

UC Berkeley

UC Berkeley Electronic Theses and Dissertations

Title

Mechanism Design for Multi-layer Supply Chains

Permalink

<https://escholarship.org/uc/item/903828k2>

Author

Kung, Ling-Chieh

Publication Date

2012

Peer reviewed|Thesis/dissertation

Mechanism Design for Multi-layer Supply Chains

by

Ling-Chieh Kung

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy

in

Engineering – Industrial Engineering and Operations Research

in the

Graduate Division
of the
University of California, Berkeley

Committee in charge:

Professor Ying-Ju Chen, Chair
Professor Zuo-Jun Shen
Professor J. Miguel Villas-Boas

Spring 2012

Mechanism Design for Multi-layer Supply Chains

Copyright 2012
by
Ling-Chieh Kung

Abstract

Mechanism Design for Multi-layer Supply Chains

by

Ling-Chieh Kung

Doctor of Philosophy in Industrial Engineering and Operations Research

University of California, Berkeley

Professor Ying-Ju Chen, Chair

In this dissertation, we consider a three-layer supply chain with a manufacturer, a reseller, and a salesperson. In the manufacturer's target market, the sales outcome is jointly determined by the market condition and the salesperson's sales effort. While the salesperson can privately observe both, the manufacturer observes none. If the manufacturer contracts with the salesperson directly, it faces a mixture of the adverse selection and moral hazard problems. Because the reseller has a closer contact to the market and the salesperson, she can better monitor the two pieces of private information. Therefore, the manufacturer may delegate the sales responsibility to the reseller to indirectly mitigate the inefficiency caused by information asymmetry. As different resellers have different monitoring expertise, the manufacturer faces a supply chain construction problem by deciding which reseller to delegate to. Unlike traditional two-layer principal-agent problems in which the principal searches for the optimal direct monitoring functions, this dissertation studies the optimal strategy of indirect monitoring.

Using the mechanism design approach and extending the traditional principal-agent model, we discuss the manufacturer's reseller selection strategy and the embedded salesforce compensation problem faced by the reseller. When the reseller can either observe the market condition or the sales effort, we show that the manufacturer should delegate to the latter one. We then study the reseller's resource allocation problem when the reseller can estimate the two aspects, both imperfectly, subject to a fixed budget constraint. When the reseller can only estimate the market condition, we show that the manufacturer's expected profit is convex on the reseller's accuracy. Collectively, our results deliver insights to manufacturers in selecting their reselling partners with various monitoring abilities and answers how the reseller's monitoring functions affect the supply chain performance.

Contents

List of Figures	iii
List of Tables	iv
1 Introduction	1
1.1 Background and Motivation	1
1.2 Research objectives	3
1.3 Research scope and limitations	4
2 Literature review	6
2.1 The principal-agent model	6
2.2 Multi-layer structures	6
2.3 Selection of monitoring strategies	7
2.4 Demand forecasting	8
3 Monitoring the market or the salesperson?	9
3.1 Model	9
3.2 Analysis	11
3.2.1 Benchmark case: direct sales	11
3.2.2 Knowledgeable reseller	13
3.2.3 Diligent reseller	15
3.2.4 Comparisons	16
3.2.5 Discussions	17
3.3 Private expertise and risk aversion	21
3.3.1 Private reseller's expertise	21
3.3.2 Resellers with negative exponential utility functions	23
3.3.3 Resellers with limited liability	26
3.4 Performance gaps	27
3.4.1 Relative importance of adverse selection and moral hazard	28
3.4.2 Negative exponential utility functions	28
3.4.3 Limited liability	30
3.4.4 Complementarity between demand and efforts	31

3.5	Summary	31
4	Focusing or balancing?	33
4.1	Model	33
4.2	Analytical results	35
4.2.1	The contract design problem	35
4.2.2	The resource allocation problem	37
4.3	Numerical studies	39
4.3.1	Impact of the physical restrictions	40
4.3.2	Impact of the relative costs	41
4.3.3	Impact of the degree of complementarity	42
4.4	Summary	44
5	The optimal forecasting accuracy	46
5.1	Model	46
5.2	Analysis	49
5.2.1	The contract design problems	49
5.2.2	Supply chain performance and the reseller's accuracy	52
5.2.3	System-optimal reseller's accuracy and supply chain structure	55
5.2.4	Profit splitting and supply chain coordination	57
5.2.5	The salesperson's accuracy	60
5.3	Extensions	61
5.3.1	Privatization of the reseller's signal	61
5.3.2	Limited liability of the salesperson	62
5.3.3	General levels of pessimism	65
5.4	Summary	67
6	Conclusions	69
	Bibliography	71
A	Appendix for Chapter 3	75
B	Appendix for Chapter 4	83
C	Appendix for Chapter 5	86

List of Figures

3.1	Expected Profits under Reseller's Risk Aversion	29
3.2	Difference of Expected Profits under Reseller's Risk Aversion	29
4.1	Sequence of events	35
4.2	Expected profits	39
4.3	Impact of K_ξ	39
4.4	Impact of c_ξ	43
4.5	Impact of c_{joint}	43
5.1	Sequence of events.	49
5.2	Nonmonotonicity of the expected sales.	53
5.3	System-optimal reseller's accuracy.	57
5.4	Incentive misalignment.	59
5.5	Monotonicity of the expected sales with various levels of pessimism.	66
5.6	System-optimal reseller's accuracy with various levels of pessimism.	66

List of Tables

4.1	Numbers of FOE, FOD, and balancing solutions	41
4.2	Numbers of FOE, FOD, and balancing solutions (continued)	42
4.3	Number of balancing solutions under different c_{joint} and K_ξ	44
B.1	Impact of K_ξ (for Figure 4.3)	85
B.2	Impact of c_ξ (for Figure 4.4)	85
B.3	Impact of c_{joint} (for Figure 4.5)	85

Acknowledgments

The first person that I want to show my appreciation is, of course, my Ph.D. advisor Dr. Ying-Ju Chen. He is always nice, kind, and friendly. He led me into the fascinating field, mechanism design, in which he is undoubtedly professional. He taught me a lot to make me capable of conducting those research in my dissertation. He spent so much time on me and thought for me from my perspective. And most importantly, instead of instructing me by words, he showed me what a true scholar is by being a true scholar himself. He let me know that “example is better than precept” and motivated me to pass this philosophy to my students in my future career.

I would also thank my committee members, Dr. Shmuel S. Oren, Dr. Zuo-Jun (Max) Shen, and Dr. J. Miguel Villas-Boas (in alphabetical order). In my qualifying examination, they gave me quite a few valuable suggestions that allowed me to greatly enhance the quality of my dissertation. During a private conversation, Dr. Candace Yano also provided many new aspects to investigate those problems in my dissertation. I appreciate all these professors for their generous support and encouragement. My dissertation will be less contributive without any of them.

UC Berkeley is such a wonderful place for any students. Here I learned a lot from my professors in many courses. In particular, I would like to thank Dr. Alper Atamtürk, Dr. Ying-Ju Chen, Dr. Sarah Drewes, Dr. Xin Guo, Dr. Dorit S. Hochbaum, Dr. Andrew Lim, Dr. Zuo-Jun (Max) Shen, and Dr. Candace Yano (in alphabetical order). Their excellent courses helped me build the necessary foundation for my future career. I will try my best to be as diligent and helpful as them when I become a teacher.

Life in Berkeley is always interesting with my good friends. I am so lucky to have Guan-Cheng, Jack, KC, Ping, Robert, and Yifen (in alphabetical order) in my department. Those nights that we spent on chatting with each other, talking about news in our department, and discussing our research ideas are unforgettable. It is also a great pleasure to participate in the volleyball team and softball team of the Berkeley Taiwanese student association. I enjoyed every practice and every game with my wonderful teammates, including Arnie, Audrey, Cedric, Emma, Gravel, Hank, Jason, John, Li-Min, Orion, Puffer, Ricky, Shawn, Shu-Tsen, Ting-Ying, Yun-Ling (in alphabetical order), and many others. One of the greatest pity of leaving Berkeley is that we can play no more games together.

Finally, I want to give the most appreciation to my parents. They raised me up, gave me everything I need, and let me know how to be responsible to myself. They sacrificed the best thirty years in their lives to give me the chance of realizing my dream. If I can make only one wish in my life, I hope they will always be proud of me.

Ling-Chieh Kung
April 23, 2012

Chapter 1

Introduction

1.1 Background and Motivation

It is pervasive for a manufacturer to sell its products to other countries. Such a strategy of “going global” allows a manufacturer to expand its territory, increase sales quantity, and become more profitable. For most of the cases, overseas manufacturers delegate the sales business to large-scale national resellers in order to run this global business. These independently-managed resellers, such as importers, wholesalers, and resellers, purchase products from the manufacturer and sell those products to consumers through local salespeople. They help manufacturers distribute products through their retail stores and salespeople. Overseas manufacturers, national resellers, and local salespeople together form a global supply chain.¹

In a global supply chain, a priori these resellers may harm or benefit the manufacturer’s profitability. Because these resellers are not owned by the manufacturer, they make decisions to optimize their own objectives. This results in the well-documented *double marginalization* problem [12, 22, 31, 48], which increases the final retail price, reduces the sales quantity, and ultimately hurts both the end consumers and the manufacturer. However, multi-layer supply chains are commonly observed in practice with resellers in between the manufacturer and salespeople. It is thus natural to investigate the underlying reasons for this practice.

One generally recognized reason to include a reseller is because they can better manage local salespeople. Facing end consumers directly, salespeople may increase the sales outcome by exerting higher efforts or offering better services. Suppose there is no reseller and the manufacturer manages a salesperson by itself. Due to the long distance, typically the manufacturer cannot observe or even estimate the salesperson’s effort level. In this case, the sales outcome is usually the only instrument available for

¹Among other examples, the Taiwanese manufacturer Acer and the Korean manufacturer Samsung both sell their products in the United States and Europe and most of their profits are attributed to the global market. In the case of computers and consumer electronics, the reseller Best Buy is one of the most important partners of Acer and Samsung in North America.

the overseas manufacturer to measure the sales efforts. However, the sales outcome is determined not only by the effort level but also by the market condition, which presents another challenge for the manufacturer to estimate. The manufacturer who looks solely at the final sales may thus reward or punish the salesperson's luck rather than his effort. Because hard working does not guarantee a high compensation in return, the salesperson may choose to exert lower efforts and bring bad services to consumers. This eventually lowers the manufacturer's expected profit.

The inclusion of a reseller, in our view, might help alleviate these informational issues through two kinds of monitoring expertise: *demand forecasting*, which allows the reseller to predict the market condition, and *performance measurement*, which helps the reseller estimate the effort level. One particular evidence is the recent invention and development of Business Intelligence (BI) systems which generally provide demand forecasting and performance measurement as the main components.² While BI systems provide these monitoring functions, in practice they are primarily adopted by large-scale resellers (or the retailing department of vertically integrated companies).³ Manufacturers do not implement BI systems by themselves. Instead, most manufacturers delegate to resellers and capitalize their downstream partners' monitoring expertise. This is because resellers can achieve more precise demand forecasting and performance measurement than the manufacturer due to the close contact with the target market and those local salespeople. As a reseller better manages her salespeople, a supply chain can attract more consumers and the manufacturer can reach a higher sales volume.⁴

In short, from the manufacturer's perspective, whether delegating to a reseller improves its profitability depends on the detriments of double marginalization and the benefits of information acquisition. To examine such a trade-off, a model of decentralized supply chain with asymmetric market and effort information is required. While the decentralized decision making process allows us to incorporate the double marginalization issue, the information asymmetry highlights the significance of mon-

²SAS Retail Intelligence, the BI solution developed by SAS for the retailing industry, is one of the examples. It comprises seven components that can be implemented individually or collectively. Different components provide insights in different aspects including store performance and demand forecasting (see <http://www.sas.com/industry/retail/ris.html>).

³For example, AmBev, the largest beverage company in Latin America, imports Pepsi-Cola, Heineken, and Skol to local retail stores through its own network. The software from SAS is adopted to facilitate information sharing within its network. National Distributing Company, importing wine and spirits, installs the MicroStrategy BI platform to measure sales performance over 50,000 retail stores throughout the United States. U.S. Lumber benefits from Cognos' BI system by collecting its sales forecast and customer information. This helps U.S. Lumber to better determine the quantity of imported forest products from Europe, Canada, and South America for different states.

⁴Although our primary motivating examples are BI systems, these are by no means the only source that facilitates better monitoring. For example, Customer Relationship Management (CRM) also helps the firms to obtain knowledge about their customers, markets, and demands. Activity-Based Costing (ABC), Balance Scorecard, and some other advanced accounting systems also aim to provide internal control to better monitor their salespeople.

itoring strategies and the value of information. In particular, due to the presence of unobservable market condition (hidden information) and sales effort (hidden action), the model will naturally exhibit an intertwined *adverse selection* and *moral hazard* problem. Because different monitoring strategies alleviate each informational issue in different levels, such a model can also be used in analyzing the relative importance of adverse selection and moral hazard under various situations.

Despite of the prevalence in practice and the need of thorough analysis, multi-layer supply chains seldom appear in the supply chain contracting literature mainly due to its difficulty. For conventional supply chain models with only two players, the principal-agent model has been widely applied to study the contract design problem. For multi-layer supply chains, however, a player may be involved in two contracting relationships. In the three-layer supply chain considered in this study, the reseller must first contract with the upstream manufacturer and then contract with the downstream salesperson. The two contracting problems are interdependent and cannot be analyzed in the traditional way. Therefore, examining multi-layer supply chains is not only of practical values but also contributive to the academic literature.

In light of the above discussion, we aim to provide a rigorous game-theoretic analysis for multi-layer supply chains in this study. In particular, we adopt the mechanism design approach to investigate the impact of the supply chain members' monitoring expertise from the informational perspective. For all of our analytical results, relevant managerial implications will also be discussed.⁵

1.2 Research objectives

We consider a three-layer supply chain with a manufacturer, a reseller, and a salesperson.⁶ In the absence of the reseller, the manufacturer implements direct sales and faces two informational problems in the two-layer supply chain: the adverse selection problem regarding the market condition (hidden information) and the moral hazard problem regarding the sales effort (hidden action). On the contrary, delegating to the reseller and constructing a three-layer supply chain allows the manufacturer to capitalize on the reseller's knowledge but may introduce inefficiency due to incentive misalignment and double marginalization. The salesperson's effort level, the manufacturer's profitability, and the supply chain performance will all be affected by the reseller's monitoring ability.

⁵Even through this is a dissertation, the plural pronoun "we" rather than the singular pronoun "I" is used throughout this manuscript.

⁶Throughout this manuscript, we refer to the manufacturer as "it", the reseller as "she", and the salesperson as "he". We refer to an "*n*-layer" supply chain as one with *n* players, where *n* may be two or three in this manuscript. However, for ease of exposition, we use the term "multi-layer supply chains" to represent supply chains with multiple pairs of principal-agent relationships. Therefore, in this study, "multi-layer" means exactly "three-layer" even though in daily conversations people generally treat "two" as "multiple".

In this study, we examine the strategies for the reseller to build her monitoring expertise and the manufacturer’s preference over different resellers. In particular, we investigate three scenarios in which the reseller’s available monitoring strategies are different. We start by comparing two extreme monitoring strategies: Perfect demand monitoring and perfect effort monitoring. The reseller may install an advanced demand forecasting system to precisely predict the market condition or observe the salesperson’s effort level with her performance measurement expertise. In either case, she cannot possess any estimation on the other aspect. In Chapter 3, we compare the two polar cases.

Because a monitoring function is typically subject to some physical restrictions and cannot be completely precise, the above two perfect monitoring strategies may not be implementable. Moreover, it is possible that focusing in only one side is suboptimal and balancing between the two sides is more effective. Therefore, we generalize the above binary setting and extend the reseller’s strategy space to the continuum between the two extreme focusing strategies. In Chapter 4, we consider the reseller’s resource allocation problem of dividing her fixed budget to invest in the two monitoring functions.

In many practical situations, it is extremely difficult, if not impossible, for the reseller to monitor the sales effort. This motivates us to consider the third scenario, in which the reseller cannot implement performance measurement and can only conduct demand forecasting. In this scenario, the reseller chooses her forecasting accuracy between completely uninformed and perfectly precise. We study the impact of the reseller’s accuracy in Chapter 5. To expand the applicability of our results, we also allow the salesperson to decide his own demand forecasting accuracy.

1.3 Research scope and limitations

In this study, we focus on “*make-to-order*” (MTO) production systems, i.e., we assume that the manufacturer has ample (unlimited) capacity and can deliver the product to consumers after demand realization. By excluding the inventory decision in “*make-to-stock*” (MTS) systems, we can concentrate on the informational perspective and examine the values of different information. In addition, improving demand forecasting in MTS systems facilitates better inventory control and reduces holding and shortage costs (see, e.g., [2, 5, 32]) in expectation. Therefore, only in MTO systems we can fairly compare the benefits of demand forecasting and performance measurement in alleviating information asymmetry.

We also assume that there is only one manufacturer in our supply chain. When there are multiple manufacturers, they may compete in contract offers in order to earn the collaboration opportunity with the reseller. The competition among manufacturers thus creates a *common agency* problem, which is notoriously complicated in the economic literature (see, e.g., [28] for an introduction). As the main objective

of this study is to extend the traditional two-layer model vertically into three layers, we choose to eliminate the common agency issue, which is a horizontal extension of the traditional model. This allows us to focus on investigating the difference between direct and indirect information elicitation.

