) distribution for the demand, the supplier assumes the demand has mean of 75 94 and computes the corresponding q^* as $q^* = q^c = 95$ Keeping the variance of the demand distribution fixed, we see what happens if this demand information over– or underestiamtes the true demand That is, we assume that the retailer knows the true demand, but the supplier has designed the menu of contracts assuming that the mean is 75 94 with $q^c = 95$

We compare the TOL and OB contract scheme in two dimensions the retailer's optimal order quantity and the supply chain's optimal expected profit Figure 13 shows the results dashed lines belong to the TOL contract, solid lines are the ones for the OB contract Curves with empty circles pertain to order quantities, and their scale is the left vertical axis, curves without symbols are associated with expected supply chain profits and their scale is on the right vertical axis

The curves with empty circles show the ratio of the retailer's order quantity based on the menu of contracts presented over the optimal order quantity, i e , the quantity that she would have ordered if the supplier's contract menu was based on the correct demand distribution For example, when the supplier substantially overestimated the demand, the TOL contract would still force the retailer to order the same fixed quantity Under the OB contract the retailer would still order a quantity above optimal, but the order quantity behaves much better even when the supplier overestimates the demand by about 20%, the retailer under the OB contract would order around 5% over the optimal order quantity, under the TOL contract the retailer would order more than 18% over the optimal order quantity

The lines without symbols give the ratio of the supply chain's profit under the distorted menu of contracts versus the expected profit computed if the supplier would have known the correct demand distribution The difference between the dashed and solid lines is drastic for the whole range of demand distortions (around ±20%), the supply chain's profit under the distorted menu of contracts is within 0 5% of the optiml profit tht would result if the supplier would have known the correct demand distribution The TOL contract performs much worse when the supplier over- or underestimates the demand by about 10%, the supply chain's profit is about 2% from the optimal profit, and worsens to almost 5% when the demand distortion reaches ±20% So, both with respect to order quantity as well as supply chain profit the OB contract outperforms the TOL contract This result is consistent with our expectation and proves that the OB contract scheme is more flexible and adjustable to demand distortion

3.7 Conclusion

We presented a linear price buyback contract to optimize a supply chain's performance in the presence of retailers' risk aversion We came up with a menu of contracts that guarantees that the supply chain's profit is maximized When the retailer's type is observable the supplier will pick the appropriate contract and present it to the retailer, the retailer will not realize any surplus and the supplier earns the highest profit

When retailer's type is unobservable, some retailers will enjoy an information rent We found that when the reservation utility is independent of type, i e , all retailers have the same reservation utility, the less risk-averse retailer earns a higher information rent When the reservation utility is type-independent, the most risk-averse retailer does not earn information rent When the reservation utility depends on type, i e , the reservation utility is downward sloping with type, the retailer type who does not enjoy information rent depends on the curvature of the reservation utility as a function of type In some situations, it is possible that the more risk-averse retailers earn a higher information rent than the less risk-averse

Our analytical and numerical results show how the supplier's ability to identify a retailer's type affects the supply chain performance We also derive when the benefit of hedging the supply chain risk overwhelms the cost of inducing the retailers to tell the truth such that the supplier is better off to offer OB contracts Finally, we also show in which situations the managing risk provides a win-win situation for the supplier as well as for the retailer

In contrast to the classical buyback contract, the menu of contracts we derived requires the supplier to have knowledge of the demand distribution We numerically demonstrate that our results are robust against violations of this assumption. It is an open question whether contracts exist that accommodate the retailer's risk aversion and coordinate the supply chain without requiring the supplier to have any information about the distribution of demand.

Chapter 4

Conclusions and Future Research

The development of research at the interface of finance and operations management has been gaining momentum in the past decade. The conversations between CFOs and COOs are no longer limited to exchanging information. On the contrary, two of the most crucial business functions demand more and more collaboration. In a recent interview with the treasurer of a Fortune 500 multinational company, we learned that the needs to hedge business operations' risk exposure to foreign exchange, commodity and credit has been growing exponentially over the years. Not to mention it takes much more rigorous analysis to fulfill these needs nowadays. It's also a key issue on the agenda of executives to align companies' operations-related interests with shareholders'. As being found in many academic research, bad operational decisions could hurt shareholders severely.

This dissertation studies the interface of finance and operations management from two perspectives. The first essay is focused on the interaction between equity markets and companies' operational decisions in the context of green vehicle innovation in the global automobile industry. In the second essay, we apply the well-developed methodologies and tools in finance to solving the problems in the field of operations management

Our findings in the first essay indicate that the operational decisions are read carefully by the investors and those decisions affect the value creation of the associated strategies in a very sophisticated manner In other words, there doesn't exist a one-size-fits-all winning strategy when it comes to green vehicle innovation For example, choosing conservative (or aggressive) technology is rarely optimal for everybody in any situation Neither is focusing on high-end product segment (or low-end) This may sound obvious but actually state the essence and complexity of developing green vehicles, or green products, to a larger extent Although the technology itself is already very complex, we find that the automakers have to be even more careful when deciding which technology and product segment to choose It turns out that both internal corporate factors (profitability and leverage) and external economic indicators (oil price) play a significant role and should be well incorporated in the decision-making

The second essay presents a linear pricing buyback contract to optimize a supply chain's performance in light of retailers' risk aversion We come up with a menu of contracts that guarantee the supply chain's profit to be maximized When the retailer's type is observable, the supplier will pick the appropriate contract and present it to the retailer, the retailer will not realize any surplus and the supplier earns the highest expected profit However, when the retailer's type is unobservable, some retailers will enjoy information rent Our analytical and numerical results show how the supplier's ability to identify a retailer's type affects the supply chain performance We also demonstrate the situations when the benefits of hedging the supply chain risk overwhelm the costs of inducing the retailers to tell the truth As such, the supplier is better off to adopt the proposed strategy Finally, we show when managing risk could result in a win-win situation for both parties

In the end, we acknowledge that more work needs to be done to better understand the interface of finance and operations management Take the green vehicle innovation for example, as the development evolves, business researchers/industry practitioners should be able to collect more facts and data to look at the problem from different angles The analysis should dig deeper Our study sheds light on the ongoing effort of the global automobile industry and builds a solid foundation for future research, however it is more interesting to investigate the long-term interaction between equity markets and companies' efforts to go green, which might lead to more insightful results Meanwhile, we should think outside the box and focus on the broader operational issues in the context of climate change As being discussed by Liu and Stallaert (2010), many traditional operational practice will have dramatically different implications on the companies' balance sheets with the development of environmental awareness and regulations Taking a closer look at those effects might be a very exciting and interesting direction for future research Applying the financial innovations to the field of operations management is another interesting stream of future research We have seen options being extensively discussed in the literature of operations management in different forms, as we have done in the second essay As a matter of fact there are many other financial innovations, such as swaps, swaption and more sophisticated hedging strategies These products, in nature, are designed for hedging uncertainties associated with their underlying assets Researchers in operations management might find those ideas very useful for dealing with the uncertainties in operations

Appendices: Proofs

Downside Risk Measurement

We use semi-variance to model the downside risk of retailer under a buyback contract. By the definition of semi-variance, we have

$$\begin{aligned} S(q) &= \int_{-\infty}^{\Pi(q)} (\Pi(q) - R)^2 \, dF(R) \\ &= \Pi(q)^2 \int_{-\infty}^{\Pi(q)} f(R) \, dR - 2\Pi(q) \int_{-\infty}^{\Pi(q)} Rf(R) \, dR \\ &\quad + \int_{-\infty}^{\Pi(q)} R^2 f(R) \, dR \end{aligned} \tag{40}$$

where $f(R)$ is p.d.f. of $F(R)$. Through the rule of integration by parts, we can derive

$$\begin{aligned} S(q) &= \Pi(q)^2 F(\Pi(q)) - 2\Pi(q) \left[RF(R) \Big|_{-\infty}^{\Pi(q)} - \int_{-\infty}^{\Pi(q)} F(R) \, dR \right] \\ &\quad + R^2 F(R) \Big|_{-\infty}^{\Pi(q)} - 2 \int_{-\infty}^{\Pi(q)} RF(R) \, dR \\ &= \Pi(q)^2 F(\Pi(q)) - 2\Pi(q)^2 F(\Pi(q)) + 2\Pi(q) \int_{-\infty}^{\Pi(q)} F(R) \, dR \\ &\quad + \Pi(q)^2 F(\Pi(q)) - 2 \int_{-\infty}^{\Pi(q)} RF(R) \, dR \\ &= 2\Pi(q) \int_{-\infty}^{\Pi(q)} F(R) \, dR - 2 \int_{-\infty}^{\Pi(q)} RF(R) \, dR \\ &= 2 \int_{-\infty}^{\Pi(q)} (\Pi(q) - R) F(R) \, dR. \end{aligned} \tag{41}$$

Retailer's Problem

The retailer's problem is modeled by (14). Given a buyback contract (w, b), the retailer decides the optimal order quantity q^* such that her expected utility is maximized The first derivative of $U(q)$ with respect to q is

$$\begin{aligned}\frac{\mathrm{d}\left\{\Pi(q)-\alpha S(q)\right\}}{\mathrm{d}q} &= \frac{\mathrm{d}\Pi(q)}{\mathrm{d}q}-\alpha\frac{\mathrm{d}S(q)}{\mathrm{d}q} \\ &= (p-w)-(p-b)G(q)-\alpha\frac{\mathrm{d}S(q)}{\mathrm{d}q} \qquad (42)\end{aligned}$$

Applying the *Leibniz Integral Rule*, we obtain $\frac{\mathrm{d}S(q)}{\mathrm{d}q}$

$$\begin{aligned}\frac{\mathrm{d}S(q)}{\mathrm{d}q} &= 2\int_{-\infty}^{\Pi(q)} F(R)\,dR\frac{\mathrm{d}\Pi(q)}{\mathrm{d}q}+2\Pi(q)\frac{\mathrm{d}\int_{-\infty}^{\Pi(q)} F(R)\,dR}{\mathrm{d}q}-2\frac{\mathrm{d}\int_{-\infty}^{\Pi(q)} RF(R)\,dR}{\mathrm{d}q} \\ &= 2\int_{-\infty}^{\Pi(q)} F(R)\,dR\frac{\mathrm{d}\Pi(q)}{\mathrm{d}q}+2\Pi(q)\int_{-\infty}^{\Pi(q)}\frac{\mathrm{d}F(R)}{\mathrm{d}q}\,dR \\ &\quad -2\int_{-\infty}^{\Pi(q)}\frac{\mathrm{d}\{RF(R)\}}{\mathrm{d}q}\,dR \\ &= 2\int_{-\infty}^{\Pi(q)} F(R)\,dR\frac{\mathrm{d}\Pi(q)}{\mathrm{d}q}+2\Pi(q)(w-b)F(\Pi(q)) \\ &\quad -2(w-b)\left\{\Pi(q)F(\Pi(q))-\int_{-\infty}^{\Pi(q)} F(R)\,dR\right\} \\ &= 2\int_{-\infty}^{\Pi(q)} F(R)\,dR\frac{\mathrm{d}\Pi(q)}{\mathrm{d}q}+2(w-b)\int_{-\infty}^{\Pi(q)} F(R)\,dR \\ &= 2(p-b)[1-G(q)]\int_{-\infty}^{\Pi(q)} F(R)\,dR \qquad (43)\end{aligned}$$

Taking (43) into (42), we get

$$\frac{\mathrm{d}U(q,w,b,\alpha)}{\mathrm{d}q}=(p-w)-(p-b)G(q)-2\alpha(p-b)[1-G(q)]\int_{-\infty}^{\Pi(q)} F(R)\,dR, \quad (44)$$

so we arrive at the necessary first-order condition

$$\left.\frac{\mathrm{d}U(q,w,b,\alpha)}{\mathrm{d}q}\right|_{q=q^*}=(p-w)-(p-b)G(q^*)-2\alpha(p-b)[1-G(q^*)]\int_{-\infty}^{\Pi(q^*)} F(R)\,dR=0 \quad (45)$$

Therefore, the retailer's q^* can be obtained from solving the above equation

The following result is needed for subsequent proofs

Lemma 2: *Under a buyback contract, a risk-averse retailer's optimal order quantity decreases with respect to her degree of risk aversion* Proof When a retailer with a degree of risk aversion α enters a buyback contract (w, b), she can maximize her expected utility by ordering q^* if and only if (45) holds. Therefore $\Gamma(q^*, w, b, \alpha) = (p - w) - (p - b)G(q^*) - 2\alpha(p - b)[1 - G(q^*)] \int_{-\infty}^{\Pi(q^*)} F(R)\, dR = 0$ is the necessary and sufficient condition for the retailer to maximize her expected utility.