Finally, though the reseller's monitoring accuracy is endogenously chosen by herself, we do not allow the reseller to modify the accuracy once it is determined. In this study, the reseller can select her accuracy before contracting with the manufacturer but cannot privately change her accuracy after the contracting stage. Allowing the reseller to modify her accuracy at any time makes the selection of accuracy a hidden action of the reseller. This will introduce an additional moral hazard problem on the reseller's accuracy and significantly complicate the model. To ensure tractability, we choose to restrict our attention to those cases that the reseller's accuracy cannot be modified once determined.

Chapter 2

Literature review

2.1 The principal-agent model

In the agency literature, both the moral hazard and adverse selection problems have been extensively studied. Broadly speaking, the impact of information asymmetry is studied in the principal-agent framework in which the agent possesses private information that the principal attempts to elicit, and it has been applied in various areas to design optimal mechanisms, including nonlinear pricing [52], managerial compensation schemes [10], supply chain contracting [7, 20, 50], and auctions [19, 33, 53, 54]. In stark contrast with the aforementioned papers, our setting exhibits a cascade of contract designs because the reseller is not only a contract follower (for the manufacturer) but also a contract designer (for the salesperson). The three-layer supply chain structure studied in our paper is not explored in these papers.

There is also substantial literature that studies supply chains in which firms have distinct information (See the complete survey by Chen [9]). In particular, incentive contracts (often in the menu form) are commonly adopted for firms to induce truthful revelation of private information from their partners' contract choice [6, 8, 21]. Because the salesperson in our model needs to be compensated appropriately through the reseller's contract design, our work is also related to the field of salesforce compensation [10, 16, 29, 34, 41, 45, 46]. The three-layer supply chain structure studied in our paper is not explored in the aforementioned papers. Moreover, with our three-layer framework, we combine supply chain contracting (in the manufacturer-reseller relationship) and salesforce compensation (in the reseller-salesperson relationship) in this study. This study thus lies in the interface of these two fields.

2.2 Multi-layer structures

The multi-layer supply chain design considered in this study is closely related to that on the economic organization that assumes full bargaining power for the principal

and examines when/whether delegation can be beneficial (see, e.g., [4, 39], and the survey by Mookherjee [43]). In contrast, playing the role of a middleman, resellers in our model also retain certain bargaining power upon delegation. In the literature of economic organization, the cost/benefit of including an additional middleman between the principal and the agent was studied [13, 24, 14, 38, 49]. However, these studies assume that the middleman is either as uninformed as the principal (as in [13, 38]) or able to monitor the agent's action (effort) (as in [24, 14, 49]). Because we include both demand forecasting and performance measurement, we go beyond these studies to compare between monitoring the agent's hidden information (market condition) and hidden action (effort level).

2.3 Selection of monitoring strategies

In this study, we discuss the impact and relative importance of demand forecasting and performance measurement in supply chains. How performance measurement may facilitate salesforce management has been a central topic in the marketing literature [1, 23, 25]. On the other hand, researchers in operations management have shown that demand forecasting can alleviate demand uncertainty and therefore benefit a firm or the whole supply chain [2, 5, 32]. Nevertheless, no study has investigated the resource allocation problem regarding demand forecasting and performance measurement simultaneously. Because the resource allocation problem has an embedded contract design problem, our study also contributes to the vast literature on salesforce management and staffing policies (cf. the review by Mantrala et al. [35]).

The issue of what to monitor, especially the choice between input-based (effort level) and output-based (sales outcome) compensations, has been studied before in the economics literature. The seminal paper by Holmstrom and Milgrom [18] considers a multi-tasking problem and shows that it is typically suboptimal to make the compensation entirely based on the inputs. Zhao [55] shows that if the principal cannot monitor all the inputs (efforts for all the tasks) by the agent, then output-based compensation should be applied. There are also other studies that address the relationship between hidden information and hidden action by comparing input-based and output-based compensations (e.g., [30, 44]). Nevertheless, none of the aforementioned papers considers the possibility of allowing the principal to mitigate both the hidden information and the hidden action, which is the primary objective of this study. The effort exertion in a decentralized supply chain has been discussed in the operations management literature [10, 26]. To the best of our knowledge, however, the resource allocation problem has no counterpart in this stream.

2.4 Demand forecasting

In the operations management literature, demand forecasting has been a central topic for decades. In a related research stream, researchers investigate the value of demand forecasting [2, 5, 15, 32]. In these papers, improved forecasting accuracy is unambiguously beneficial, whereas we show that this may be harmful to the entire supply chain and/or individual supply chain members in Chapter 5.

In recent years, researchers start to demonstrate the potential detriments of improving the demand forecasting ability of the downstream player(s) in two-layer supply chains. Miyaoka and Hausman [42] study a supplier-manufacturer relationship wherein the supplier makes a capacity decision and the manufacturer forecasts future demands. Shin and Tunca [47] consider a single supplier and multiple resellers and show that horizontal competition among resellers can drive resellers to overinvest in demand forecasting. Taylor and Xiao [51] demonstrate that a manufacturer's expected profit is convex in a newsvendor reseller's accuracy. Similar to Miyaoka and Hausman [42], they also find that the upstream player can be hurt when the downstream player improves her forecasting accuracy. Our study differs from theirs by taking the sales agent into consideration and considering a three-layer supply chain. Chen and Xiao [11] investigate a three-layer supply chain with a salesperson that is similar to ours. However, while in their supply chain the reseller and the sales agent always share the same demand signal, in Chapter 5 we allow the salesperson to conduct his own forecast. Our model thus exhibits two layers of adverse selection, as a distinguishing feature of our paper from the literature.

Chapter 3

Monitoring the market or the salesperson?

In this chapter, we compare the two extreme monitoring strategies of the reseller: perfect demand monitoring and perfect effort monitoring. In Section 3.1, we describe the basic model setting. Section 3.2 investigates the optimal contract design problem for the basic model and establish our main insights. The two sections also provide the foundation of studying extensions in Section 3.3. Performance gaps among different strategies under various environments are analyzed in Section 3.4. Finally, we summarize our findings in Section 3.5. All proofs are in Appendix A.

3.1 Model

We consider a supply chain in which a manufacturer relies on the salesperson to sell its products. The supply chain is operated in a make-to-order (MTO) manner, i.e., the manufacturer can deliver the products to the salesperson after demand is realized. Without loss of generality, we normalize the production cost to 0 and the selling price to 1.

Based on his past experience and local expertise, the salesperson is able to observe the market condition. Moreover, he can enhance the sales by exerting effort and providing better services. Specifically, the sales outcome x is determined by a random market condition θ , the salesperson's effort level a , and a random noise ϵ in the additive form

$$x = \theta + a + \epsilon, \tag{3.1}$$

where $\epsilon \sim N(0, \sigma^2)$ is a normally distributed random noise with σ^2 as its variance. The additive form implies that the effort level and the market condition are independent. Another setting is that higher efforts impact more as the market condition goes up, in which case the multiplicative form $x = \theta a + \epsilon$ is more appropriate. This alternative setting is investigated in Section 3.2.5. We assume that the salesperson incurs a cost

$V(a) = \frac{1}{2}a^2$ for choosing effort level a , where the quadratic form is made for simplicity. This setting is generalized to $V(a) = \frac{1}{2k}a^2$ for $k \in (0, \infty)$ in Section 3.2.5 to adjust the relative importance of adverse selection and moral hazard. It can also be shown that our results are qualitatively similar as long as $V(a)$ is strictly convex. The probability of x being negative is assumed to be sufficiently small.

Apart from the manufacturer and the salesperson, there are resellers in the market. Compared to the manufacturer, a reseller (she) has superior information that may help motivate the salesperson due to her close contact. We consider two types of resellers distinguished by their monitoring abilities. The first type of resellers, labelled as “*knowledgeable*” resellers, are able to observe the market condition θ . The second type of resellers, labelled as “*diligent*” resellers, can monitor the effort level a . The manufacturer has the option of delegating its sales business to either type of resellers. In the basic model analyzed in Section 3.2, the manufacturer directly sees a reseller’s expertise; the case with unobservable reseller’s expertise is investigated in Section 3.3.1. To highlight the informational effect, we normalize the monitoring costs of all scenarios to zero.

We assume the following exogenous parameters are publicly known: the functional form (3.1), the cost of efforts $\frac{1}{2}a^2$, the parameter σ^2 , and the realized sales outcome x . While the salesperson and the knowledgeable reseller observe the realization of θ , the diligent reseller and the manufacturer treat θ as random with distribution F , density f , and mean $\mu \equiv \mathbb{E}\theta$. We assume that F satisfies the increasing failure rate (IFR) property, i.e., the inverse failure rate $H(\theta) \equiv \frac{f(\theta)}{1-F(\theta)}$ decreases in θ .¹

While the manufacturer is risk-neutral and maximizes its expected profit, the salesperson is risk-averse and maximizes his expected utility. The salesperson’s risk preference is represented by a negative exponential utility function $U(z) = -e^{-\rho z}$ where z is his net income and $\rho > 0$ is the coefficient of absolute risk aversion. To examine the impact of the resellers’ risk attitude, we assume resellers are risk-neutral in Section 3.2 and then generalize our results to risk-averse resellers in Section 3.3. In particular, we consider two ways to represent risk aversion: negative exponential utility functions (in Section 3.3.2) and limited liability (Section 3.3.3). Both the salesperson’s and resellers’ (risk-free) reservation net incomes are normalized to zero without loss of generality.

In our three-layer supply chain, the manufacturer contracts with the reseller and then the reseller contracts with the salespeople. We restrict our attention to the class of linear contracts because of the prevalence in practice. Specifically, we use (α, β) to denote the contract signed by the reseller and the salesperson, where α is the fixed payment and β is the commission rate. With this contract, the salesperson receives an aggregate payment $\alpha + \beta x$ if sales outcome x is realized. Similarly, if the manufacturer and the reseller sign the contract (u, v) with fixed payment u and commission rate v ,

¹This condition, adopted in the screening literature to rule out the bunching phenomenon (cf. [27]), is satisfied by most usual distributions, including uniform, normal, logistic, chi-square, exponential and Laplace. See [3] for a more complete list.

the reseller will receive $u + vx$ from the manufacturer and $u - \alpha + (v - \beta)x$ as her net payoff. If the fixed payments are negative, they are interpreted as the franchise fees instead. Note also that this family of contracts includes one-part tariffs (when no fixed payment is involved) and sell-out contracts (when the manufacturer passes the sales proceeds to the reseller entirely by requesting a fixed franchise fee). While wholesale contracts are pervasive in industry, the relevant analysis is included in Section 3.3.3 as an extreme case of limited liability.

The above model assumptions, including the linear payment structure, the negative exponential utility, and the normally distributed randomness, together referred to as the LEN (linear-exponential-normal) assumption, are commonly adopted in the agency literature for tractability [10, 17, 18]. Although linear payment schemes are suboptimal, they are widely accepted to be a good workhorse to tackle the incentive provision problems and normally adopted by practitioners as well as in the academic literature [29, 41, 46].

3.2 Analysis

In this section, we analyze the case with risk-neutral resellers whose monitoring expertise is publicly known. To answer our research question, we characterize the optimal (menu of) contracts for the supply chain with no reseller (as a benchmark case), with the knowledgeable reseller, or with the diligent reseller, respectively.

3.2.1 Benchmark case: direct sales

Let us start with the direct selling scheme in which the manufacturer contracts with the salesperson directly. In this case, the manufacturer faces a mixture of adverse selection and moral hazard. This two-layer problem serves as a benchmark case, and will be compared with the two indirect selling schemes to illustrate the benefit of including a reseller (either knowledgeable or diligent). Though this benchmark case has been studied in the literature, we include it here for completeness.

In this manufacturer-salesperson relationship, the sequence of events is as follows. 1) The salesperson observes the market condition θ ; 2) Because the manufacturer is unable to observe the market condition θ , it offers a menu of contracts $\{\alpha(\theta), \beta(\theta)\}$ for the salesperson to self-select; 3) The salesperson chooses a contract in the menu and determines his effort level $a(\theta)$ accordingly. 4) The sales outcome x is realized, the manufacturer collects the sales revenue, and the salesperson is compensated. We suppress the descriptions on the cases where any downstream contracting party opts not to accept the offer, in which case the game ends and each player receives a null payoff.

To characterize the optimal compensation design problem, we use backward induction and start with the salesperson's problem. Suppose the salesperson has ob-

served θ but has chosen the contract $(\alpha(\tilde{\theta}), \beta(\tilde{\theta}))$. By choosing effort level a , he faces the final sales $x = \theta + a + \epsilon \sim N(\theta + a, \sigma^2)$ because $\epsilon \sim N(0, \sigma^2)$. Thus, the salesperson's net income $z(a) \equiv \alpha + \beta x - \frac{1}{2}a^2$ follows the normal distribution $N(\alpha + \beta(\theta + a) - \frac{1}{2}a^2, \sigma^2\beta^2)$. Given $z(a)$, the salesperson's expected utility is $\mathbb{E}[-e^{-\rho z(a)}] = -e^{-\rho CE_S(\theta, \tilde{\theta}|a)}$, where

$$CE_S(\theta, \tilde{\theta}|a) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a) - \frac{1}{2}a^2 - \frac{1}{2}\rho\sigma^2[\beta(\tilde{\theta})]^2$$

is called the salesperson's *certainty equivalent*. Because the exponential function is monotonic, maximizing the expected utility is equivalent to maximizing the certainty equivalent by choosing $a = \beta(\tilde{\theta})$. With this, the salesperson's maximum certainty equivalent is

$$CE_S(\theta, \tilde{\theta}) \equiv \max_{a \geq 0} CE_S(\theta, \tilde{\theta}|a) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})\theta + \frac{1}{2}[\beta(\tilde{\theta})]^2(1 - \rho\sigma^2).$$

Let $CE_S(\theta) \equiv CE_S(\theta, \theta)$.

In equilibrium, the manufacturer induces the salesperson to report the market condition truthfully by choosing the contract $(\alpha(\theta), \beta(\theta))$ upon observing θ . It then follows that the expected sales is $\theta + a(\theta)$ and consequently the manufacturer's expected profit is $(1 - \beta(\theta))(\theta + a(\theta)) - \alpha(\theta)$ if the market condition realization is θ . Therefore, the manufacturer's goal is to find the menu of contracts $\{\alpha(\theta), \beta(\theta)\}$ that solves²

$$M^* = \max_{\{\alpha(\theta) \text{ urs}, \beta(\theta) \geq 0\}} \mathbb{E}_\theta \left[(1 - \beta(\theta))(\theta + \beta(\theta)) - \alpha(\theta) \right]$$

$$\text{s.t. } CE_S(\theta) \geq CE_S(\theta, \tilde{\theta}), \quad \forall \theta, \tilde{\theta} \in (-\infty, \infty), \quad (3.2)$$

$$CE_S(\theta) \geq 0, \quad \forall \theta \in (-\infty, \infty). \quad (3.3)$$

The incentive compatibility (IC) constraint (3.2) ensures that it is the salesperson's best interest to choose the intended contract $(\alpha(\theta), \beta(\theta))$. The individual rationality (IR) constraint (3.3) ensures the participation of the salesperson (because his reservation wage is zero). the following lemma characterizes the optimal menu of contracts.

Lemma 1. *Suppose the manufacturer contracts directly with the salesperson, its optimal menu of contracts consists of the commission rate $\beta^*(\theta) = \frac{[1-H(\theta)]^+}{1+\rho\sigma^2}$. With the optimal menu, it induces the effort level $a^*(\theta) = \beta^*(\theta)$ and receives an expected profit*

$$M^* = \mathbb{E}_\theta \left[\theta + \frac{[1-H(\theta)]^+^2}{2(1+\rho\sigma^2)} \right].^3$$

²Throughout this study, we use "urs." as the abbreviation of "unrestricted in sign".

³Throughout this study, we use the convention $y^+ \equiv \max\{0, y\}$.

As indicated by Lemma 1, the mixture of adverse selection and moral hazard problems gives rise to an inefficient effort level. To limit the risk premiums that are necessary to compensate the salesperson for bearing risk, the manufacturer finds it optimal to cut down the commission rate since it reduces the amount of risk borne by the salesperson. Consequently, $\beta^*(\theta)$ is distorted downwards from the manufacturer's profit margin (1). Consider the moral hazard issue first. As the salesperson is more risk averse (ρ increases) or the demand is more volatile (σ^2 increases), more risk premiums must be paid and thus a larger downward distortion (captured by the term $1 + \rho\sigma^2$) arises in the commission rate. On the other hand, the term $[1 - H(\theta)]^+$ accounts for the adverse selection program in this manufacturer-salesperson relationship: As the salesperson privately observes the market condition θ , the manufacturer must distort the commission rate in order to induce truthful revelation. Collectively, these two effects lead to a distorted effort level as well as a liability for the manufacturer (as seen from its expected profit M^*). Note that while cutting down the commission rate is optimal, in practice $\beta^*(\theta)$ cannot be too small if a minimum level of effort level is required. The optimal $\beta^*(\theta)$ may then be at a boundary point.