According to the implicit differentiation rule:

$$\frac{\mathrm{d}q^*}{\mathrm{d}\alpha} = -\frac{\frac{\partial \Gamma}{\partial \alpha}}{\frac{\partial \Gamma}{\partial q^*}}, \tag{46}$$

where

$$\frac{\partial \Gamma}{\partial \alpha} = -2(p - b)[1 - G(q^*)] \int_{-\infty}^{\Pi(q^*)} F(R)\, dR, \tag{47}$$

and

$$\begin{aligned} \frac{\partial \Gamma}{\partial q^*} &= -(p - b)g(q^*) - 2\alpha(p - b)\Big\{-g(q^*) \int_{-\infty}^{\Pi(q^*)} F(R)\, dR \\ &\quad +(p - b)[1 - G(q^*)]^2 F(\Pi(q^*))\Big\} \\ &= -\frac{(w - b)g(q^*)}{1 - G(q^*)} - 2\alpha(p - b)^2[1 - G(q^*)]^2 F(\Pi(q^*)). \end{aligned} \tag{48}$$

Since $b < w < p$, we get $\frac{\partial \Gamma}{\partial \alpha} < 0$ and $\frac{\partial \Gamma}{\partial q^*} < 0$ and hence, by (46), $\frac{\mathrm{d}q^*}{\mathrm{d}\alpha} < 0$. It indicates that the retailer's q^* intends to be less when her α increases under a specific buyback contract.

Proof of Lemma 1

Part (i). The first order optimality condition $\Gamma(q^c, w_\alpha^c, b_\alpha^c, \alpha) = 0$ must hold in the optimal coordinating buyback contract for a retailer α. The change of w_α^c with respect to b_α^c is described as $\frac{\mathrm{d}w_\alpha^c}{\mathrm{d}b_\alpha^c}$.

By the implicit differentiation rule, we could derive

$$\frac{\mathrm{d}w_\alpha^c}{\mathrm{d}b_\alpha^c} = -\frac{\frac{\partial \Gamma}{\partial b_\alpha^c}}{\frac{\partial \Gamma}{\partial w_\alpha^c}}. \tag{49}$$

Since

$$\frac{\partial \Gamma}{\partial b_\alpha^c} = G(q^c) + 4\alpha[1 - G(q^c)] \int_{-\infty}^{\Pi(q^c)} F(R)\, dR > 0, \tag{50}$$

and

$$\frac{\partial \Gamma}{\partial w_\alpha^c} = -1 < 0, \tag{51}$$

we can conclude that $\frac{\mathrm{d}w_\alpha^c}{\mathrm{d}b_\alpha^c} > 0$.

Part (ii). We first note that the signs of $\frac{\mathrm{d}b_\alpha^c(U_0)}{\mathrm{d}U_0}$ and $\frac{\mathrm{d}U(q^c;w_\alpha^c,b_\alpha^c,\alpha)}{\mathrm{d}b_\alpha^c}$ are identical, but the latter is more convenient to obtain. Given the contract (w_α^c, b_α^c), the retailer α's optimal expected utility is denoted as $U(q^c; w_\alpha^c, b_\alpha^c, \alpha)$. The change of U with respect to the buyback price is $\frac{\mathrm{d}U(q^c;w_\alpha^c,b_\alpha^c,\alpha)}{\mathrm{d}b_\alpha^c}$. Then we can derive

$$\begin{aligned}
\frac{\mathrm{d}U}{\mathrm{d}b_\alpha^c} &= \frac{\partial U}{\partial w_\alpha^c}\frac{\mathrm{d}w_\alpha^c}{\mathrm{d}b_\alpha^c} + \frac{\partial U}{\partial b_\alpha^c} \\
&= -q^c\{G(q^c) + 4\alpha[1 - G(q^c)] \int_{-\infty}^{\Pi(q^c)} F(R)\, dR\} + \frac{2\alpha S(q^c)}{p - b_\alpha^c} + \int_0^{q^c} G(x)\, dx \\
&= \frac{1}{p - b_\alpha^c}\Big\{-q^c(p - b_\alpha^c) - 4q^c\alpha(p - b_\alpha^c)[1 - G(q^c)] \int_{-\infty}^{\Pi(q^c)} F(R)\, dR \\
&\quad + 2\alpha S(q^c) + (p - b_\alpha^c) \int_0^{q^c} G(x)\, dx\Big\} \\
&= \frac{1}{p - b_\alpha^c}\Big\{-q^c(p - b_\alpha^c) - 2q^c[p - w_\alpha^c - (p - b_\alpha^c)G(q^c)] \\
&\quad + 2\alpha S(q^c) + (p - b_\alpha^c) \int_0^{q^c} G(x)\, dx\Big\} \\
&= \frac{1}{p - b_\alpha^c}\Big\{q^c(p - b_\alpha^c)G(q^c) - (p - b_\alpha^c) \int_0^{q^c} G(x)\, dx - 2U(q^c)\Big\} \\
&= \frac{1}{p - b_\alpha^c}\Big\{(p - b_\alpha^c) \int_0^{q^c} xg(x)\, dx - 2U(q^c)\Big\} \\
&= \frac{1}{p - b_\alpha^c}\Big\{q^c[(p - b_\alpha^c)G(q^c) - (p - w_\alpha^c)] + \Pi(q^c) - 2U(q^c)\Big\}
\end{aligned}$$

Since $\Gamma(q^c, w_\alpha^c, b_\alpha^c, \alpha) = 0$, we have $(p - b_\alpha^c)G(q^c) - (p - w_\alpha^c) \le 0$. For any $\alpha \in [0, \bar{\alpha}]$, we have $U(q^c) \ge \frac{\Pi(q^c)}{2}$ since we assumed that $\bar{\alpha} = \frac{\Pi(q^c,\alpha,w_\alpha^c(U_0),b_\alpha^c(U_0))}{2S(\alpha,w_\alpha^c(U_0),b_\alpha^c(U_0))}$ so that $\Pi(q^c) - 2U(q^c) \le 0$. Hence we can conclude that $\frac{\mathrm{d}U(q^c,w_\alpha^c,b_\alpha^c,\alpha)}{\mathrm{d}b_\alpha^c} < 0$, for any $\alpha \in [0, \bar{\alpha}]$. Because $\frac{\mathrm{d}w_\alpha^c}{\mathrm{d}b_\alpha^c} > 0$, it follows that $\frac{\mathrm{d}U(q^c,w_\alpha^c,b_\alpha^c,\alpha)}{\mathrm{d}w_\alpha^c} < 0$, for any $\alpha \in [0, \bar{\alpha}]$.

Again, since the signs of $\frac{\mathrm{d}U(q^c;w^c_\alpha,b^c_\alpha,\alpha)}{\mathrm{d}w^c_\alpha}$ and $\frac{\mathrm{d}w^c_\alpha(U_0)}{\mathrm{d}U_0}$ are identical, the result of the lemma follows at once.

Proof of Theorem 1

By assumption, for any $\alpha \in [0,\bar{\alpha}]$, $U(q^c;\alpha) \geq \frac{\Pi(q^c;\alpha)}{2}$ should be satisfied. Hence $U(q^c;w^c_\alpha,b^c_\alpha) \geq 0 = \underline{U}(\alpha)$. The uniqueness follows from Lemma 1, part (ii). If $\underline{U}(\alpha) > 0$, the existence of a coordinating contract obviously depends on the feasibility of equations (18) and(19).

The last part also follows from Lemma 1, part (ii). The higher the retailer's utility, the lower the supplier's profit, since the total supply chain's profit remains the same. Hence, the contract that maximizes the supplier's profit is $(w^*_\alpha, b^*_\alpha) = \max\{(w^c_\alpha, b^c_\alpha)\}$.

Proof of Proposition 1

We prove the proposition by contradiction. Assume to the contrary that a retailer α optimally orders q^c in the coordinating buyback contract for $\hat{\alpha}$, $(w^c_{\hat{\alpha}}, b^c_{\hat{\alpha}})$, where $\hat{\alpha} \neq \alpha$. Therefore $\Gamma(q^c, w^c_{\hat{\alpha}}, b^c_{\hat{\alpha}}, \alpha) = 0$ must hold according to Theorem 1. Since $(w^c_{\hat{\alpha}}, b^c_{\hat{\alpha}})$ is the coordinating buyback contract for $\hat{\alpha}$, we have $\Gamma(q^c, w^c_{\hat{\alpha}}, b^c_{\hat{\alpha}}, \hat{\alpha}) = 0$. Then $\Gamma(q^c, w^c_{\hat{\alpha}}, b^c_{\hat{\alpha}}, \alpha) = 0$ holds if and only if $\hat{\alpha} = \alpha$, contradicting the assumption that $\hat{\alpha} \neq \alpha$. This completes the proof.

Proof of Theorem 2.

We can study how a retailer's optimal expected utility changes with respect to buyback price by looking at $\frac{\mathrm{d}U(q^*;w,b,\alpha)}{\mathrm{d}b}$.

$$\begin{aligned}\frac{\mathrm{d}U(q^*;w,b,\alpha)}{\mathrm{d}b} &= \frac{\partial U}{\partial w}\frac{\mathrm{d}w}{\mathrm{d}b} + \frac{\partial U}{\partial b}, \\ &= -q^*\frac{\mathrm{d}w}{\mathrm{d}b} + \frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\,dx,\end{aligned}$$

since

$$\frac{\partial U}{\partial w} = -q^*,$$

and

$$\frac{\partial U}{\partial b} = \frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\,dx.$$

Thus $\frac{\mathrm{d}U(q^*,w,b,\alpha)}{\mathrm{d}b} > 0$, if $\frac{\mathrm{d}w}{\mathrm{d}b} < \frac{\frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\,dx}{q^*}$, which means the retailer's optimal expected utility increases by entering a buyback contract with a higher buyback price; $\frac{\mathrm{d}U(q^*;w,b,\alpha)}{\mathrm{d}b} < 0$, if $\frac{\mathrm{d}w}{\mathrm{d}b} > \frac{\frac{2\alpha S(q^*)}{p-b} + \int_0^{q^*} G(x)\,dx}{q^*}$, meaning that the retailer's optimal expected utility decreases by entering a buyback contract with a higher buyback price. In other words, the retailer prefers a buyback contract with a lower buyback price.

Proof of Proposition 2.

Under a buyback contract (w, b), according to the *envelope theorem*, we have

$$\frac{\mathrm{d}U(q;w,b,\alpha)}{\mathrm{d}\alpha} = \frac{\partial U(q;w,b,\alpha)}{\partial q}\frac{\mathrm{d}q}{\mathrm{d}\alpha} + \frac{\partial U(q;w,b,\alpha)}{\partial \alpha}\frac{\mathrm{d}\alpha}{\mathrm{d}\alpha}, \tag{52}$$

$$\frac{\mathrm{d}U(q;w,b,\alpha)}{\mathrm{d}\alpha} = \left.\frac{\partial U(q;w,b,\alpha)}{\partial \alpha}\right|_{q=q*}. \tag{53}$$

Therefore, we can prove

$$\frac{\mathrm{d}U(q^*;w,b,\alpha)}{\mathrm{d}\alpha} = -S(q^*) < 0. \tag{54}$$

It shows that the retailer's $U(q^*;w,b,\alpha)$ decreases if she is more risk averse.

$$\frac{\mathrm{d}U_b(q^*, w, b, \alpha)}{\mathrm{d}\alpha} = \frac{\partial U_b(q^*, w, b, \alpha)}{\partial q}\frac{\mathrm{d}q}{\mathrm{d}\alpha} + \frac{\partial U_b(q^*, w, b, \alpha)}{\partial \alpha}\frac{\mathrm{d}\alpha}{\mathrm{d}\alpha} \tag{55}$$