3.2.2 Knowledgeable reseller

When the manufacturer includes the knowledgeable reseller, the sequence of events is as follows. 1) The manufacturer and the reseller agrees with a contract (u, v) ; 2) The reseller and the salesperson observe the market condition θ ; 3) The reseller announces the contract (α, β) ; 4) The salesperson determines his effort level a and then the sales x is realized. Note that in this scenario, a two-stage contract design problem arises, and the upstream and downstream contracting issues are intertwined.

We again start with the salesperson's problem. Given (α, β) and θ , the salesperson chooses effort level a and receives $CE_S^K(\theta|a) = \alpha + \beta(\theta + a) - \frac{1}{2}a^2 - \frac{1}{2}\rho\sigma^2\beta^2$ as his certainty equivalent. With the optimizer $a = \beta$, the salesperson's maximum certainty equivalent is $CE_S^K(\theta) = \alpha + \beta\theta + \frac{1}{2}\beta^2(1 - \rho\sigma^2)$. Given the salesperson's effort level, the expected sales is $\theta + \beta$ and consequently the reseller's expected profit is $u - \alpha + (v - \beta)(\theta + \beta)$. Therefore, the reseller's goal is to find the contract (α, β) that solves

$$R^K(\theta) = \max_{\alpha \text{ urs}, \beta \geq 0} u - \alpha + (v - \beta)(\theta + \beta)$$

$$\text{s.t.} \quad \alpha + \beta\theta + \frac{1}{2}\beta^2(1 - \rho\sigma^2) \geq 0,$$

where the constraint ensures that the salesperson is willing to accept the contract. Lemma 2 summarizes the solution to the above problem.

Lemma 2. *Given the contract (u, v) and the market condition θ , the knowledgeable reseller optimally offers the commission rate $\beta^K(\theta) = \frac{1}{1 + \rho\sigma^2}v$, induces the effort level $a^K(\theta) = \beta^K(\theta)$, and generates $R^K(\theta) = u + v\theta + \frac{1}{2(1 + \rho\sigma^2)}v^2$.*

Since the knowledgeable reseller also observes the market condition, she faces a pure moral hazard problem when contracting with the salesperson. Recall that ρ measures the salesperson's risk attitude and σ^2 reflects the sales volatility faced by the salesperson. As in the two-layer case analyzed in Lemma 1, $1 + \rho\sigma^2$ is an indicator of how costly – in terms of the amount of risk premium that is necessary for the salesperson to bear risks – it is for the reseller to induce the salesperson to exert efforts. In $R^K(\theta)$, the reseller's maximum expected profit contains the additional sales $\frac{1}{2(1+\rho\sigma^2)}v^2$ for motivating the salesperson to exert higher efforts. Notably, this quantity decreases as the cost of inducing higher efforts increases (i.e., ρ or σ^2 increases).

Having obtained the reseller's optimal contract for the salesperson, we proceed to the manufacturer's problem. The manufacturer could potentially design a menu of contracts for the reseller to choose. However, because the reseller observes θ after the contract is signed, this is unnecessary and a single (pooling) contract achieves the maximum. Thus, for ease of presentation we simply assume that the manufacturer offers a single contract (u, v) . Anticipating the effort level $\frac{1}{1+\rho\sigma^2}v$, the manufacturer knows that it will receive an expected profit $(1 - v)(\mu + \frac{1}{1+\rho\sigma^2}v) - u$ by offering (u, v) . Its goal is thus to solve

$$M^K = \max_{u \text{ urs}, v \geq 0} (1 - v)\left(\mu + \frac{1}{1 + \rho\sigma^2}v\right) - u$$

$$\text{s.t.} \quad u + v\mu + \frac{1}{2(1 + \rho\sigma^2)}v^2 \geq 0.$$

At the contracting stage, the reseller does not possess the information of the market condition. Therefore, her participation depends on her expected payoff, $\mathbb{E}_\theta[R^K(\theta)]$, which is guaranteed to be nonnegative by the constraint. An alternative scenario in which the reseller observes the market condition before she signs the contract is discussed in Section 3.2.5. The solution is characterized in the following lemma.

Lemma 3. *When including the knowledgeable reseller, the manufacturer's optimal contract (u^K, v^K) consists of $v^K = 1$ and $u^K = -\mu - \frac{1}{2(1+\rho\sigma^2)}$. Under this contract, the manufacturer's expected payoff is $M^K = \mu + \frac{1}{2(1+\rho\sigma^2)}$ with the induced effort level $a^K = \frac{1}{1+\rho\sigma^2}$ for all θ .*

Lemma 3 shows that the manufacturer finds it optimal to completely delegate the business to the reseller after charging a fixed payment, which can be interpreted as a franchise fee. This (pure) franchise fee contract is reminiscent of a “sell-out” contract, and it allows the manufacturer to bypass the potential effort distortion due to the delegation. As the reseller's profit margin is fixed at $v^K = 1$, double marginalization is avoided and the only source of effort distortion follows from the pure moral hazard problem (as captured by the term $\frac{1}{1+\rho\sigma^2}$). Therefore, the manufacturer can capitalize on the reseller's information advantage and fully extract the reseller's surplus.

3.2.3 Diligent reseller

Recall that a diligent reseller is able to observe the effort level and therefore can specify the required effort level in the contract. However, because of the unobservable market condition, she must offer a menu of contracts $\{\alpha(\theta), \beta(\theta), a(\theta)\}$ for the salesperson to report θ truthfully. In this case, the sequence of events is as follows. 1) The manufacturer announces the contract (u, v) ; 2) The salesperson observes the market condition θ ; 3) The reseller offers the menu of contracts $\{\alpha(\cdot), \beta(\cdot), a(\cdot)\}$ to the salesperson; 4) The salesperson follows the effort level specified in the contract. Then the sales x is realized and everyone receives the payoff according to the chosen contracts.

By backward induction, we first suppose that the salesperson observes a market condition θ but chooses the contract $(\alpha(\tilde{\theta}), \beta(\tilde{\theta}), a(\tilde{\theta}))$. In this case, he will get $\alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a(\tilde{\theta}) + \epsilon) - \frac{1}{2}[a(\tilde{\theta})]^2$ as his net income and

$$CE_S^D(\theta, \tilde{\theta}) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a(\tilde{\theta})) - \frac{1}{2}[a(\tilde{\theta})]^2 - \frac{1}{2}\rho\sigma^2[\beta(\tilde{\theta})]^2 \quad (3.4)$$

as his certainty equivalent. Let $CE_S^D(\theta) \equiv CE_S^D(\theta, \theta)$. The reseller's goal is to find the menu of contracts $\{\alpha(\theta), \beta(\theta), a(\theta)\}$ that solves

$$R^D(\theta) = \max_{\substack{\{\alpha(\theta)_{\text{urs}}, \beta(\theta) \geq 0 \\ , a(\theta) \geq 0\}}} \mathbb{E}_\theta [u - \alpha(\theta) + (v - \beta(\theta))(\theta + a(\theta))] \quad (3.5)$$

$$\text{s.t.} \quad CE_S^D(\theta) \geq CE_S^D(\theta, \tilde{\theta}) \quad \forall \theta, \tilde{\theta} \in (-\infty, \infty) \quad (3.5)$$

$$CE_S^D(\theta) \geq 0 \quad \forall \theta \in (-\infty, \infty). \quad (3.6)$$

The IC constraint (3.5) requires truth-telling and the IR constraint (3.6) guarantees participation. Lemma 4 summarizes the solution.

Lemma 4. *Given the contract (u, v) , the diligent reseller offers $\alpha^D(\theta) = \frac{1}{2}v^2$, $\beta^D(\theta) = 0$, and $a^D(\theta) = v$ and receives $R^D = u + v\mu + \frac{1}{2}v^2$.*

According to Lemma 4, the diligent reseller should not offer any commission to the salesperson; rather, she should enforce the salesperson to exert the optimal effort level v and compensate the salesperson just his cost of exerting efforts ($\frac{1}{2}v^2$). Since she receives no commission, the risk-averse salesperson's payoff is not related to the random sales outcome. This makes him get rid of the undesirable risk and requires no risk premium. Because the salesperson is now willing to accept any effort level as long as he receives a sufficient fixed payment, the reseller can implement the first-best effort level. Finally, due to the additive form of sales outcome (3.1), the marginal cost/benefit of exerting effort is independent of the market condition. This explains why the optimal contract is a single contract, even with the adverse selection issue in

the reseller-salesperson relationship.⁴

Having obtained the reseller's optimal contract for the salesperson, we now consider the manufacturer's problem. Anticipating the downstream players' behavior, the manufacturer designs a contract (u, v) to solve

$$M^K = \max_{u, v \geq 0} (1 - v)(\mu + v) - u$$

$$\text{s.t. } u + v\mu + \frac{1}{2}v^2 \geq 0,$$

where the expected sales quantity $\mu + v$ comes from $a^D(\theta) = v$ and the constraint ensures the reseller's participation. The solution is characterized below.

Lemma 5. *When including the diligent reseller, the manufacturer's optimal contract (u^D, v^D) consists of $v^D = 1$ and $u^D = -\mu - \frac{1}{2}$. Under this contract, the manufacturer's maximum expected payoff is $M^D = \mu + \frac{1}{2}$ with the induced effort level $a^D(\theta) = 1$ for all θ .*

We find that in this case, the manufacturer also passes the entire sales revenue to the diligent reseller in order to bypass the double marginalization problem. This "selling-the-business" strategy therefore motivates the reseller to enforce the efficient effort level (1) for the whole supply chain. Also note that in the reseller-salesperson relationship, no effort distortion is encountered due to the reseller's monitoring. Again, the manufacturer extracts the entire surplus from the reseller by the appropriately designed fixed payment.

3.2.4 Comparisons

Now we compare supply chain efficiency and the manufacturer's profit in the three supply chains. According to Lemmas 1, 3, and 5, we have

$$a^*(\theta) = \frac{[1 - H(\theta)]^+}{1 + \rho\sigma^2} < a^K(\theta) = \frac{1}{1 + \rho\sigma^2} < a^D(\theta) = 1$$

for every realization of θ . Therefore, including a reseller (no matter knowledgeable or diligent) increases supply chain efficiency by inducing higher efforts. Even though the reseller helps in neither productivity nor marketability, her monitoring alleviates information asymmetry in the supply chain and ultimately benefits the whole system by better motivating the salesperson.

⁴When the effects of effort level and market condition are not independent, the optimal contract will no longer be a single contract. In Section 3.2.5 we address this issue. Also note that this optimal contract requires the reseller to bear all the risk (with the zero commission rate). As we will see in Section 3.3.2, when the reseller is risk-averse, zero commission rate will not be optimal and her risk attitude will affect the contract offered.

Note that the diligent reseller is more effective than the knowledgeable reseller in inducing higher efforts. This is because when the diligent reseller monitors the risk-averse salesperson, she is able to exclude uncertainty in the salesperson's payoff through the contractual agreement; thus, no risk premium is required and no effort distortion arises. Though the hidden market condition amplifies effort distortion under direct sales, adverse selection results in a loss of efficiency only if moral hazard is present. On the contrary, even if the knowledgeable reseller is as informed as the salesperson regarding the market condition, the sales commission still exposes the salesperson to the undesirable risk. Consequently, the induced effort level will be distorted downwards. Since the overall supply chain performance is determined by the effort level, the dominance of $a^D(\theta)$ over $a^K(\theta)$ implies that delegating to a diligent reseller is more beneficial from the supply chain's perspective.

This distortion on effort level ultimately gives rise to a lower expected profit for the manufacturer. Because double marginalization can be avoided when including a reseller, the reseller's information directly helps the manufacturer in obtaining a higher expected profit. Recall that when either type of reseller is present, the manufacturer receives $M^D = \mu + \frac{1}{2}$ or $M^K = \mu + \frac{1}{2(1+\rho\sigma^2)}$ upon delegation, both of which are higher than M^* under direct sales. Thus, indirect sales is more profitable than direct sales, in stark contrast with the conventional wisdom that follows from the double marginalization argument [12, 22, 31, 48]. This also illustrates the benefit of demand forecasting even when there is no inventory decision. We summarize this finding in the following proposition.

Proposition 1. *The manufacturer can induce a higher effort and receive a higher expected profit by contracting with the diligent reseller than with the knowledgeable reseller. Moreover, indirect sales with either types of resellers is more profitable than direct sales.*

3.2.5 Discussions

Having obtained the above dominance result, we now discuss some potential variants of our model characteristics to evaluate its robustness.

Complementarity between demand and efforts

In certain scenarios, it is possible that a higher effort is more effective as the potential demand is higher. To capture this complementarity, we examine an alternative model in which the sales outcome takes the multiplicative form $x = \theta a + \epsilon$, where θ and ϵ are the same random variables as before. This multiplicative form implies that as the demand is higher, the marginal benefit of providing higher efforts becomes higher as well (cf. the marginal benefit of offering higher efforts is independent of the market condition in the additive form (3.1)). Thus, monitoring the market allows the knowledgeable reseller to evaluate how effective the salesperson's efforts are, whereas the

diligent reseller can only enforce appropriate efforts based on the prior assessment of this benefit.

At first glance, it seems that in this alternative setting, the manufacturer may prefer the knowledgeable reseller more likely. However, as we demonstrate in the next proposition, the dominance continues to hold.

Proposition 2. *When $x = \theta a + \epsilon$, the manufacturer is expected to induce a higher effort level and obtain a higher profit if contracting with the diligent reseller. The expected profits with the knowledgeable and the diligent resellers are $\frac{1}{2}E_\theta \left[\frac{\theta^4}{\theta^2 + \rho\sigma^2} \right]$ and $\frac{1}{2}E_\theta [\theta^2]$, respectively.*

Despite the apparent difference in the model characteristics, this proposition tells us that all the comparisons between the knowledgeable and diligent resellers continue to be valid. Specifically, delegating to the diligent reseller is more profitable for the manufacturer and more efficient in the system’s perspective. As shown in the appendix, the manufacturer can also offer a commission rate 1 and implement the “selling-the-business” strategy no matter which type to delegate. This allows the manufacturer to extract all the surplus from the reseller and in fact integrates the reseller. The dominance result can then be derived by the same arguments for the additive form.

Relative importance of adverse selection and moral hazard

Another question regarding the dominance result is whether it hinges on the specific “weight” or relative importance of the adverse selection and moral hazard issues. From our framework, the relative importance can be best captured by scaling the cost of exerting efforts by setting $V(a) = \frac{1}{2k}a^2$, where $k \in (0, \infty)$. When k is scaled up from 1, the efficient effort level increases since the cost decreases. Therefore, inducing higher efforts becomes more effective, which means the moral hazard issue becomes more important. In this case, intuitively the preference over the diligent reseller is amplified. On the other hand, as k approaches 0, inducing the effort level becomes more costly and less effective; on the extreme case, the effort level is optimally set at zero and perfectly predictable, where the moral hazard problem vanishes. Thus, decreasing the value of k adjusts the relative importance in favor of the adverse selection problem, and one would conjecture that the dominance result no longer holds.⁵ Nevertheless, this intuition is incorrect:

Proposition 3. *For any given $k \in (0, \infty)$, the manufacturer is expected to induce a higher effort level and obtain a higher profit if contracting with the diligent reseller.*

⁵Another possibility to adjust the importance of the moral hazard issue is to scale the impact of effort on the sales outcome (i.e., $x = \theta + wa + \epsilon$, where $w \in (0, \infty)$). However, this adjustment is in fact equivalent to scaling k since all that matters is the marginal cost/benefit of exerting higher efforts.

The expected profits with the knowledgeable and the diligent resellers are $\mu + \frac{k^2}{2(k+\rho\sigma^2)}$ and $\mu + \frac{k}{2}$, respectively.

Proposition 3 shows that the manufacturer unambiguously prefers the diligent reseller to the knowledgeable one, regardless of the relative importance of adverse selection and moral hazard. This is because delegating to the diligent reseller always induces an efficient effort level by monitoring the salesperson directly; on the contrary, irrespective of how unimportant the moral hazard issue is, the knowledgeable reseller must pay some risk premiums to the salesperson and consequently downwards distort the effort level. The dominance result thus continues to be valid.

Timing of contracting

We next examine the effect of different timing on the supply chain efficiency. Suppose that the knowledgeable reseller now observes the market condition before contracting with the manufacturer. In this case, the manufacturer faces an adverse selection (regarding the market condition) vis-a-vis the knowledgeable reseller. In order to induce the reseller to reveal this market condition truthfully, it must pay a positive information rent to some of the knowledgeable resellers (specifically, those who observe a high market condition). Since the compensation design problem in the reseller-salesperson relationship remains unchanged, this alternative timing unambiguously hurts the manufacturer and results in a manufacturer's expected profit lower than M^K . On the contrary, while facing the diligent reseller, the timing does not matter since the diligent reseller's information arrives only after the salesperson chooses the effort level. Thus, the manufacturer obtains the same expected profit with the diligent reseller (i.e., M^D), which has been shown to be higher than M^K . This suggests that the dominance of the diligent reseller over the knowledgeable reseller is *strengthened* with this alternative timing.

Contract forms

One may argue that a menu of contracts allows the diligent reseller to elicit information from the salesperson and obtain the market condition. However, since the diligent reseller turns out to offer a single contract, she can still achieve R^D without using a menu. This implies that the dominance does not depend on the use of a contract menu. Similarly, it can be shown that allowing the knowledgeable reseller to use a menu does not improve her expected payoff.

Another question regarding the contract form is the linear contract used in this supply chain, which is suboptimal for the knowledgeable reseller. According to [40], if the knowledgeable reseller can design an arbitrarily complicated nonlinear contract, she will be able to approximate as closely as she wants to the first-best effort level and eliminate the pure moral hazard problem. Delegating to the two types of resellers then makes no difference. However, as argued in the literature, it is impractical for

a principal (the knowledgeable reseller in our case) to design such a complicated contract: Either the principal is not sophisticated enough or the contract cannot be executed. Therefore, in practice the manufacturer should still delegate to the diligent one, who can achieve first best with a simple linear contract.

Direct monitoring

Given the fact that indirect sales outperforms direct sales, it is clear that obtaining information indirectly is better than obtaining no information. It is then natural to examine whether the manufacturer can be better off by obtaining information directly, i.e., building its own monitoring expertise. To answer this question, we revisit the two-layer supply chain in Section 3.2.1 and allow the manufacturer to directly observe either the market or the effort level. Note that to collect information directly, the manufacturer typically needs to make a huge amount of investments. For example, it may need to build and operate its own retail stores at the local markets and install a relevant information system. On the contrary, delegating to the reseller and using only indirect monitoring is generally much cheaper. The manufacturer should thus adopt direct monitoring only if it increases the expected sales volume by a sufficiently large amount. The next proposition, however, shows that this is not true by comparing the profitability of direct and indirect monitoring.

Proposition 4. *By observing the market condition (respectively, effort level) directly, the manufacturer generates the same expected profit as delegating to the knowledgeable (respectively, diligent) reseller.*

As the proposition shows, direct monitoring and indirect monitoring generate the same expected sales. Even though the manufacturer cannot control the reseller in the case of indirect monitoring, there is no efficiency loss brought by the decentralized decision making. In other words, switching from delegation to direct monitoring does not create any additional benefit for the manufacturer and the supply chain. As it is conceivable that collecting information directly is much more expensive than signing a contract with the reseller, it is better for the manufacturer to do delegation. Our result then provides a reason for us to commonly see delegation in practice.

So far we have considered several variants of our basic model. All of them preserve the manufacturer's preference on the diligent reseller. Moreover, under all these scenarios, the manufacturer applies the "selling-the-business" strategy (by setting $v^K = v^D = 1$) and extracts all the surplus from the reseller. This observation gives rise to an immediate question: What if the manufacturer cannot "sell the business" to avoid double marginalization? In the next section, we extend our model and study different supply chain structures in which such a strategy is no longer available.

3.3 Private expertise and risk aversion

In this section, we extend our basic model setting and study some alternative supply chains. Specifically, the manufacturer faces some difficulties due to the unobservability of the reseller’s expertise and the reseller’s risk aversion. In the latter case, we discuss two different forms of risk aversion, i.e., exponential negative utility functions and limited liability. Any of these issues prevents the manufacturer from extracting all the surplus from its reselling partner. Therefore, in these more realistic settings, all the intuitions obtained in Section 3.2 should be reinvestigated. Remarkably, in all these variants, we still establish the clear-cut preference on the diligent reseller.

3.3.1 Private reseller’s expertise

Consider the scenario in which the manufacturer is unable to distinguish between the knowledgeable reseller and the diligent one. This scenario is typically termed the “second-best” scenario from the manufacturer’s perspective. Due to this information asymmetry, the manufacturer must rely on a menu of contracts to induce the reseller’s truthful revelation. Specifically, let (u_s^K, v_s^K) and (u_s^D, v_s^D) denote the menu of contracts intended for the knowledgeable and diligent resellers, respectively, where the subscript s indicates the “second-best” scenario.

The major difference between public and private reseller’s expertise is that the manufacturer now needs to ensure that the reseller is willing to reveal her “type” from her self-selection. Recall that under an arbitrary contract (u, v) , the knowledgeable reseller derives the expected payoff $R^K \equiv \mathbb{E}_\theta R^K(\theta) = u + v\mu + \frac{1}{2(1+\rho\sigma^2)}v^2$, whereas the diligent reseller obtains $R^D = u + v\mu + \frac{1}{2}v^2$ instead. Therefore, the following reseller’s incentive compatibility constraints must be satisfied:

$$u_s^K + v_s^K \mu + \frac{1}{2(1 + \rho\sigma^2)}(v_s^K)^2 \geq u_s^D + v_s^D \mu + \frac{1}{2(1 + \rho\sigma^2)}(v_s^D)^2, \quad (3.7)$$

$$u_s^D + v_s^D \mu + \frac{1}{2}(v_s^D)^2 \geq u_s^K + v_s^K \mu + \frac{1}{2}(v_s^K)^2. \quad (3.8)$$

These constraints ensure that the reseller receives a higher expected payoff under truth-telling than misrepresenting herself as a different type. Moreover, the menu of contracts must guarantee at least a null expected payoff for each type of reseller:

$$u_s^K + v_s^K \mu + \frac{1}{2(1 + \rho\sigma^2)}(v_s^K)^2 \geq 0, \quad (3.9)$$

$$u_s^D + v_s^D \mu + \frac{1}{2}(v_s^D)^2 \geq 0. \quad (3.10)$$

In equilibrium, the manufacturer’s menu of contracts must induce the reseller’s truth-telling. While delegating to the knowledgeable reseller, the induced effort level is

$\frac{1}{1+\rho\sigma^2}v_s^K$; the corresponding expected sales and the manufacturer's expected profit are $\mu + \frac{1}{1+\rho\sigma^2}v_s^K$ and $(1 - v_s^K)(\mu + \frac{1}{1+\rho\sigma^2}v_s^K) - u_s^K$, respectively. On the other hand, if the diligent reseller is delegated, the induced effort level is v_s^D ; the expected sales and the manufacturer's expected profit are $\mu + v_s^D$ and $(1 - v_s^D)(\mu + v_s^D) - u_s^D$, respectively. Collectively, the manufacturer's goal is to find a menu of contracts (u_s^K, v_s^K) and (u_s^D, v_s^D) that solve the following optimization problem:

$$\begin{aligned} \max_{\substack{u_s^K \text{ urs}, v_s^K \geq 0, \\ u_s^D \text{ urs}, v_s^D \geq 0}} \quad & p \left[(1 - v_s^K) \left(\mu + \frac{1}{1+\rho\sigma^2} v_s^K \right) - u_s^K \right] + (1 - p) \left[(1 - v_s^D) (\mu + v_s^D) - u_s^D \right] \\ \text{s.t.} \quad & (3.7) - (3.10), \end{aligned}$$

where p denotes the population (proportion) of knowledgeable resellers. The solution to the manufacturer's problem is summarized below:

Proposition 5. *With private reseller's expertise, the manufacturer offers*

$$\begin{aligned} v_s^K &= \frac{1}{1 + (1 - p)\rho\sigma^2/p}, & u_s^K &= -v_s^K \mu - \frac{1}{2(1 + \rho\sigma^2)} (v_s^K)^2, \\ v_s^D &= 1, & \text{and } u_s^D &= -\mu - \frac{1}{2} + \left[\frac{1}{2} - \frac{1}{2(1 + \rho\sigma^2)} \right] (v_s^K)^2 \end{aligned}$$

as the optimal menu of contracts. Under this menu, the knowledgeable reseller receives zero expected payoff, whereas the diligent reseller obtains an information rent $(\frac{1}{2} - \frac{1}{2(1+\rho\sigma^2)})(v_s^K)^2$. The induced effort levels are respectively $a_s^K(\theta) = \frac{1}{1+\rho\sigma^2}v_s^K$ and $a_s^D(\theta) = 1$.

Proposition 5 shows that when the manufacturer is unable to distinguish between a knowledgeable reseller and a diligent one, it distorts downwards the commission rate offered to the knowledgeable reseller (as seen in $v_s^K = \frac{1}{1+(1-p)\rho\sigma^2/p} < 1$). The intuition is the following. Recall that for a given contract (u, v) , the diligent reseller derives a higher expected profit than the knowledgeable reseller (via the comparison between $R^K = u + v\mu + \frac{1}{2(1+\rho\sigma^2)}v^2$ and $R^D = u + v\mu + \frac{1}{2}v^2$). Moreover, the difference enlarges as the commission rate v becomes larger. Thus, in order to differentiate the two resellers, the manufacturer must rely on the heterogeneity of commission rates in the menu. It thus distorts downwards the commission rate intended for the knowledgeable reseller.

Notably, this distortion deteriorates as the moral hazard issue becomes more severe ($\rho\sigma^2$ becomes larger) or there are relatively more diligent resellers (p becomes smaller). Since the diligent reseller is immune to the moral hazard issue but the knowledgeable reseller is not, as the moral hazard issue gets worse, the performance gap between delegating to a diligent reseller and a knowledgeable reseller enlarges. This entices the manufacturer to further distort the commission rate for the knowledgeable reseller to make a better differentiation. Furthermore, when the population

of diligent resellers expands, differentiating the commission rate becomes more profitable to the manufacturer. This is because the downward distortion prevents the knowledgeable reseller from mimicking the diligent reseller and reduces the diligent reseller's information rents. When there are more diligent resellers, reducing their rents is relatively more important, even if the efficiency with knowledgeable resellers is sacrificed.

The distortion of commission rate intended for the knowledgeable reseller also exacerbates the distortion of effort level, since it calls for the celebrated double marginalization problem. As a result, upon delegating to the knowledgeable reseller, now the induced effort level ($a_s^K(\theta) = \frac{1}{1+\rho\sigma^2}v_s^K < \frac{1}{1+\rho\sigma^2} = a^K(\theta)$) is even lower. On one hand, the inherent moral hazard issue remains, leading to the term $\frac{1}{1+\rho\sigma^2}$. On the other hand, the information asymmetry in the manufacturer-reseller relationship creates a new source of distortion (captured by the term v_s^K). We conclude that private expertise constitutes a barrier to efficient effort level as well as supply chain efficiency.

Finally, it is worth mentioning that the diligent reseller, albeit without market information, is able to retain a positive information rent. This is because compared to a knowledgeable reseller, a diligent reseller makes a higher expected profit from any given contract (u, v) due to the diligent monitoring over the salesperson's effort level. Hence, a diligent reseller is awarded some information rents in return.

3.3.2 Resellers with negative exponential utility functions

In this section, we examine the situation in which the reseller is risk-averse and have a negative exponential utility function. Because the selling-the-business strategy exposes the reseller to the undesired risk, it will not be accepted by the reseller. Full profit extraction is thus no longer possible for the manufacturer. This is especially problematic when the manufacturer delegates to the diligent reseller. When the diligent reseller is risk-neutral, she is willing to accept a sell-out contract ($v^D = 1$), offer a no-commission contract ($\beta^D = 0$), and bear the risk for the whole supply chain. Without this risk neutrality, these two contracts will not be implemented and the moral hazard issue will not be eliminated completely. In this case, adverse selection does amplify efficiency loss in the supply chain. Whether the diligent reseller is still dominating now requires reinvestigation.

To address this question, we assume that a reseller is endowed with a negative exponential utility $-e^{-ry}$, where y is her payoff and $r > 0$ is the coefficient of absolute risk aversion. We assume that both types of resellers, i.e., knowledgeable and diligent, have an identical risk aversion magnitude so that the comparison is fair. Moreover, within our three-layer structure we assume that the resellers are no more risk-averse than salespeople, i.e., $r \leq \rho$. Typically, a reseller is much larger than a salesperson in terms of size/economic scale. This assumption is thus reasonable since the degree of risk aversion generally decreases as the size of a party increases. The risk-neutral case can be treated as a limiting case when r approaches 0.

We start our analysis with the risk-averse knowledgeable reseller. As in the risk-neutral case, the salesperson's certainty equivalent is $CE_S(\theta) = \alpha + \beta\theta + \frac{1}{2}(1 - \rho\sigma^2)\beta^2$ and the optimal effort level is $a_A^K(\theta) = \beta$ (subscript A is used for "risk aversion" in this section). Getting payoff $u - \alpha + (v - \beta)(\theta + \beta + \epsilon)$, the risk-averse reseller's utility is $-e^{-r[u - \alpha + (v - \beta)(\theta + \beta + \epsilon)]} = -e^{-rCE_R^K(\theta)}$, where $CE_R^K(\theta) = u - \alpha + (v - \beta)(\theta + \beta) - \frac{1}{2}r(v - \beta)^2\sigma^2$ is the reseller's certainty equivalent and the subscript R stands for "reseller". To maximize her certainty equivalent, the risk-averse reseller's problem now becomes

$$CE_R^K(\theta) = \max_{\alpha \text{ urs}, \beta \geq 0} u - \alpha + (v - \beta)(\theta + \beta) - \frac{1}{2}r(v - \beta)^2\sigma^2$$

s.t. $CE_S(\theta) \geq 0$.

Let $\{\alpha_A^K(\theta), \beta_A^K(\theta)\}$ be the optimal contract. It then follows that the induced effort level is $\beta_A^K(\theta)$ and the risk-neutral manufacturer's problem is

$$M_A^K(r) = \max_{u \text{ urs}, v \geq 0} \mathbb{E}_\theta [(1 - v)(\theta + \beta_A^K(\theta)) - u]$$

s.t. $\mathbb{E}_\theta [CE_R^K(\theta)] \geq 0$,

where $M_A^K(r)$ is the manufacturer's maximum expected payoff and the subscript A stands for "averse". The solutions to the above two problems are summarized below.

Lemma 6. *It is optimal for the manufacturer to offer $v_A^K = \frac{1+r\sigma^2}{1+r\sigma^2+r\rho\sigma^2}$ as the commission rate to the risk-averse knowledgeable reseller. Then the reseller should optimally offer $\beta_A^K(\theta) = \frac{1+r\sigma^2}{1+\rho\sigma^2+r\sigma^2}v_A^K$ as the salesperson's commission rate and induce effort level $a_A^K(\theta) = \frac{1+r\sigma^2}{1+\rho\sigma^2+r\sigma^2}v_A^K$ for all θ . The manufacturer receives $M_A^K(r) = \mu + \frac{(1+r\sigma^2)^2}{2(1+\rho\sigma^2+r\sigma^2)(1+r\sigma^2+r\rho\sigma^4)}$.*

Compared with Lemmas 2 and 4, the absolute risk aversion coefficient r now affects the optimal contracts, the induced effort level, and the expected profit of the manufacturer. Consider the commission rate v_A^K first. The fact $v_A^K < 1$ shows that the manufacturer should not sell the business to the reseller. As the reseller becomes more risk-averse, she prefers a contract that is less risky, which consists of a lower commission rate. Therefore, v_A^K decreases in r . On the other hand, that the reseller is more risk-averse means the salesperson is relatively less risk-averse compared to the reseller. This drives the reseller to offer a higher commission rate (note that the coefficient $\frac{1+r\sigma^2}{1+\rho\sigma^2+r\sigma^2}$ increases in r). Because the induced effort level $a_A^K(\theta)$ and the manufacturer's expected surplus are jointly affected by these two opposite forces, under certain scenarios they are non-monotonic in r (first decreasing and then increasing). Though such non-monotonicity may be an interesting issue to be further studied, at this moment we will continue on the comparison between the two types of resellers under the same risk magnitude r .

Now consider the risk-averse diligent reseller. With the definition of $CE_S(\tilde{\theta}, \theta)$ and $CE_S(\theta)$ in (3.4), her problem is

$$\begin{aligned}
CE_R^D = & \max_{\substack{\{\alpha(\theta) \text{ urs,} \\ \beta(\theta) \geq 0, a(\theta) \geq 0\}}} \mathbb{E}_\theta \left[u - \alpha(\theta) + (v - \beta(\theta))(\theta + a(\theta)) - \frac{1}{2}r(v - \beta(\theta))^2\sigma^2 \right] \\
\text{s.t. } & CE_S(\theta) \geq CE_S(\theta, \tilde{\theta}) \quad \forall \theta \in (-\infty, \infty) \\
& CE_S(\theta) \geq 0 \quad \forall \theta \in (-\infty, \infty),
\end{aligned}$$

where the objective is to maximize her expected certainty equivalent. Though the complicated optimal menu of contracts $\{\alpha_A^D(\theta), \beta_A^D(\theta), a_A^D(\theta)\}$ can be derived, it is difficult to solve the manufacturer's problem optimally due to the complex structure of $\beta^D(\theta)$. Nevertheless, the following lemma provides a lower bound of the manufacturer's maximum expected profit.

Lemma 7. *The manufacturer can obtain an expected profit $M_A^D(r)$, which is at least $\bar{M}_A^D(r) = \mu + \frac{1}{2(1+r\sigma^2)}$, by contracting with the risk-averse diligent reseller.*

The intuition of this lemma is as follows. Suppose there exists a ‘naive’ diligent reseller who offers $\{\bar{\alpha}_A^D(\theta), \bar{\beta}_A^D(\theta) = 0, a_A^D(\theta)\}$ to the salesperson. Note that while the optimal commission rate $\beta_A^D(\theta)$ depends on the contract offered by the manufacturer and θ , the naive reseller simply ignores θ and offers no commission rate (with a necessary modification on the fixed payment to maintain the optimal effort level $a_A^D(\theta)$ and induce the salesperson to participate). Therefore, we may interpret the suboptimal behavior as a result of lack of intelligence. The manufacturer then looks for a contract $(\bar{u}_A^D, \bar{v}_A^D)$ that is optimal when facing the naive reseller. It is clear that the ‘true’ reseller will also accept $(\bar{u}_A^D, \bar{v}_A^D)$ since she can always do better than the naive one. Because the two resellers assign the same effort level $a_A^D(\theta)$, the manufacturer obtains the same expected profit $\bar{M}_A^D = (1 - \bar{v}_A^D)(\mu + a_A^D(\theta)) - \bar{u}_A^D$ by offering $(\bar{u}_A^D, \bar{v}_A^D)$ to the two resellers. Since $(\bar{u}_A^D, \bar{v}_A^D)$ is only one of the manufacturer's available options facing the true reseller, it follows that \bar{M}_A^D is a lower bound of the manufacturer's maximum expected profit. Finally, $\bar{M}_A^D = \mu + \frac{1}{2(1+r\sigma^2)}$ can be found by analyzing the manufacturer's contracting problem with the naive reseller. All the details are provided in the appendix.