We can derive

$$\begin{aligned}
\frac{\partial U_b(q^*, w, b, \alpha)}{\partial q} &= \frac{\partial(\frac{\partial U(q^*,w,b,\alpha)}{\partial w}\frac{\mathrm{d}w}{\mathrm{d}b} + \frac{\partial U(q^*,w,b\ \alpha)}{\partial b})}{\partial q} \\
&= \frac{\partial(\frac{\partial U(q^*,w,b,\alpha)}{\partial w})}{\partial q}\frac{\mathrm{d}w}{\mathrm{d}b} + \frac{\partial(\frac{\partial U(q^*,w\ b\ \alpha)}{\partial b})}{\partial q} \\
&= 0
\end{aligned} \tag{56}$$

Then

$$\begin{aligned}
\frac{\mathrm{d}U_b(q^*, w, b, \alpha)}{\mathrm{d}\alpha} &= \frac{\partial U_b(q^*, w, b, \alpha)}{\partial \alpha} \\
&= \frac{\partial(\frac{\partial U(q^*,w,b,\alpha)}{\partial w})}{\partial \alpha}\frac{\mathrm{d}w}{\mathrm{d}b} + \frac{\partial(\frac{\partial U(q^*,w\ b\ \alpha)}{\partial b})}{\partial \alpha} \\
&= 0\frac{\mathrm{d}w}{\mathrm{d}b} + \frac{\partial(\frac{\partial U(q^*,w\ b\ \alpha)}{\partial b})}{\partial \alpha} \\
&= \frac{2S(q^*)}{p-b} > 0,
\end{aligned} \tag{57}$$

since $\frac{\partial U(q^*\ w\ b\ \alpha)}{\partial w} = -q^*$

Proof of Proposition 3.

Similar to the proof of Proposition 2 According to the *envelope theorem*, we can obtain

$$\frac{\mathrm{d}U^{OB}(q, b^{OB}, o, \alpha)}{\mathrm{d}\alpha} = \frac{\partial U^{OB}(q, b^{OB}, o, \alpha)}{\partial q}\frac{\mathrm{d}q}{\mathrm{d}\alpha} + \frac{\partial U^{OB}(q, b^{OB}, o, \alpha)}{\partial \alpha}\frac{\mathrm{d}\alpha}{\mathrm{d}\alpha}, \tag{58}$$

$$\frac{\mathrm{d}U^{OB}(q, b^{OB}, o, \alpha)}{\mathrm{d}\alpha} = \left.\frac{\partial U^{OB}(q, b^{OB}, o\ \ \alpha)}{\partial \alpha}\right|_{q=q*} \tag{59}$$

Therefore, we can prove

$$\frac{\mathrm{d}U^{OB}(q^*, b^{OB}, o, \alpha)}{\mathrm{d}\alpha} = -S^{OB}(q^*) < 0 \tag{60}$$

Under the OB contract, the retailer's marginal optimal expected utility with respect to b^{OB} is

$$\begin{aligned} U_b^{OB}(q^*;b^{OB},o,\alpha) &= \frac{\mathrm{d}U^{OB}(q^*;b^{OB},o,\alpha)}{\mathrm{d}b^{OB}} \\ &= \frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial o}\frac{\mathrm{d}o}{\mathrm{d}b^{OB}} + \frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial b^{OB}}. \quad (61) \end{aligned}$$

Therefore

$$\frac{\mathrm{d}U_b^{OB}(q^*;b^{OB},o,\alpha)}{\mathrm{d}\alpha} = \frac{\partial U_b^{OB}(q^*;b^{OB},o,\alpha)}{\partial q}\frac{\mathrm{d}q}{\mathrm{d}a} + \frac{\partial U_b^{OB}(q^*;b^{OB},o,\alpha)}{\partial \alpha}\frac{\mathrm{d}\alpha}{\mathrm{d}\alpha}. \quad (62)$$

We can derive

$$\begin{aligned} \frac{\partial U_b^{OB}(q^*;b^{OB},o,\alpha)}{\partial q} &= \frac{\partial(\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial o}\frac{\mathrm{d}o}{\mathrm{d}b^{OB}} + \frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial b^{OB}})}{\partial q} \\ &= \frac{\partial(\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial o})}{\partial q}\frac{\mathrm{d}o}{\mathrm{d}b^{OB}} + \frac{\partial(\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial b^{OB}})}{\partial q} \\ &= 0. \quad (63) \end{aligned}$$

Then

$$\begin{aligned} \frac{\mathrm{d}U_b^{OB}(q^*;b^{OB},o,\alpha)}{\mathrm{d}\alpha} &= \frac{\partial U_b^{OB}(q^*;b^{OB},o,\alpha)}{\partial \alpha} \\ &= \frac{\partial(\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial o})}{\partial \alpha}\frac{\mathrm{d}o}{\mathrm{d}b^{OB}} + \frac{\partial(\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial b^{OB}})}{\partial \alpha} \\ &= 0\frac{\mathrm{d}o}{\mathrm{d}b^{OB}} + \frac{\partial(\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial b^{OB}})}{\partial \alpha} \\ &= \frac{2S^{OB}(q^*)}{p - b^{OB}} > 0, \quad (64) \end{aligned}$$

since $\frac{\partial U^{OB}(q^*;b^{OB},o,\alpha)}{\partial o} = -q^*$.

Proof of Proposition 4.

We first need to prove that (34) is a necessary condition for the constraints of (29) and (30) binding. Suppose there are three types: α_k, $\alpha_\imath$ and $\alpha_j \in [0, \bar{\alpha}]$, where $\alpha_k = \alpha_i - \epsilon$ and $\alpha_j = \alpha_i + \epsilon$, $\epsilon \to 0$. If (34) holds, we have

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i)=0} = 0. \tag{65}$$

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_k}, o_{\alpha_k}, \alpha_k)=0} = 0. \tag{66}$$

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_j)=0} = 0. \tag{67}$$

If the retailer's type is α_i, (65) ensures she will order q^c under the contract $(b^{OB}_{\alpha_i}, o_{\alpha_i})$ that is designed for her type. Then the constraint of (29) is satisfied. Meanwhile, the first order condition of U^{OB} with respect to the buyback price at the OB contract $(b^{OB}_{\alpha_i}, o_{\alpha_i})$ holds. However, in order to ensure U^{OB} is maximized under the contract $(b^{OB}_{\alpha_i}, o_{\alpha_i})$, we need to show $U^{OB}(q^*)$ is a concave function.