With our assumption $r \leq \rho$, we now have

$$\begin{aligned}
M_A^K &= \mu + \frac{(1 + r\sigma^2)^2}{2(1 + \rho\sigma^2 + r\sigma^2)(1 + r\sigma^2 + r\rho\sigma^4)} \\
&\leq \mu + \frac{(1 + r\sigma^2)^2}{2(1 + 2r\sigma^2)(1 + r\sigma^2 + r^2\sigma^4)} < \mu + \frac{1}{2(1 + r\sigma^2)} = \bar{M}_A^D \leq M_A^D,
\end{aligned}$$

where the first inequality comes from the assumption $r < \rho$ and the second inequality comes from a direct comparison. Therefore, the diligent reseller is more profitable

to the manufacturer. This conclusion, which is a generalization to Proposition 1, is summarized in the following proposition.

Proposition 6. *Suppose that both resellers are risk-averse with the same risk aversion magnitude and less risk-averse than the salesperson, then the manufacturer prefers the diligent reseller to the knowledgeable reseller.*

Proposition 6 shows that our main insight is not prone to the specific choice of the reseller’s risk attitude. In fact, the results in Section 3.2 are the limiting cases of those derived in this section as r approaches 0. This implies that Proposition 6 is a generalization of Proposition 1.

According to Lemmas 3 and 7, we have $M_A^D > M^K$, which means delegating to the risk-averse diligent reseller is better than the risk-neutral knowledgeable reseller. In other words, the effectiveness of resolving moral hazard dominates the efficiency loss from risk aversion. As we already know that including the risk-neutral knowledgeable reseller is more profitable than direct sales, we obtain the following corollary.

Corollary 1. *Suppose that both resellers are risk-averse with the same risk aversion magnitude and less risk-averse than the salesperson, then the manufacturer prefers including the diligent reseller to direct sales.*

This corollary shows that, even if the manufacturer must leave some rent to the resellers due to her risk aversion, delegating to the risk-averse diligent reseller is still more profitable than selling directly to the consumers. However, as we demonstrate in Section 3.4.2, this is no longer the case when delegating to the risk-averse knowledgeable reseller. Operating a three-layer supply chain with risk-averse resellers thus requires more efforts in searching for the right reseller. It is also worth mentioning that when the reseller is risk-averse, the manufacturer shall keep a portion of the sales proceeds to facilitate the optimal risk sharing along the supply chain. In practice, we observe both the sell-out contracts and the general two-part tariffs in different scenarios/industries. Our results may partially explain such a discrepancy from the perspective of contracting parties’ risk attitudes.

3.3.3 Resellers with limited liability

So far we have restricted our attention to two-part tariffs. Specifically, this contract form allows the manufacturer to charge any amount of franchise fee from the reseller (as long as the reseller is willing to participate). The manufacturer can thus acquire the reseller’s information at no cost. Therefore, in this section we generalize our basic model by assuming that resellers have limited liability and are unwilling to pay a high franchise fee. More precisely, we impose an additional constraint $u \geq B$, where $B \in (-\infty, 0]$ and $|B|$ is the maximum amount of franchise fee that either reseller may pay. Such as general setting includes the sell-out contracts used in the

basic model (when B approaches $-\infty$), wholesale contracts/one-part tariffs (when $B = 0$), and all two-part tariffs in between the two extreme cases. The question to examine is whether the diligent reseller is still preferred when resellers are protected by limited liability.

Let us first consider the knowledgeable reseller. Because she will behave in the same way as in the basic model once an offer (u, v) is accepted, her expected payoff will still be $u + v\mu + \frac{1}{2(1+\rho\sigma^2)}v^2$ and the induced effort level is still $\frac{1}{1+\rho\sigma^2}v$. Therefore, the manufacturer's problem while contracting with the knowledgeable reseller becomes

$$\begin{aligned} M_L^K(B) = \max_{u \geq B, v \geq 0} & (1 - v) \left(\mu + \frac{1}{1 + \rho\sigma^2} v \right) \\ \text{s.t.} \quad & u + v\mu + \frac{1}{2(1 + \rho\sigma^2)} v^2 \geq 0. \end{aligned} \tag{3.11}$$

The subscript L indicates "limited liability" and $M_L^K(B)$ is the manufacturer's maximum expected profit with the lower bound B . Similarly, the problem with the diligent reseller is

$$\begin{aligned} M_L^D(B) = \max_{u \geq B, v \geq 0} & (1 - v)(\mu + v) \\ \text{s.t.} \quad & u + v\mu + \frac{1}{2}v^2 \geq 0. \end{aligned} \tag{3.12}$$

To derive the result that $M_L^D(B) \geq M_L^K(B)$ for a given B , it suffices to show that for every feasible solution for (3.11), there exists a feasible solution for (3.12) that leads to a better outcome. This is clearly true: The feasible region for (3.11) is a subset of that for (3.12) and any feasible solution for (3.11) generates a smaller objective value for (3.11) than for (3.12). Therefore, our main result can be generalized to any given B . The manufacturer thus always prefers the diligent reseller regardless of its ability of charging a fixed payment.

3.4 Performance gaps

For all the different models we discussed, it is shown that delegating to the diligent reseller outperforms the other two selling schemes. However, the manufacturer may incur different costs under different supply chain configurations. Though arguably implementing direct sales requires a large amount of operational costs, there may still be situations that delegation is even more costly. For example, delegation requires signing a contract with a reseller and regularly maintaining the partnership, which may incur substantial costs. Searching for the diligent reseller may also incur more investments than adopting direct sales. Moreover, different resellers may have different outside options. A higher outside option then requires the manufacturer to pay to implement delegation.

To aid the manufacturer to determine the optimal strategy in the presence of these costs, we *quantify* the performance gaps among the three options under various scenarios in this section. In particular, we investigate how the performance gaps are affected by the relative importance of adverse selection and moral hazard, the risk attitude of the reseller (either with a negative exponential utility function or limited liability), and the complementarity between demand and efforts.

3.4.1 Relative importance of adverse selection and moral hazard

When the salesperson's cost of exerting effort level a is $V(a) = \frac{1}{2k}a^2$ (cf. Section 3.2.5), let $M^*(k)$, $M^K(k)$, and $M^D(k)$ be the manufacturer's maximum expected profits under direct sales, indirect sales with the knowledgeable reseller, and indirect sales with the diligent reseller, respectively. It has been derived in Proposition 3 that $M^D(k) = \mu + \frac{k}{2}$ and $M^K(k) = \mu + \frac{k^2}{2(k+\rho\sigma^2)}$. It is also straightforward to show that $M^*(k) = \mu + \mathbb{E} \left[\frac{[k-H(\theta)]^+}{2(k+\rho\sigma^2)} \right]$ following the proof of Proposition 1. It is then clear that direct sales is still dominated by delegating to either reseller for all $k \in (0, 1]$. However, note that

$$\lim_{k \rightarrow 0} M^D(k) = \lim_{k \rightarrow 0} M^K(k) = \lim_{k \rightarrow 0} M^*(k) = \mu,$$

which implies that the performance gaps diminish as k approaches 0. Roughly speaking, as the effort cost becomes higher, the benefit of identifying and contracting with a diligent reseller becomes lower. It is then possible that delegating to the knowledgeable reseller or even running direct sales is a better choice when the cost of delegating to the diligent reseller is high enough.

3.4.2 Negative exponential utility functions

Recall that we define $r \in (0, \rho]$ as the resellers' coefficient of absolute risk aversion in Section 3.3.2. In this framework, let $M_A^K(r)$ (resp., $M_A^D(r)$) be the manufacturer's expected profit if it collaborates with the risk-averse knowledgeable (resp., diligent) reseller whose coefficient of absolute risk aversion is r . Though $M_A^K(r)$ is characterized in Lemma 6, we do not have an analytical expression for $M_A^D(r)$. Therefore, we perform numerical studies to investigate the performance gaps among $M_A^K(r)$, $M_A^D(r)$, and M^* , where M^* was found in Lemma 1 as the expected profit under direct sales. Note that M^* is independent of r because the manufacturer does not contract with the reseller when adopting direct sales. For an example with $\rho = 3$, $\sigma^2 = 3$, $\mu = 5$, and the variance of θ is 0.2, we depict $M^K(r)$, $M^D(r)$, and M^* in Figure 3.1. The difference $M^D(r) - M^K(r)$ is drawn in Figure 3.2. This example contains all those interesting observations discussed below.

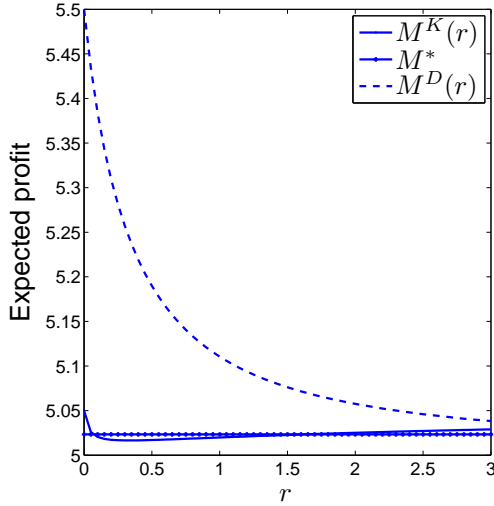


Figure 3.1: Expected Profits under Reseller's Risk Aversion

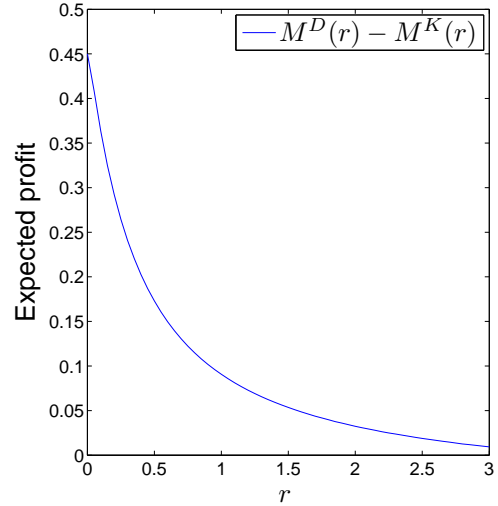


Figure 3.2: Difference of Expected Profits under Reseller's Risk Aversion

In all the results we obtain, we find that $M_A^D(r)$ is always decreasing in r . However, as we point out in Section 3.3.2, $M_A^K(r)$ can be first decreasing and then increasing in r . As M^* does not depend on r , it follows that $M_A^D(r) - M^*$ decreases in r and $M_A^K(r) - M^*$ first decreases and then increases in r . We also observe that $M_A^D(r) - M_A^K(r)$ is always decreasing in r . Recall that when the manufacturer delegates to the diligent reseller in our basic model, the first-best result depends on the risk neutrality of the diligent reseller. It is then not surprising that risk aversion harms the manufacturer more if the diligent reseller is delegated. We summarize this finding below.

Observation 1. *Delegating to the diligent reseller becomes relatively less profitable when the resellers becomes more risk-averse.*

We now consider whether the manufacturer will prefer direct sales to delegation. Because Corollary 1 shows that delegating to the diligent reseller is always more beneficial than direct sales, below we only discuss the knowledgeable reseller. We find that the risk aversion of the knowledgeable reseller may seriously harm the manufacturer and make direct sales a better choice. This observation is highlighted below.

Observation 2. *When the variance of θ is small enough, it is possible that $M^* > M_A^K(r)$ for some r . To have this result, r may need to be moderate, i.e., not too close to 0 or ρ .*

When r is very close to 0, resellers are only slightly risk-averse. As $M^K > M^*$ when the reseller is risk-neutral, it is intuitive that $M_A^K(r) > M^*$ when risk aversion

does not have a significant effect. As r increases and the reseller becomes more risk-averse, the benefits of delegation are reduced and thus $M_A^K(r)$ decreases. We may thus see $M^* > M_A^K(r)$ when r is not too small. However, because $M_A^K(r)$ can also increase in r when r is large, it is possible that delegating to the knowledgeable reseller dominates direct sales again when the reseller is highly risk-averse (r is large). The manufacturer thus needs to be careful when it chooses between indirect sales with the knowledgeable reseller and direct sales.

3.4.3 Limited liability

When the manufacturer is limited in the amount of franchise fee it can charge, we have shown in Section 3.3.3 that $M_L^D(B) \geq M_L^K(B)$ for all $B \in (-\infty, 0]$, i.e., the manufacturer always prefers the diligent reseller. The next proposition characterizes how the performance gap changes in B .

Proposition 7. $M_L^D(B) - M_L^K(B)$ is nonincreasing in B for $B \in (-\infty, 0)$.

This implies that delegating to the diligent reseller becomes relatively less effective as the manufacturer can only charge a smaller fixed payment. Recall that for the basic model, we have established that $|u^D| = \mu + \frac{1}{2} > \mu + \frac{1}{2(1+\rho\sigma^2)} = |u^K|$ (cf. Lemmas 3 and 5), which means the manufacturer must charge a higher franchise fee from the diligent reseller to implement the optimal contracts. It is thus clear that a higher degree of limited liability harms the manufacturer more when the reseller is diligent. In fact, in the extreme case that $B = 0$ and only a wholesale contract is allowed, it can be easily shown that there exists a unique threshold of μ such that $M_L^D(0) = M_L^K(0)$ if and only if μ is above the threshold. Delegating to either reseller then makes no difference.

When B increases, the corresponding constraints in (3.11) and (3.12) become tighter and thus $M_L^K(B)$ and $M_L^D(B)$ both weakly decrease. However, the expected profit M^* under direct sales is not affected by B . Therefore, $M_L^D(B) - M^*$ and $M_L^K(B) - M^*$ are both nonincreasing in B . Our next proposition indicates that the differences may even become negative, which implies direct sales dominates delegation. Note that we only discuss the diligent reseller in the proposition because she has dominated the knowledgeable one.

Proposition 8. *There exists a lower bound $\hat{\mu} > 0$ such that for all $\mu \geq \hat{\mu}$, we have $M^* > M_L^D(B)$ if and only if $B \geq \hat{B}(\mu)$, where $\hat{B}(\mu) < 0$ is uniquely defined by μ .*

It is intuitive that direct sales becomes more beneficial when the resellers have a higher limited liability (when B is large). Interestingly, this is especially true when the market condition is good in expectation. To understand this result, recall that μ measures the expected market condition or, roughly speaking, the size of the market. If the market is small, the manufacturer will not earn a lot if it runs the business by

itself. Selling the business to the reseller will be better as long as the reseller is willing to pay a reasonable franchise fee. However, if the market is big, the manufacturer will ask for a high payment. When the reseller's willingness-to-pay is considerably lower than the asked amount, it is better for the manufacturer to adopt direct sales. To further support the above intuition, recall that in the basic model the optimal fixed payment $u^D = -\mu - \frac{1}{2}$ decreases in μ . A higher μ will make u^D more severely violate the constraint $u \geq \bar{L}$ and result in less effective delegation. Direct sales will then become more profitable.

3.4.4 Complementarity between demand and efforts

Recall that when the sales outcome is in the additive form $x = \theta + a + \epsilon$, we have $M^K = \mu + \frac{1}{2(1+\rho\sigma^2)}$, $M^D = \mu + \frac{1}{2}$, and thus $M^D - M^K$ does not depend on θ . In other words, $M^K - M^D$ does not change when the manufacturer modifies its belief about the market condition. However, when the sales outcome is in the multiplicative form $x = \theta a + \epsilon$, it follows from Proposition 2 that $M^D - M^K$ now depends on the distribution of θ . This is because when demand and efforts are complementary, different realizations of the market condition drive the salesperson to choose different effort levels. Among all possibilities for θ to change, we are particularly interested in the situation that μ alters. Studying this situation allows us to investigate the relative effectiveness of the two resellers in big markets (when μ is large) and small markets (when μ is small). The following analytical finding regarding uniform distribution provides a partial answer. Numerical experiments for other distributions also demonstrate similar qualitative results.

Proposition 9. *When $x = \theta a + \epsilon$ and θ follows a uniform distribution with mean μ , $M^D - M^K$ increases in μ .*

When the manufacturer delegates to the diligent reseller in a big market, the complementarity allows her to induce a high effort level. However, if the delegation occurs in a small market, the diligent reseller's monitoring will become less effective. On the other hand, the demand forecasting ability possessed by the knowledgeable reseller is not affected if the variance of θ does not change. Therefore, when the market size goes down, the diligent reseller will become relatively less effective.

3.5 Summary

In this chapter, we investigate the effect of demand forecasting and performance measurement on motivating salespeople and creating new demands. Within our three-layer supply chain, we jointly study the manufacturer's partner selection problem and the resellers' salesforce compensation problem. Since decision making within this supply chain is decentralized, including a reseller with a certain monitoring ability is

different from having the ability by the manufacturer itself. All intuitions obtained from traditional two-layer supply chains therefore cannot be applied directly. We show that the manufacturer unambiguously prefers the reseller who is able to monitor the salesperson to the one that can monitor the market. This dominance result is not prone to our model characteristics regarding the degree of complementarity between effort level and market condition, the relative importance between moral hazard and adverse selection, the reseller's risk attitude, the observability of the resellers' monitoring expertise, and the contract form. We further show that the performance gap between delegating to the two resellers decreases when adverse selection becomes relatively more important, the reseller becomes more risk-averse, or the market size goes down. Moreover, because the efficiency of direct sales does not depend on the reseller, direct sales may outperform both indirect selling schemes when the reseller is too risk-averse.

Chapter 4

Focusing or balancing?

In this chapter, we extend the binary decision model in Chapter 3 and allow the reseller to be partially informed for both the market condition and sales effort. While the reseller cannot completely eliminate one source of information disadvantage, she now can mitigate the information asymmetry by partially monitoring both aspects. We also introduce physical restrictions and a resource constraint to make the environment more realistic. The reseller's accuracy selection problem then becomes arguably more complicated.

Throughout this chapter, we assume that the manufacturer-reseller relationship follows the basic setting described in Section 3.1. In other words, the manufacturer can “sell the business” to the reseller and eliminate the double marginalization problem. In this case, the manufacturer will always delegate to the reseller that can generate the highest profit in expectation for herself if the manufacturer does not exist. Therefore, in the discussions below we will focus on the reseller and examine only the reseller-salesperson relationship, in which the reseller selects her monitoring accuracy to maximize her expected profit.

In Section 4.1, we describe the model setting and assumptions. The reseller's contract design and resource allocation problems are formulated and analyzed in Section 4.2. We perform numerical studies in Section 4.3 to generate more insights and summarize our findings in Section 4.4. All the proofs are in Appendix B.

4.1 Model

We consider a supply chain in which a reseller (she) relies on a salesperson (he) to sell the products. The supply chain is operated in a make-to-order (MTO) manner, in which the reseller can determine the procurement quantity after the demand realization. Without loss of generality, we normalize the unit procurement cost to 0 and the unit retail price to 1. While the reseller is risk-neutral and maximizes her expected profit, the salesperson is risk-averse and maximizes his expected utility. The

salesperson's risk preference is represented by a negative exponential utility function $U(z) = -e^{-\rho z}$, where $\rho > 0$ is the coefficient of absolute risk aversion and z is his net income. The salesperson's (risk-free) reservation net income is normalized to zero without loss of generality.

While the salesperson is able to observe the realization of the market condition, he may further enhance the sales outcome by exerting effort. Specifically, the sales outcome x is determined by a normally distributed market condition $\theta \sim N(\mu_\theta, \sigma_\theta^2)$, the salesperson's sales effort a , and a random noise ϵ in the additive form (3.1). In this chapter, we assume that $\epsilon \sim N(0, \sigma_\epsilon^2)$. We assume that $\mu_\theta > 0$, $\sigma_\theta^2 > 0$, $\sigma_\epsilon^2 > 0$, and the probability of x being negative is sufficiently small. To exert effort a , the salesperson incurs a cost $\frac{1}{2}a^2$, where the quadratic form is made for simplicity. The functional form (3.1), the cost of effort $\frac{1}{2}a^2$, the parameters μ_θ , σ_θ^2 , and σ_ϵ^2 , and the realized sales outcome x are all common knowledge. However, the market condition θ and the sales effort a are not observable by the reseller.

The reseller may invest in demand forecasting and obtain an estimator $s = \theta + \tau$ for θ . She may then use the estimate s to update her belief on the market condition. The reseller may also invest in performance measurement and estimate the sales effort through the estimator $q = a + \xi$. We assume that $\tau \sim N(0, \sigma_\tau^2)$ and $\xi \sim N(0, \sigma_\xi^2)$. The two variance terms $\sigma_\tau^2 > 0$ and $\sigma_\xi^2 > 0$ are referred to the reseller's *monitoring accuracy* of *demand monitoring* and *effort monitoring*, respectively. In what follows, we refer to s as the *demand signal*. It is also assumed that τ is independent of θ , ξ is independent of a , and τ and ξ are independent. Because the salesperson is an employee of the reseller, in practice he knows the estimation made by his company. Therefore, we assume that the realized value of s and q as well as all the distributions are common knowledge.

For the monitoring accuracy, we impose the feasibility constraints $\sigma_\tau^2 \geq K_\tau$ and $\sigma_\xi^2 \geq K_\xi$ with $K_\tau \geq 0$ and $K_\xi \geq 0$ being exogenous parameters. These constraints incorporate the physical restrictions that the reseller may encounter in improving accuracy in either aspect. In addition, the reseller faces a resource constraint in allocating her budget to these two functions. With C being the total budget and $g(\sigma_\tau^2, \sigma_\xi^2)$ being the cost for achieving σ_τ^2 and σ_ξ^2 , the reseller's resource constraint is $g(\sigma_\tau^2, \sigma_\xi^2) \leq C$. It is assumed that g increases as σ_τ^2 or σ_ξ^2 decreases because more accurate estimators should be more expensive. g is also assumed to be jointly convex in σ_τ^2 and σ_ξ^2 so that improving accuracy is more costly when the accuracy is already high. As we will see in Section 4.3, the convexity also allows us to incorporate the complementarity between the two aspects.

In the reseller-salesperson relationship, we restrict our attention to the class of linear contracts that are prevalent in practice. Specifically, we use (α, β, w) to denote the contract signed by the reseller and the salesperson, where α is a fixed payment, β is a commission rate regarding the sales outcome x , and w is an input bonus rate based on the estimate q . With this contract, the salesperson receives an aggregate payment $\alpha + \beta x + wq$ if sales outcome x and effort estimate q are realized. Since

the reseller is unable to observe the market condition θ , her best strategy is to offer a menu of contracts for the salesperson to self-select and reveal θ truthfully. The menu of contracts offered by the reseller is thus denoted as $\{\alpha(\theta), \beta(\theta), w(\theta)\}$. Note that the reseller will design the contract based on her posterior belief on the market condition.

The sequence of events is summarized in Figure 4.1: 1) The reseller decides her monitoring accuracy σ_τ^2 and σ_ξ^2 ; 2) θ is realized and privately observed by the salesperson. The two players then observe the demand signal s . 3) Based on the signal s and the accuracy σ_τ^2 , the reseller updates her posterior belief on θ to $\theta|_s$ and announces a compensation scheme $\{\alpha(\cdot), \beta(\cdot), w(\cdot)\}$ to her salesperson; 4) The salesperson chooses a contract (α, β, w) based on θ and s he observes or rejects this offer; 5) If the salesperson rejects the contract, the game ends and each player receives a null payoff. Otherwise, the selling season starts, the salesperson exerts sales effort a , the reseller gets the effort estimate q , the sales quantity x is realized, and the salesperson is rewarded accordingly.

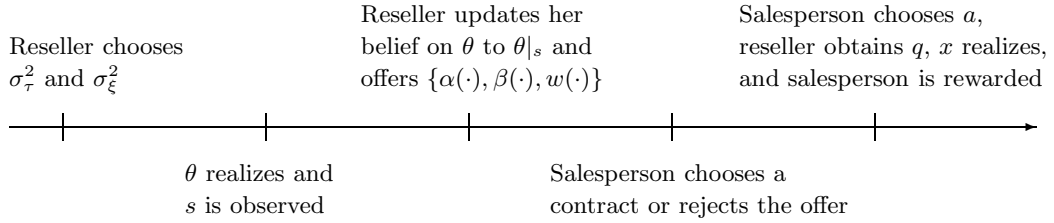


Figure 4.1: Sequence of events

4.2 Analytical results

4.2.1 The contract design problem

Consider the salesperson's problem for a given menu of contracts first. Suppose that the true market condition is θ but the salesperson chooses the contract $(\alpha(\tilde{\theta}), \beta(\tilde{\theta}), w(\tilde{\theta}))$ by reporting a false market condition $\tilde{\theta}$, then by exerting effort a , his net income will be $z(a) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a + \epsilon) + w(\tilde{\theta})q - \frac{1}{2}a^2$. Given $z(a)$, the salesperson's expected utility is $\mathbb{E}[-e^{-\rho z(a)}] = -e^{-\rho CE(\theta, \tilde{\theta}|a)}$, where

$$CE(\theta, \tilde{\theta}|a) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a) + w(\tilde{\theta})a - \frac{1}{2}a^2 - \frac{1}{2}\rho[\beta(\tilde{\theta})]^2\sigma_\epsilon^2 - \frac{1}{2}\rho[w(\tilde{\theta})]^2\sigma_\xi^2$$

is called the salesperson's *certainty equivalent*. Let $CE(\theta, \tilde{\theta}) \equiv \max_{a \geq 0} CE(\theta, \tilde{\theta}|a)$. Because the exponential function is monotonic, the salesperson can maximize his expected utility by choosing $a^*(\tilde{\theta}) = \beta(\tilde{\theta}) + w(\tilde{\theta})$ to maximize the certainty equivalent. With this optimal effort level, the salesperson receives his maximum certainty

equivalent

$$CE(\theta, \tilde{\theta}) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})\theta + \left[\beta(\tilde{\theta}) + w(\tilde{\theta})\right]^2 - \frac{1}{2}\rho \left[\beta(\tilde{\theta})\right]^2 \sigma_\epsilon^2 - \frac{1}{2}\rho \left[w(\tilde{\theta})\right]^2 \sigma_\xi^2. \quad (4.1)$$

Let $CE(\theta) \equiv CE(\theta, \theta)$.

With the salesperson's response in mind, the reseller considers her contract design problem as follows. First, from the representation $s = \theta + \tau$, she applies Bayesian inference to derive the posterior belief of θ given s . With $\sigma^2 \equiv \sigma_\tau^2 / (\sigma_\tau^2 + \sigma_\theta^2)$, the conjugate property of normal distributions leads to the posterior distribution $\theta|_s \sim N(\sigma^2\mu_\theta + (1 - \sigma^2)s, \sigma_\theta^2\sigma^2)$. Denote $F(\theta|s)$, $f(\theta|s)$, and $H(\theta|s) \equiv \frac{1-F(\theta|s)}{f(\theta|s)}$ as the distribution, density, and inverse failure functions of the posterior distribution $\theta|_s$. In equilibrium, the salesperson observing θ will choose the contract $(\alpha(\theta), \beta(\theta), w(\theta))$ that is intended for him. The reseller then pays $\beta(\theta)(\theta + a(\theta))$ as the expected sales commission, $w(\theta)a(\theta)$ as the expected input compensation, and $\alpha(\theta)$ as the fixed payment. Therefore, conditioning on the observed demand signal s , she maximizes her expected profit by solving

$$\max_{\substack{\alpha(\theta) \text{ urs,} \\ \beta(\theta) \geq 0, w(\theta) \geq 0}} \mathbb{E}_{\theta|s} \left[(1 - \beta(\theta))[\theta + \beta(\theta) + w(\theta)] - w(\theta)[\beta(\theta) + w(\theta)] - \alpha(\theta) \right] \quad (4.2)$$

$$\text{s.t.} \quad CE(\theta) \geq CE(\theta, \tilde{\theta}) \quad \forall \theta, \tilde{\theta} \in (-\infty, \infty), \quad (4.3)$$

$$CE(\theta) \geq 0 \quad \forall \theta \in (-\infty, \infty), \quad (4.4)$$

where the incentive compatibility (IC) constraint (4.3) guarantees truth-telling and the individual rationality (IR) constraint (4.4) guarantees the salesperson's participation. Note that σ_ξ^2 is embedded in $CE(\theta, \tilde{\theta})$ and σ_τ^2 and s affect the underlying distribution $\theta|_s$. The optimal menu of contracts is summarized below.

Proposition 10. *The reseller's optimal menu of contracts consists of*

$$\beta^*(\theta) = \left[\frac{\rho\sigma_\xi^2 - (1 + \rho\sigma_\xi^2)H(\theta|s)}{\rho\sigma_\xi^2 + (1 + \rho\sigma_\xi^2)\rho\sigma_\epsilon^2} \right]^+,$$

$$w^*(\theta) = \frac{1 - \beta(\theta)}{1 + \rho\sigma_\xi^2}, \text{ and}$$

$$\alpha^*(\theta) = -\beta(\theta)\theta - \frac{[\beta(\theta) + w(\theta)]^2}{2} + \frac{1}{2}\rho \left[\beta(\theta)^2\sigma_\epsilon^2 + w(\theta)^2\sigma_\xi^2 \right] + \int_{-\infty}^{\theta} \beta(y)dy.$$

The induced effort level is $a^*(\theta) = \beta^*(\theta) + w^*(\theta)$.

The menu of contracts aims to differentiate salespeople observing different market conditions. A high-type salesperson (observing a good market condition) prefers a high commission rate because he is optimistic about the sales outcome. Therefore,

the reseller finds it optimal to cut down the commission rate $\beta^*(\theta)$ intended for low-type salespeople (observing a bad market condition). This is captured by the inverse failure function $H(\theta|s)$, which is decreasing in θ for the normal distribution. The input compensation $w^*(\theta)$, on the contrary, is decreasing in θ . The reason for a high-type salesperson to prefer a high commission rate rather than a high input bonus rate is clear: High commission may be earned with luck but high input bonus definitely requires the costly effort. Since a high-type salesperson believes the market condition is good, he is willing to accept a low input bonus rate in exchange of a high commission rate. Reducing the input bonus rate for high-type salespeople thus helps the reseller make a better differentiation. Note that the induced effort level $a^*(\theta)$ is jointly determined by $\beta^*(\theta)$ and $w^*(\theta)$ in an additive form. Though the decreasing $w^*(\theta)$ lowers the effort level when θ becomes larger, the reduction is dominated by the incentive brought by $\beta^*(\theta)$. Therefore, the high-type salesperson is willing to work harder.

Intuitively, the reseller should be able to induce a higher expected effort level by improving her monitoring accuracy. The following proposition confirms the intuition for effort monitoring.

Proposition 11. *When σ_ξ^2 decreases, $\beta^*(\theta)$ decreases, $w^*(\theta)$ increases, and $a^*(\theta)$ increases for all θ . In addition, $\mathbb{E}[a^*(\theta)]$ strictly increases as σ_ξ^2 decreases.*

Compared with the sales commission, which is affected by the market condition, the risk-averse salesperson typically prefers to be rewarded through the more controllable input bonus. However, this is only the case when the reseller's effort monitoring is precise. Therefore, once the reseller improve her effort monitoring accuracy, the two parties will agree on a lower commission rate and a higher input bonus rate. More interestingly, though the effort level is determined by the two opposite forces, the positive effect brought by increasing the input bonus rate always dominates the negative effect of decreasing the commission rate. The salesperson will thus be willing to work harder. As this is true for all possible values of θ , the expected induced effort level is increased. This lemma thus provides a simple guideline for the reseller: Investing more in effort monitoring directly helps the reseller better motivate the salesperson.

Having obtained the reseller's optimal menu of contracts, we now proceed to her resource allocation problem.

4.2.2 The resource allocation problem

By offering the optimal contracts, the reseller's expected profit given her choice of the monitoring accuracy is

$$R(\sigma_\tau^2, \sigma_\xi^2) \equiv \mathbb{E}_s \left\{ \mathbb{E}_{\theta|s} \left[(1 - \beta^*(\theta))(\theta + a^*(\theta)) - w^*(\theta)a^*(\theta) - \alpha^*(\theta) \middle| s \right] \right\},$$

where $\alpha^*(\theta)$, $\beta^*(\theta)$, $w^*(\theta)$, and $a^*(\theta)$ are defined in Proposition 10. Inside the expectation over s is the maximized objective function (4.2) of the contract design problem. Because the demand signal s has not been observed when the reseller makes the choice of monitoring accuracy, she takes expectation over s , whose realization depends on the accuracy σ_τ^2 . The reseller's resource allocation problem is thus formulated as

$$\begin{aligned} \max_{\sigma_\tau^2 \geq 0, \sigma_\xi^2 \geq 0} \quad & R(\sigma_\tau^2, \sigma_\xi^2) \\ \text{s.t.} \quad & \sigma_\tau^2 \geq K_\tau, \sigma_\xi^2 \geq K_\xi, g(\sigma_\tau^2, \sigma_\xi^2) \leq C. \end{aligned} \tag{4.5}$$

The complicated structure of the optimal menu of contracts prohibits us from analytically solving (4.5) completely. Furthermore, finding the optimal accuracy mix may be numerically challenging as well because in essence we need to conduct a two-dimensional numerical search. Fortunately, the structural property stated in the following proposition allows us to obtain a clear insight and largely reduce the search space.

Proposition 12. *In the reseller's resource allocation problem (4.5), the expected profit $R(\sigma_\tau^2, \sigma_\xi^2)$ strictly increases as σ_ξ^2 decreases.*

As we have seen in Lemma 11, with a higher accuracy of effort monitoring, the reseller can better motivate the salesperson, ultimately benefiting the end consumers. Proposition 12 further shows that the reseller is strictly better off when she improves the accuracy. Therefore, a larger amount of investment in effort monitoring benefits both the end consumer and the reseller. This demonstrates the benefits, from the reseller's perspective, of resolving the moral hazard problem. As long as it is still possible to improve the accuracy of effort monitoring (without worsening demand monitoring), the reseller should invest more to do so.