According to Proposition 3, we can derive that

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^*, b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_i)=0} < \left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_j)=0} = 0. \tag{68}$$

and

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^*, b^{OB}_{\alpha_k}, o_{\alpha_k}, \alpha_i)=0} > \left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_k}, o_{\alpha_k}, \alpha_k)=0} = 0. \tag{69}$$

Thus we have

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^*, b^{OB}_{\alpha_k}, o_{\alpha_k}\ \alpha_i)=0} > \left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i)=0} > \left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_i)=0}. \tag{70}$$

From (70), when $\epsilon \to 0$, we can derive

$$\left.\frac{\mathrm{d}^2U^{OB}}{\mathrm{d}b^{OB^2}}\right|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i)=0} < 0. \tag{71}$$

(71) and (65) indicate $U^{OB}(q^*; \alpha)$ is a concave function and it is maximized under the contract $(b^{OB}_{\alpha}, o_{\alpha})$. Therefore, the constraint of (30) is binding.

Next we derive the relationship between b^{OB} and o.

According to (61), we can obtain

$$\left.\frac{\mathrm{d}U^{OB}}{\mathrm{d}b^{OB}}\right|_{\Gamma^{OB}(q^c,b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i)=0} = \frac{\partial U^{OB}(q^c;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i)}{\partial o_{\alpha_i}}\frac{\mathrm{d}o_{\alpha_i}}{\mathrm{d}b^{OB}_{\alpha_i}}+\frac{\partial U^{OB}(q^c;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i)}{\partial b^{OB}_{\alpha_i}} = 0. \tag{72}$$

Because

$$\frac{\partial U^{OB}(q^c;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i)}{\partial o_{\alpha_i}} = -q^c, \tag{73}$$

and

$$\frac{\partial U^{OB}(q^c;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i)}{\partial b^{OB}_{\alpha_i}} = \frac{2\alpha_i S^{OB}(q^c)}{p-b^{OB}_{\alpha_i}} + \int_0^{q^c} G(x)\,dx. \tag{74}$$

Thus we can obtain

$$\frac{\mathrm{d}o_{\alpha_i}}{\mathrm{d}b^{OB}_{\alpha_i}} = \frac{\frac{2\alpha_i S^{OB}(q^c)}{p-b^{OB}_{\alpha_i}} + \int_0^{q^c} G(x)\,dx}{q^c}, \text{ for any } \alpha_i \in [0,\bar{\alpha}]. \tag{75}$$

Proof of Corollary 1

We prove the corollary by contradiction. Assume to the contrary that the buyback price for α_j is lower than the one for α_i and $\alpha_i < \alpha_j$. That is, $b^{OB}_{\alpha_j} < b^{OB}_{\alpha_i}$. According to proposition (3.5.1), we have

$$\begin{aligned} U^{OB}(q^c;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i) &- U^{OB}(q^*;b^{OB}_{\alpha_j},o_{\alpha_j},\alpha_i) \\ &< U^{OB}(q^*;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_j) - U^{OB}(q^c;b^{OB}_{\alpha_j},o_{\alpha_j},\alpha_j). \end{aligned} \tag{76}$$

By Proposition 4, we can obtain that

$$U^{OB}(q^c;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_i) - U^{OB}(q^*;b^{OB}_{\alpha_j},o_{\alpha_j},\alpha_i) > 0,$$

therefore

$$U^{OB}(q^*;b^{OB}_{\alpha_i},o_{\alpha_i},\alpha_j) - U^{OB}(q^c;b^{OB}_{\alpha_j},o_{\alpha_j},\alpha_j) > 0.$$

This indicates that $\frac{dU^{OB}}{db^{OB}}\Big|_{\Gamma^{OB}(q^c, b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_j)=0} \neq 0$, which contradicts Proposition 4. Thus, this completes the proof that $b^{OB}_{\alpha_j} > b^{OB}_{\alpha_i}$, if $\alpha_j > \alpha_i$. According to the equation (35), we know that $\frac{do_\alpha}{db^{OB}_\alpha} > 0$ and therefore, $o_{\alpha_j} > o_{\alpha_i}$.

By Proposition 3 and 4, we can obtain

$$U^{OB}(q^*; b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_i) > U^{OB}(q^c; b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_j)$$

and

$$U^{OB}(q^c; b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i) > U^{OB}(q^*; b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_i),$$

respectively. Thus, we can derive that

$$U^{OB}(q^c; b^{OB}_{\alpha_i}, o_{\alpha_i}, \alpha_i) > U^{OB}(q^c; b^{OB}_{\alpha_j}, o_{\alpha_j}, \alpha_j),$$

where $\alpha_i < \alpha_j$.

Proof of Theorem 3.

According to Proposition 4, (35) is the necessary condition to enforce the coordination constraint and the IC constraint. Nonetheless (35) only states the change of option cost with respect to the buyback price. In order to calculate a specific menu of OB contracts, o_α and b^{OB}_α should be derived based on (35), as shown in (36), where s could be any value such that the derived menu of OB contracts complies with the retailer's IR constraint.

Proof of Proposition 5.

We first note that $\frac{db_s}{ds} > 0$. Because of the chain rule we know that, e.g., $\frac{dU^{OB}(q^c;s,\alpha)}{ds} = \frac{dU^{OB}(q^c;s,\alpha)}{db_s}\frac{db_s}{ds}$, and similarly for $\frac{d\Pi^{OB}(q^c;s,\alpha)}{ds}$. So, only the sign of $\frac{dU^{OB}(q^c;s,\alpha)}{db_s}$ and $\frac{d\Pi^{OB}(q^c;s,\alpha)}{db_s}$ matters. According to Theorem 3, the option price

$o_{\alpha_\imath}$ of the OB contract $(b_{\alpha_\imath}^{OB}, o_{\alpha_\imath})$ for a retailer $\alpha_\imath \in [0, \bar{\alpha}]$ depends on the value of $s \in [0, \bar{\alpha}]$. The option price can be described as

$$o_{\alpha_\imath}(b_{\alpha_\imath}^{OB}, s) = o_{\alpha_\imath}(b_{\alpha_\imath}^{OB}) - o_{\alpha_\imath}(b_s). \tag{77}$$