Proposition 12 offers another technical implication. Because $R(\sigma_\tau^2, \sigma_\xi^2)$ decreases in σ_ξ^2 , any feasible accuracy mix satisfying $g(\sigma_\tau^2, \sigma_\xi^2) < C$ and $\sigma_\xi^2 > K_\xi$ can be improved by decreasing σ_τ^2 . Therefore, at least one of the constraints $g(\sigma_\tau^2, \sigma_\xi^2) \leq C$ and $\sigma_\xi^2 \geq K_\xi$ will be binding at optimality. This necessary condition for the optimal solution is summarized in the following corollary.

Corollary 2. *In the reseller's resource allocation problem (4.5), at least one of the constraints $g(\sigma_\tau^2, \sigma_\xi^2) \leq C$ and $\sigma_\xi^2 \geq K_\xi$ is binding at the optimal solution.*

This necessary condition partially resolves the complexity of the underlying resource allocation problem as it allows us to discard a large class of candidate solutions that are never optimal. Unfortunately, even with this necessary condition, the general problem (4.5) cannot be solved analytically. We thus investigate the general case numerically in Section 4.3.

According to Proposition 1 in Chapter 3, if the reseller can choose to eliminate either the adverse selection or moral hazard problem, eliminating moral hazard is

more beneficial. This suggests that moral hazard creates a higher loss in the reseller's expected profit and is relatively more critical in the reseller-salesperson relationship. Therefore, it is intuitive to conjecture that effort monitoring generally brings more *benefits* than demand monitoring. Nevertheless, because the physical and resource constraints are absent in the above analysis, the *costs* of these two functions are ignored. In particular, effort monitoring may be extremely expensive and not cost-effective to implement. To provide the full picture of this resource allocation problem, we resort to the numerical studies in the next section.

4.3 Numerical studies

The first step in conducting numerical studies is to choose a specific form of the resource constraint $g(\sigma_\tau^2, \sigma_\xi^2) \leq C$, which restricts the variances σ_τ^2 and σ_ξ^2 to be not too small. To make our experiments more intuitive with respect to σ_τ^2 and σ_ξ^2 , we adopt an equivalent no-less-than form $\tilde{g}(\sigma_\tau^2, \sigma_\xi^2) \geq B$, where \tilde{g} is a concave function on σ_τ^2 and σ_ξ^2 . In the following experiments, we adopt

$$\tilde{g}(\sigma_\tau^2, \sigma_\xi^2) = c_\tau \sigma_\tau + c_\xi \sigma_\xi + c_{joint} \sigma_\tau \sigma_\xi \geq B \quad (4.6)$$

as the resource constraint, where c_τ , c_ξ , and B are positive and c_{joint} is nonnegative. With the concavity in σ_τ^2 and σ_ξ^2 , the first two terms introduce the increasing marginal cost in improving accuracy: Reducing σ_τ^2 (σ_ξ^2) is more expensive when σ_τ^2 (σ_ξ^2) is already small. The values of c_τ and c_ξ adjust costs so that improving demand (effort) monitoring becomes more expensive if c_τ (c_ξ) becomes smaller. The complementarity between σ_τ^2 and σ_ξ^2 is incorporated by the multiplicative term $c_{joint} \sigma_\tau \sigma_\xi$, where larger c_{joint} implies a higher degree of complementarity. In particular, the costs of the two functions are independent when $c_{joint} = 0$.

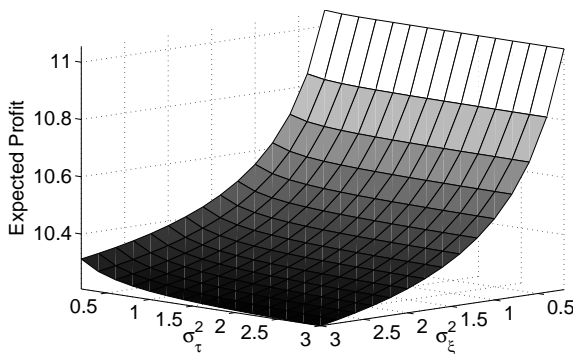


Figure 4.2: Expected profits

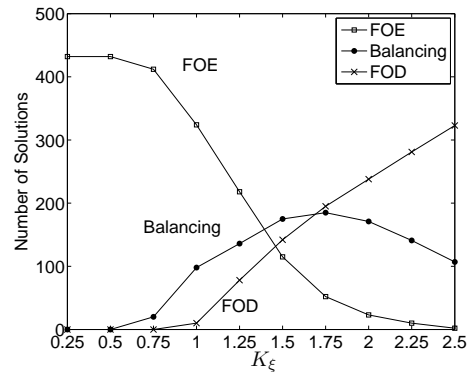


Figure 4.3: Impact of K_ξ

We start our numerical study by performing a preliminary experiment to address the relative effectiveness of demand monitoring and effort monitoring. For ρ , σ_θ^2 , and

σ_ϵ^2 , we test each of them for values 0.5, 1, and 2 and generate $3^3 = 27$ scenarios. We set $\mu_\theta = 10$ in all experiments. Ignoring the constraints in the resource allocation problem (4.5), Figure 4.2 illustrate the expected profit as functions of σ_τ^2 and σ_ξ^2 .¹ These figures show that 1) improving effort monitoring (decreasing σ_ξ^2) is more profitable than improving demand monitoring (decreasing σ_τ^2), and 2) improving demand monitoring is not effective when effort monitoring is precise (σ_ξ^2 is close to 0). Therefore, effort monitoring generally brings more benefits in the absence of those constraints.

Now we provide a finer examination by adding the constraints back. Because effort monitoring is more beneficial in general, we adjust K_ξ , c_τ , and c_{joint} to introduce higher physical restrictions on effort monitoring, cheaper demand monitoring, and higher degrees of complementarity. For each of the 160 combinations of different values of K_ξ , c_τ , and c_{joint} (listed in Tables 4.1 and 4.2), we test the 27 scenarios and count the frequencies of three types of optimal solutions: the focusing-on-demand solution ($\sigma_\tau^2 = K_\tau$, $\sigma_\xi^2 > K_\xi$; abbreviated as ‘‘FOD’’ below), the focusing-on-effort solution ($\sigma_\tau^2 > K_\tau$, $\sigma_\xi^2 = K_\xi$; ‘‘FOE’’), and the balancing solution ($\sigma_\tau^2 > K_\tau$, $\sigma_\xi^2 > K_\xi$).² See Tables 4.1 and 4.2 for the complete result. With these numerical results, we next analyze the effects of changing K_ξ , c_ξ , and c_{joint} in the sequel.

4.3.1 Impact of the physical restrictions

We start from the physical restriction K_ξ . Figure 4.3 depicts how the reseller’s preference differs with different values of K_ξ .³ From this figure, we observe the following:

Observation 3. *Focusing on effort is preferred when K_ξ is small, focusing on demand is preferred when K_ξ is large, and balancing is attractive when K_ξ is moderate.*

We find that FOE becomes less attractive when K_ξ becomes larger, which is intuitive since the FOE solution is forced to be worse. It is also intuitive that FOD becomes more attractive. Interestingly, the number of balancing solutions first increases (when $K_\xi \leq 1.75$) and then decreases (when $K_\xi \geq 1.75$). The intuition behind this is explained as follows. Each time K_ξ increases, the effectiveness of effort monitoring decreases and thus the reseller prefers demand monitoring more. When effort monitoring is still good enough (when K_ξ is not too large), the reseller should not abandon effort monitoring completely. Therefore, it is optimal to partially switch to demand monitoring by adopting the balancing strategy. However, when effort monitoring is totally ineffective (K_ξ is too large), the reseller will fully switch to demand monitoring. Balancing is thus attractive only when K_ξ is moderate.

¹To obtain a value for a σ_τ^2 – σ_ξ^2 pair in these figures, we average the 27 values from all the scenarios.

²We have $\tilde{g}(\sigma_\tau^2, \sigma_\xi^2) = B$ for all the three types. Because none of these experiments results in a non-binding solution, we conclude that the resource constraint is binding at optimality for most of the time, if not always.

³Numbers for Figures 4.3, 4.4, and 4.5 are presented in Appendix B

c_{joint}	c_ξ	K_ξ				
		0.25	0.5	0.75	1	1.25
5	0.25	27/0/0	27/0/0	27/0/0	26/0/1	24/0/3
5	0.5	27/0/0	27/0/0	27/0/0	26/0/1	21/0/6
5	0.75	27/0/0	27/0/0	27/0/0	26/0/1	21/2/4
5	1	27/0/0	27/0/0	27/0/0	25/0/2	19/5/3
7.5	0.25	27/0/0	27/0/0	27/0/0	24/0/3	15/0/12
7.5	0.5	27/0/0	27/0/0	27/0/0	22/0/5	15/0/12
7.5	0.75	27/0/0	27/0/0	27/0/0	22/0/5	14/4/9
7.5	1	27/0/0	27/0/0	26/0/1	20/0/7	12/8/7
10	0.25	27/0/0	27/0/0	26/0/1	20/0/7	11/0/16
10	0.5	27/0/0	27/0/0	26/0/1	19/0/8	10/5/12
10	0.75	27/0/0	27/0/0	25/0/2	17/0/10	10/9/8
10	1	27/0/0	27/0/0	24/0/3	16/0/11	10/9/8
12.5	0.25	27/0/0	27/0/0	26/0/1	19/0/8	9/9/9
12.5	0.5	27/0/0	27/0/0	24/0/3	16/0/11	9/9/9
12.5	0.75	27/0/0	27/0/0	24/0/3	13/3/11	9/9/9
12.5	1	27/0/0	27/0/0	22/0/5	13/7/7	9/9/9

(* $x/y/z$: the number of FOE/FOD/balancing solutions)

Table 4.1: Numbers of FOE, FOD, and balancing solutions

4.3.2 Impact of the relative costs

Now consider c_ξ , which represents the relative cost of effort monitoring. Intuitively, a higher cost in effort monitoring should drive the reseller to prefer the relatively cheaper demand monitoring. Nevertheless, Figure 4.4 shows the completely opposite trend.

Observation 4. *When c_ξ decreases and effort monitoring is relatively more expensive, focusing on effort and balancing become more preferable while focusing on demand becomes less attractive.*

To understand this counterintuitive result, note that when one function becomes more expensive, both focusing solutions receive negative effects. To remain equally accurate in one side, the reseller will be forced to give up some precision in the other side due to the higher cost. Given that a precision loss in effort monitoring generally harms the reseller more (cf. Figure 4.2), it is reasonable for the reseller to prefer FOE more as effort monitoring becomes more expensive (c_ξ decreases). Note that balancing also becomes more profitable when c_ξ decreases. It is clear that this also results from the force driving the reseller to deviate from FOD.

c_{joint}	c_ξ	K_ξ				
		1.5	1.75	2	2.25	2.5
5	0.25	17/2/8	12/6/9	7/8/12	4/9/14	1/9/17
5	0.5	17/5/5	10/8/9	7/9/11	4/9/14	1/16/10
5	0.75	15/7/5	9/9/9	4/9/14	1/17/9	0/18/9
5	1	12/9/6	8/9/10	4/15/8	1/18/8	0/18/9
7.5	0.25	8/5/14	4/8/15	1/9/17	0/9/18	0/18/9
7.5	0.5	8/7/12	4/9/14	0/9/18	0/18/9	0/18/9
7.5	0.75	8/9/10	3/9/15	0/16/11	0/18/9	0/18/9
7.5	1	7/9/11	1/12/14	0/18/9	0/18/9	0/18/9
10	0.25	6/9/12	1/9/17	0/15/12	0/18/9	0/18/9
10	0.5	4/9/14	0/10/17	0/18/9	0/18/9	0/18/9
10	0.75	4/9/14	0/17/10	0/18/9	0/18/9	0/23/4
10	1	3/10/14	0/18/9	0/18/9	0/20/7	0/27/0
12.5	0.25	3/9/15	0/17/10	0/18/9	0/18/9	0/23/4
12.5	0.5	3/9/15	0/18/9	0/18/9	0/20/7	0/27/0
12.5	0.75	0/16/11	0/18/9	0/18/9	0/26/1	0/27/0
12.5	1	0/18/9	0/18/9	0/22/5	0/27/0	0/27/0

(* $x/y/z$: the number of FOE/FOD/balancing solutions)

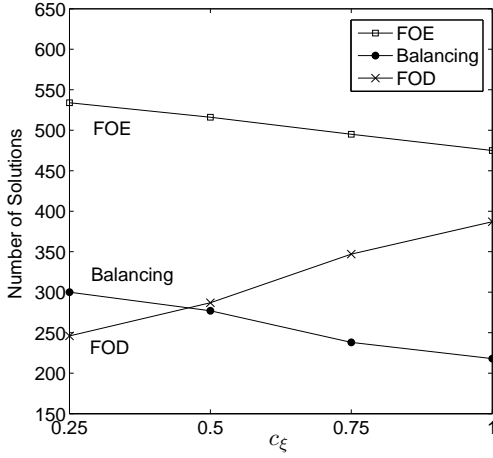
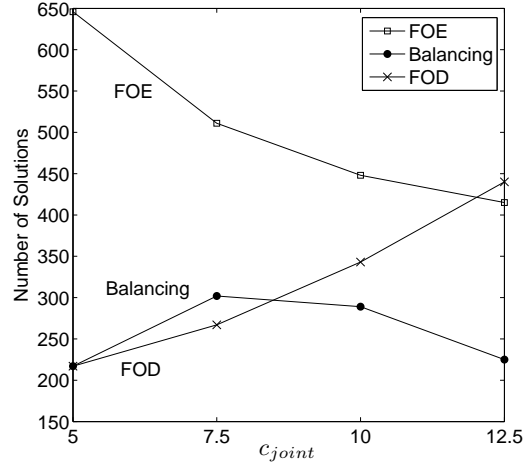
Table 4.2: Numbers of FOE, FOD, and balancing solutions (continued)

Interestingly, this observation shows that the effort monitoring function possesses the property of “Giffen goods”, i.e., the higher the price, the larger the consumption. In a typical example of Giffen goods, one may substitute meat by bread when bread becomes more expensive. This is because while bread is directly required for one’s daily life, meat is valuable mainly when there is enough bread. The choice between the two monitoring functions is similar: While effort monitoring is more direct and effective, demand monitoring only creates marginal benefits. Because effort monitoring is more important, the reseller should invest in demand monitoring only when she has extra money, i.e., when effort monitoring is cheap. Therefore, when the cost of effort monitoring goes up and the current accuracy mix becomes infeasible, the reseller should substitute demand monitoring by the more critical effort monitoring. This explains the above observation.

4.3.3 Impact of the degree of complementarity

The last study is for the complementarity between the costs of demand monitoring and effort monitoring. Figure 4.5 gives rise to the following observation.

Observation 5. *When the two functions become more complementary (c_{joint} in-*

Figure 4.4: Impact of c_ξ Figure 4.5: Impact of c_{joint}

creases), focusing on effort becomes less profitable, focusing on demand becomes more profitable, and balancing becomes more profitable when c_{joint} is small but less profitable when c_{joint} is large.

The first part of this observation demonstrates the decreasing attractiveness of FOE as the degree of complementarity increases. Recall that effort monitoring is more effective than demand monitoring when they are independent. With complementarity, being precise in one aspect allows the reseller to monitor the other aspect more easily. Therefore, a higher degree of complementarity allows a focusing-on-demand reseller to utilize the effectiveness of effort monitoring. On the contrary, suppose that the reseller focuses on effort. It is indeed the case that the reseller can also monitor demand more easily through complementarity. However, both Proposition 4 and Figure 4.2 suggest that improving demand monitoring offers only limited benefits when the accuracy of effort monitoring is already high. This implies that, for a focusing-on-effort reseller, the benefits brought by demand monitoring is small. In short, complementarity is beneficial if the reseller focuses on demand but of the least value if she focuses on effort. It is thus profitable for the reseller to switch from FOE to FOD when it is highly complementary. This also explains the second part.

The third part deserves more attention. Intuitively, when the two aspects of monitoring become more complementary, we expect the reseller to prefer balancing more. To discover the reason behind this nonmonotonicity of preference over the balancing strategy, we need to simultaneously consider K_ξ , the physical restriction on the accuracy of effort monitoring, and c_{joint} , the degree of complementarity. From Figure 4.3, we know that balancing is preferred only when K_ξ is moderate. Moreover, the previous paragraph explains why FOD is preferred when c_{joint} is large. It is thus not surprising that in Table 4.3, the number of balancing solutions increases in c_{joint}

only when K_ξ is moderate and c_{joint} is not too large. When K_ξ is small enough, effort monitoring dominates demand monitoring and FOE is always the best strategy. On the contrary, when K_ξ is large, a too large c_{joint} only encourages the reseller to focus on demand and utilize the high degree of complementarity. In particular, when K_ξ is so large that direct effort monitoring is impossible, FOD is the only way to monitor the effort (indirectly through the complementarity) and thus more preferable. In general, whether a higher c_{joint} results in a preference over the balancing strategy depends on the relationship between c_{joint} and K_ξ .

c_{joint}	K_ξ									
	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
5	0	0	0	5	16	24	37	45	45	45
7.5	0	0	1	20	40	47	58	55	45	36
10	0	0	7	36	44	54	53	39	34	22
12.5	0	0	12	37	36	50	37	32	17	4

Table 4.3: Number of balancing solutions under different c_{joint} and K_ξ

As we have illustrated through the numerical studies, the physical restrictions on accuracy, the costs of improving accuracy, and the degree of complementarity all play roles in determining the optimal accuracy mix. Our results show that the investment decision must be made carefully. Contrary to common intuitions, focusing on demand may become less profitable when effort monitoring is more expensive and balancing may become less attractive when the two functions are more complementarity. In practice, we observe resellers implementing different investment strategies: some focus on demand forecasting, some care more about performance measurement, and some balance between the two functions. Our results may partially explain such a discrepancy.