The change of $o_{\alpha\imath}$ with respect to b_s is

$$\begin{aligned} \frac{\mathrm{d}o_{\alpha_\imath}}{\mathrm{d}b_s} &= \frac{\mathrm{d}o_{\alpha_\imath}(b_{\alpha_\imath}^{OB})}{\mathrm{d}b_s} - \frac{\mathrm{d}o_{\alpha_\imath}(s)}{\mathrm{d}b_s} \\ &= 0 - \frac{\mathrm{d}o_{\alpha_\imath}(s)}{\mathrm{d}b_s} \\ &= -\frac{\mathrm{d}o_{\alpha_\imath}(b_{\alpha_\imath}^{OB})}{\mathrm{d}b_{\alpha_\imath}^{OB}}\bigg|_{b_{\alpha\imath}^{OB}=b_s}. \end{aligned} \tag{78}$$

Therefore, we can derive that

$$\frac{\mathrm{d}o_{\alpha_\imath}}{\mathrm{d}b_s} = -\frac{\frac{2\alpha_\imath S^{OB}(q^c)}{p-b_s} + \int_0^{q^c} G(x)\,dx}{q^c} < 0, \text{ where } b_s \in (c, p). \tag{79}$$

(79) indicates that $o_{\alpha_\imath}$ decreases with b_s. Because $\frac{\mathrm{d}o}{\mathrm{d}b^{OB}} > 0$, we can claim that $b_{\alpha_\imath}^{OB}$ decreases with b_s as well.

The change of the retailer $\alpha_\imath$'s optimal expected utility $U^{OB}(q^c; b_{\alpha\imath}^{OB}, o_{\alpha_\imath}(b_s), \alpha_\imath)$ with respect to b_s is

$$\begin{aligned} \frac{\mathrm{d}U^{OB}(q^c, b_{\alpha_\imath}^{OB}, o_{\alpha_\imath}(b_s), \alpha_\imath)}{\mathrm{d}b_s} &= \frac{\partial U^{OB}}{\partial o_{\alpha_\imath}}\frac{\mathrm{d}o_{\alpha_\imath}}{\mathrm{d}b_s} \\ &= (-q^c)\Big(-\frac{\frac{2\alpha_\imath S^{OB}(q^c)}{p-b_s} + \int_0^{q^c} G(x)\,dx}{q^c}\Big) \\ &= \frac{2\alpha_\imath S^{OB}(q^c)}{p-b_s} + \int_0^{q^c} G(x)\,dx > 0. \end{aligned} \tag{80}$$

(80) indicates that for any retailer $\alpha_\imath \in [0, \bar{\alpha}]$, her optimal expected utility $U^{OB}(q^c, b_{\alpha_\imath}^{OB}, o_{\alpha_\imath}(b_s), \alpha_\imath)$ increases with b_s.

The change of $\frac{\mathrm{d}U^{OB}(q^c, b_\alpha^{OB}, o_\alpha(b_s), \alpha)}{\mathrm{d}b_s}$ with respect to α is

$$\begin{aligned} \frac{\mathrm{d}^2U^{OB}(q^c, b_\alpha^{OB}, o_\alpha(b_s), \alpha)}{\mathrm{d}b_s\mathrm{d}\alpha} &= \frac{\mathrm{d}\big(\frac{2\alpha S^{OB}(q^c)}{p-b_s} + \int_0^{q^c} G(x)\,dx\big)}{\mathrm{d}\alpha} \\ &= \frac{2S^{OB}(q^c)}{p-b_s} > 0. \end{aligned} \tag{81}$$

Similarly, from the supplier's perspective, we can obtain

$$\begin{aligned}\frac{\mathrm{d}\mathbf{\Pi}^{OB}(q^c, b^{OB}_{\alpha_i}, o_{\alpha_i}(b_s), \alpha_i)}{\mathrm{d}b_s} &= \frac{\partial \mathbf{\Pi}^{OB}}{\partial o_{\alpha_i}} \frac{\mathrm{d}o_{\alpha_i}}{\mathrm{d}b_s} \\ &= q^c(-\frac{\frac{2\alpha_i S^{OB}(q^c)}{p-b_s} + \int_0^{q^c} G(x)\,dx}{q^c}) \\ &= -\frac{2\alpha_i S^{OB}(q^c)}{p-b_s} - \int_0^{q^c} G(x)\,dx < 0 \qquad (82)\end{aligned}$$

and

$$\frac{\mathrm{d}^2\mathbf{\Pi}^{OB}(q^c, b^{OB}_{\alpha}, o_{\alpha}(b_s), \alpha)}{\mathrm{d}b_s \mathrm{d}\alpha} = -\frac{2S^{OB}(q^c)}{p-b_s} < 0. \qquad (83)$$

Proof of Proposition 6.

The supplier chooses s, the least risk-averse among the retailers who have no type information advantage, to earn as much as her reservation utility.

Suppose any retailer $\alpha_k \neq s$. Since s has no information advantage, α_k will be better off by pretending being s. That is

$$U(q^c; w_{\alpha_k}, b_{\alpha_k}, \alpha_k) < U(q^*; w_s, b_s, \alpha_k). \qquad (84)$$

In the OB contract scheme, we have

$$U^{OB}(q^c; b^{OB}_{\alpha_k}, o_{\alpha_k}, \alpha_k) > U^{OB}(q^*; b^{OB}_s, o_s, \alpha_k) \qquad (85)$$

according to (30).

Since the OB contract for s is the same as the buyback contract she can get when she is observable, we can have

$$U^{OB}(q^*; b^{OB}_s, o_s, \alpha_k) = U(q^*; w_s, b_s, \alpha_k). \qquad (86)$$

Thus, from (84), (85) and (86), we can obtain

$$U^{OB}(q^c; b^{OB}_{\alpha_k}, o_{\alpha_k}, \alpha_k) > U(q^c; w_{\alpha_k}, b_{\alpha_k}, \alpha_k) = \underline{U}(\alpha_k), \qquad (87)$$

which indicates that, under the derived menu of OB contracts, α_k must be able to capture more than her reservation utility. The curve of the retailer's optimal expected utility in terms of her degree of risk under the OB contracts scheme must dominate the curve of her reservation utility. Hence the IR constraint must be satisfied.

Proof of Theorem 4.

In the benchmark case, the retailer type $\alpha \in [0, \bar{\alpha}]$ and $\underline{U}(\alpha) = 0$. Let $(\hat{w}, \hat{b})$ denote the buyback contract that satisfies the condition (38) and (39).

The menu of OB contracts is calculated such that the risk-neutral retailer can earn as much as under $(\hat{w}, \hat{b})$. Then the OB contracts for other types can be derived through Theorem 3 with $s = 0$. The OB contract for $\alpha = 0$ is $(w^{OB} = \hat{w}, b_0^{OB} = \hat{b}, o_0 = 0)$, which is actually the same as $(\hat{w}, \hat{b})$, therefore $U^{OB}(q^*; b_0^{OB}, o_0, \alpha_\imath) = U(q^*, \hat{w}, \hat{b}, \alpha_\imath)$ for any $\alpha_\imath \in [0, \bar{\alpha}]$. According to (30), $U^{OB}(q^c, b_{\alpha_\imath}^{OB}, o_{\alpha_\imath}, \alpha_\imath) > U^{OB}(q^*, b_0^{OB}, o_0, \alpha_\imath) = U(q^*, \hat{w}, \hat{b}, \alpha_\imath)$, indicating that any risk-averse retailer $\alpha_\imath$ can get better off by entering the OB contract designed for her than $(\hat{w}, \hat{b})$.

Then we turn to the supplier's side. The change of the supplier's optimal expected profit with the retailer $\alpha_\imath$ who enters the dedicated OB contract $(w^{OB}, b_{\alpha_\imath}^{OB}, o_{\alpha_\imath})$ is described by

$$\begin{aligned}
\frac{\mathrm{d}\Pi^{OB}(q^c; b_{\alpha_\imath}^{OB}, o_{\alpha_\imath}, \alpha_\imath)}{\mathrm{d}b_{\alpha_\imath}^{OB}} &= \frac{\partial \Pi^{OB}}{\partial o_{\alpha_\imath}} \frac{\mathrm{d}o_{\alpha_\imath}}{\mathrm{d}b_{\alpha_\imath}^{OB}} + \frac{\partial \Pi^{OB}}{\partial b_{\alpha_\imath}^{OB}} + \frac{\partial \Pi^{OB}}{\partial \alpha_\imath}\left(\frac{\partial \alpha_\imath}{\partial o_{\alpha_\imath}} \frac{\mathrm{d}o_{\alpha_\imath}}{\mathrm{d}b_{\alpha_\imath}^{OB}} + \frac{\partial \alpha_\imath}{\partial b_{\alpha_\imath}^{OB}}\right) \\
&= \frac{\partial \Pi^{OB}}{\partial o_{\alpha_\imath}} \frac{\mathrm{d}o_{\alpha_\imath}}{\mathrm{d}b_{\alpha_\imath}^{OB}} + \frac{\partial \Pi^{OB}}{\partial b_{\alpha_\imath}^{OB}} \\
&= q^c\left(\frac{\frac{2\alpha_\imath S^{OB}(q^c)}{p - b_{\alpha_\imath}^{OB}} + \int_0^{q^c} G(x)\,dx}{q^c}\right) - \int_0^{q^c} G(x)\,dx \\
&= \frac{2\alpha_\imath S^{OB}(q^c)}{p - b_{\alpha_\imath}^{OB}} > 0
\end{aligned} \qquad (88)$$

The change of the supplier's optimal expected profit with the retailer α_i who enters the buyback contract $(\hat{w}, \hat{b})$ is described by

$$
\begin{aligned}
\frac{\mathrm{d}\mathbf{\Pi}(q^*; \hat{w}, \hat{b}. \alpha_i)}{\mathrm{d}\alpha_i} &= \frac{\partial \mathbf{\Pi}}{\partial q^*}\frac{\mathrm{d}q^*}{\mathrm{d}\alpha_i} + \frac{\partial \mathbf{\Pi}}{\partial \alpha_i} \\
&= \frac{\partial \mathbf{\Pi}}{\partial q^*}\frac{\mathrm{d}q^*}{\mathrm{d}\alpha_i} \\
&= ((\hat{w} - c) - \hat{b}G(q^*))\frac{\mathrm{d}q^*}{\mathrm{d}\alpha_i}
\end{aligned}
\tag{89}
$$

The q^* of any risk-averse retailer $\alpha_i \in (0, \bar{\alpha}]$ under the contract $(\hat{w}, \hat{b})$ is less than that of the retailer $\alpha = 0$ according to Lemma 2. Since the risk neutral retailer optimal quantity $q^* = q^c$ under the contract $(\hat{w}, \hat{b})$, we can prove that $G(q^*) < G(q^c) = \frac{\hat{w}-c}{\hat{b}}$. Thus $((\hat{w} - c) - \hat{b}G(q^*)) > 0$. By Lemma 2, we also know $\frac{\mathrm{d}q^*}{\mathrm{d}\alpha_i} < 0$. Therefore, we can prove

$$
\frac{\mathrm{d}\mathbf{\Pi}(q^*; \hat{w}, \hat{b}, \alpha_i)}{\mathrm{d}\alpha_i} < 0. \tag{90}
$$

From (88) and (90), we can conclude that

$$
\mathbf{\Pi}^{OB}(q^c; b_{\alpha_i}^{OB}, o_{\alpha_i}, \alpha_i) > \mathbf{\Pi}^{OB}(q^c; b_0^{OB}, o_0, 0), \tag{91}
$$

and

$$
\mathbf{\Pi}(q^*; \hat{w}, \hat{b}, \alpha_i) < \mathbf{\Pi}(q^c; \hat{w}, \hat{b}, 0). \tag{92}
$$

Because $\mathbf{\Pi}^{OB}(q^c; b_0^{OB}, o_0^{OB}, 0) = \mathbf{\Pi}^{OB}(q^c; \hat{w}, \hat{b}, 0)$, we have $\mathbf{\Pi}^{OB}(q^c; b_{\alpha_i}^{OB}, o_{\alpha_i}^{OB}, \alpha_i) > \mathbf{\Pi}(q^*; \hat{w}, \hat{b}, \alpha_i)$, which indicates that the supplier will have a higher expected profit under the OB contract scheme than $(\hat{w}, \hat{b})$. Therefore, we can conclude that the supplier is better off under the OB contract scheme when the retailer is risk averse. Since all retailer types order q^c under the OB contract scheme, the supply chain always stays coordinated.

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