4.4 Summary

In this chapter, we study two specific monitoring functions, demand forecasting and performance measurement. We show that these two functions help the reseller motivate the salesperson and increase demand volume. In particular, improving effort monitoring helps the reseller induce a higher expected effort level and earn a higher expected profit. We further consider the resource allocation problem in which the reseller must make an investment decision and allocate her limited budget to the two functions. Through numerical experiments, we find that performance measurement is generally more effective than demand forecasting, but the optimal accuracy mix is also affected by the physical restrictions on accuracy, the relative costs, and the degree of complementarity. Our experiments generate some counterintuitive insights.

Specifically, a more expensive effort monitoring does not necessarily drive a reseller to give up monitoring effort, and a higher complementarity between the two functions does not always imply the balancing strategy is more profitable.

Chapter 5

The optimal forecasting accuracy

In this chapter, we consider the scenario in which effort monitoring is impossible. In this case, the reseller may only estimate the market condition through demand forecasting. We will allow the reseller to be completely precise, completely imprecise, or possess any accuracy between the two extreme situations. To enhance the applicability of our results, we will also allow the salesperson to be partially precise.

The discussion starts from the description of our basic model in Section 5.1. In Section 5.2, we characterize the optimal contracts, derive our main findings, and discuss their managerial implications. We then generalize our analysis and examine several extensions in Section 5.3. Section 5.4 summarizes our findings. All proofs are in the Appendix C.

5.1 Model

Demand and supply. We consider a supply chain in which a manufacturer sells a product through a reseller, who then relies on her salesperson to sell to the end market at a fixed price in a single selling season. The market demand x in the selling season is random and may be either high or low. The high demand volume is normalized to 1 and the low demand volume is normalized to 0. The realization of x depends on a random market condition θ and the sales effort $a \geq 0$ privately exerted by the salesperson. More precisely, we assume that

$$\Pr(x = 1|\theta, a) = \theta a = 1 - \Pr(x = 0|\theta, a).$$

With our MTO assumption, the demand quantity x is also the sales outcome. Without loss of generality, we normalize the production cost to 0 and the selling price to 1. Note that $\mathbb{E}[x|\theta, a] = \theta a$ and the demand tends to be high when the market condition is good (θ is large) and the salesperson works hard (a is large). It costs the salesperson $V(a) = \frac{1}{2}a^2$ for exerting effort a .¹

¹If the cost of effort $V(a)$ is convex rather than quadratic, we can follow the similar arguments in the salesforce compensation literature to verify that our results are qualitatively similar as long

We assume that $\theta \in \{\theta_L, \theta_H\}$, $0 < \theta_L < \theta_H < 1$, and denote the probability for the market condition to be bad as γ , i.e.,

$$\Pr(\theta = \theta_L) \equiv \gamma = 1 - \Pr(\theta = \theta_H).$$

The value of γ represents how the supply chain members evaluate the popularity of the product. If they believe the product will be popular among consumers, they will assign a high value to γ . On the contrary, a low value of γ shows that the supply chain members are pessimistic about the sales outcome. Therefore, in this paper we refer to γ as the *level of pessimism*. We will assume $\gamma = \frac{1}{2}$ to simplify our analysis in Section 5.2 and then generalize it to be any value within $(0, 1)$ in Section 5.3.3. Let $\eta \equiv \frac{\theta_H}{\theta_L}$ be the *market condition ratio*, which turns out to be an important factor in our analysis.

Forecasting accuracy. While the manufacturer knows nothing about the market condition θ , the reseller and the salesperson can estimate θ through independent demand forecasting. Prior to the selling season, the reseller obtains a demand signal s_R , which is either good ($s_R = G$) or bad ($s_R = B$). Let λ_R be the probability for the reseller to make a correct prediction on the market condition, we have

$$\lambda_R \equiv \Pr(s_R = B|\theta = \theta_L) = \Pr(s_R = G|\theta = \theta_H)$$

and $\Pr(s_R = G|\theta = \theta_L) = \Pr(s_R = B|\theta = \theta_H) = 1 - \lambda_R$. Because a higher value of λ_R implies a higher probability to forecast correctly, we define λ_R as the reseller's *forecasting accuracy*. Similarly, the salesperson can collect a demand signal s_A , which may be favorable ($s_A = F$) or unfavorable ($s_A = U$), with the forecasting accuracy $\lambda_A \equiv \Pr(s_A = U|\theta = \theta_L) = \Pr(s_A = F|\theta = \theta_H)$. Naturally, we have $\Pr(s_A = F|\theta = \theta_L) = \Pr(s_A = U|\theta = \theta_H) = 1 - \lambda_A$. We assume that s_R and s_A are independent, the manufacturer sees none of the two signals, and λ_R and λ_A are publicly observed by all members.²

Without loss of generality, it is assumed that λ_R and λ_A are between $\frac{1}{2}$ and 1. If one's accuracy is 1, she or he can precisely observe the true market condition and is called *precise*. On the other hand, if the accuracy is $\frac{1}{2}$, forecasting is nothing but tossing a coin and the demand signal is actually uninformative. When this happens, the reseller or the salesperson is called *uninformed*. If instead λ_R or λ_A is within 0 and $\frac{1}{2}$, we can relabel a good signal as bad and vice versa. As the salesperson is an employee of the reseller, in practice he can see the market information acquired by the reseller. On the contrary, the salesperson typically does not voluntarily share his personal experience and knowledge with his employer, the reseller. Therefore, we assume the salesperson can observe both s_R and s_A but the reseller can only

as the resulting optimal effort level is no greater than 1.

²This assumption is also made in [11, 51]. As mentioned in these two papers, the assumption that the forecasting accuracy is public is appropriate when such knowledge can be perceived from each member's historical forecasting performance or the evaluation of their information systems.

observe s_R . In Section 5.3.1, we explain why disallowing the salesperson to observe the reseller's signal does not change our results. This equivalence result follows directly from the classical arguments by Maskin and Tirole [36, 37]. Thus, the particular information structure in our basic model is adopted mainly for ease of exposition. To highlight the impact of the informational issues, we ignore the costs of forecasting and improving accuracy. Patching these costs in our setting is straightforward.

Contracting. Because the sales effort a is unobservable, the reseller can only compensate the salesperson according to the observable sales outcome x . Therefore, the best she can do is to offer a sales-contingent compensation scheme $T_A(x)$, which specifies different transfers for the salesperson under different sales outcomes. Because $x \in \{0, 1\}$, it is without loss of generality to define $T_A(0) = \alpha$ and $T_A(1) = \alpha + \beta$. Straightforward analysis shows that any negative β induces the salesperson to exert no effort. Therefore, we conveniently interpret the nonnegative β as a sales bonus. It should be emphasized that, as the sales outcome is binary, the compensation scheme $T_A(x) = \alpha + \beta x$ is actually the *most general* contract form.³ Because the salesperson has superior information about the market condition, the reseller's best strategy is to offer the salesperson a menu of contracts. From the revelation principle and the fact that s_A is binary, we can restrict the menu to be $\{(\alpha_F, \beta_F), (\alpha_U, \beta_U)\}$, where (α_j, β_j) defines the compensation scheme intended for the salesperson observing $s_A = j$.

Similarly, the manufacturer may compensate the reseller only based on the sales outcome. Let $T_R(x)$ be the total payment for the reseller under the sales outcome x . Due to the binary nature of x , the most general contract form can be expressed as $T_R(x) = u + vx$, where u is the fixed payment and v is the sales bonus awarded to the reseller when $x = 1$. Because the manufacturer does not observe s_R , the manufacturer should offer the reseller a menu of contracts $\{(u_G, v_G), (u_B, v_B)\}$ so that it is in the reseller's best interest to choose (u_k, v_k) if she observes signal $s_R = k \in \{G, B\}$.

Throughout this paper, all the players are risk-neutral and act to maximize their expected profits. To further examine the impact of the private sales effort and the moral hazard issue, we will impose various levels of limited liability on the salesperson in Section 5.3.2. Without loss of generality, we normalize the reseller's and the salesperson's reservation net incomes to 0.

Timing. The sequence of events, as illustrated in Figure 5.1, is as follows: 1) The reseller and the salesperson determine their accuracy λ_R and λ_A , respectively. Once determined, λ_R and λ_A are publicly observed by everyone. 2) The market condition θ is realized but observed by no one. The reseller and the salesperson conduct forecasting and observe the demand signals s_R and s_A , respectively. 3) The manufacturer offers a menu for the reseller to choose one contract from; 4) Based on the demand signal s_R and the chosen contract, the reseller offers a menu for the

³The binary outcome assumption is admittedly a simplification of practical situations. Nevertheless, because moral hazard problems with general outcomes are known to be intractable, the two-type framework has been widely adopted in the economics literature. It is well-known to be a good workhorse for understanding various business contexts.

salesperson to choose one contract from. In these two stages, if either the reseller or the sales agent rejects the offer, the game ends and every supply chain member receives a null payoff. 5) Based on the signals s_R and s_A and the chosen contract, the salesperson exerts sales effort a ; 6) The demand quantity x is realized, the sales revenue goes to the manufacturer, and the reseller and the salesperson receive their payments according to the chosen contracts and the realization of x .

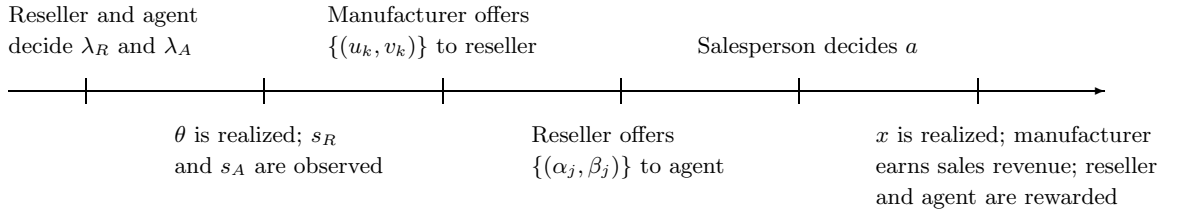


Figure 5.1: Sequence of events.

In the next section, we address our main research question within the basic framework. We then relax certain assumptions in Section 5.3 to demonstrate the robustness of the insights we obtain.

5.2 Analysis

In this section, we characterize the optimal menus of contracts offered by the manufacturer and the reseller. The impact of the reseller's and the salesperson's forecasting accuracy on supply chain performance and the profitability of supply chain members is then discussed. For ease of exposition, let the type- (j, k) salesperson be the salesperson observing signals $S_A = j$ and $S_R = k$ and the type- k reseller be the reseller observing signal $S_R = k$, where $j \in \{F, U\}$ and $k \in \{G, B\}$.

5.2.1 The contract design problems

Suppose that the type- (j, k) salesperson has chosen a contract (α_t, β_t) by reporting $s_A = t$. Let $N_{jk} \equiv \mathbb{E}[\theta | s_A = j, s_R = k]$ be the salesperson's belief on the expected market condition. Then the profit-maximizing salesperson chooses his sales effort a to solve

$$\mathcal{A}_{jk}(t) \equiv \max_{a \geq 0} \mathbb{E} \left[\alpha_t + \beta_t x - \frac{1}{2} a^2 \middle| s_A = j, s_R = k \right] = \max_{a \geq 0} \alpha_t + \beta_t N_{jk} a - \frac{1}{2} a^2.$$

With the optimizer $a_{jk}^*(t) = N_{jk} \beta_t$, the resulting expected profit is $\mathcal{A}_{jk}(t) = \alpha_t + \frac{1}{2} \beta_t^2 N_{jk}^2$. Let $\mathcal{A}_{jk} \equiv \mathcal{A}_{jk}(j)$ and $a_{jk}^* \equiv a_{jk}^*(j)$ be the salesperson's expected profit and effort under truth-telling.

Taking the salesperson's response into consideration, the type- k reseller designs a compensations scheme $\{(\alpha_F, \beta_F), (\alpha_U, \beta_U)\}$ to maximize her own expected profit. As the reseller observes the demand signal $s_R = k$, she believes that $s_A = j$ with probability $\bar{P}_{jk} \equiv \Pr(s_A = j | s_R = k)$.⁴ Moreover, because the menu should induce the type- (j, k) salesperson to choose (α_j, β_j) , we have $\mathbb{E}[x | s_A = j, s_R = k] = N_{jk} a_{jk}^* = N_{jk}^2 \beta_j$. Suppose the reseller has chosen a contract (u_t, v_t) by reporting $s_R = t$, she will then earn $u_t - \alpha_j + (v_t - \beta_j) N_{jk}^2 \beta_j$ in expectation when the salesperson sees signal $s_A = j$. Therefore, the type- k reseller solves⁵

$$\mathcal{R}_k(t) \equiv \max_{\substack{\alpha_F \text{ urs.}, \beta_F \geq 0, \\ \alpha_U \text{ urs.}, \beta_U \geq 0}} \sum_{j \in \{F, U\}} \bar{P}_{jk} \left[u_t - \alpha_j + (v_t - \beta_j) N_{jk}^2 \beta_j \right] \quad (5.1)$$

$$\text{s.t.} \quad \mathcal{A}_{Fk} \geq 0, \quad \mathcal{A}_{Uk} \geq 0 \quad (5.2)$$

$$\mathcal{A}_{Fk} \geq \mathcal{A}_{Fk}(U), \quad \mathcal{A}_{Uk} \geq \mathcal{A}_{Uk}(F). \quad (5.3)$$

The objective function (5.1) is to maximize the reseller's expected profit (based on her own belief). The two individual rationality (IR) constraints in (5.2) guarantee a nonnegative expected payoff for both types of salesperson. The two incentive compatibility (IC) constraints in (5.3) ensure that both types of salesperson prefer the contract intended for them. Let $\mathcal{R}_k \equiv \mathcal{R}_k(k)$ be the reseller's expected profit under truth-telling. In the following lemma, we characterize the reseller's optimal menu.

Lemma 8. *If the reseller has observed the demand signal $s_R = k \in \{G, B\}$ and has chosen the contract (u_t, v_t) , it is optimal for her to offer*

$$\beta_F^* = v_t, \quad \beta_U^* = \frac{\bar{P}_{Uk}}{\bar{P}_{Uk} + \bar{P}_{Fk}(N_{Fk}^2/N_{Uk}^2 - 1)} v_t \equiv Y_k v_t,$$

$$\alpha_F^* = \frac{(\beta_{Uk}^*)^2}{2} (N_{Fk}^2 - N_{Uk}^2) - \frac{(\beta_{Fk}^*)^2}{2} N_{Fk}^2, \quad \text{and} \quad \alpha_U^* = -\frac{(\beta_{Uk}^*)^2}{2} N_{Uk}^2$$

to the salesperson. The reseller's expected profit is $\mathcal{R}_k(t) = u_t + \frac{1}{2} Z_k v_t^2$, where

$$Z_k \equiv \bar{P}_{Fk} N_{Fk}^2 + \frac{\bar{P}_{Uk}^2 N_{Uk}^2}{\bar{P}_{Uk} + \bar{P}_{Fk}(N_{Fk}^2/N_{Uk}^2 - 1)}.$$

Inside the coefficient Y_k , the term $N_{Fk}^2/N_{Uk}^2 - 1$ captures the influence of the adverse selection problem in the reseller-salesperson relationship. While there is no distortion on β_F^* , β_U^* is downwards distorted whenever $N_{Fk}^2/N_{Uk}^2 - 1 > 0$. When $\lambda_A = \frac{1}{2}$, we have $N_{Fk} = N_{Uk}$ and $\beta_U^* = v_t$, which mean that the adverse selection

⁴ N_{jk} and \bar{P}_{jk} can be explicitly expressed by $\lambda_A, \lambda_R, \theta_H$, and θ_L by applying Bayesian updating. For example, we have $N_{FG} = [\theta_H \lambda_A \lambda_R + \theta_L (1 - \lambda_A)(1 - \lambda_R)] / [\lambda_A \lambda_R + (1 - \lambda_A)(1 - \lambda_R)]$ and $\bar{P}_{FG} = \lambda_A \lambda_R + (1 - \lambda_A)(1 - \lambda_R)$ under the assumption $\gamma = \frac{1}{2}$. These quantities can also be generalized to functions of γ when $\gamma \neq \frac{1}{2}$.

⁵Throughout this paper, we use "urs." as the abbreviation of "unrestricted in sign".

problem no longer exists. This is because the sales agent's private demand signal s_A is uninformative and thus he possesses no informational advantage. The reseller then just needs to offer a single contract to the salesperson. However, as long as $\lambda_A > \frac{1}{2}$, the signal s_A provides useful information to the salesperson. Because the salesperson who observes a favorable signal believes that the sales volume will tend to be high, he prefers a high sales bonus. Therefore, to better differentiate the two types of the salesperson, it is in the reseller's best interest to distort downwards the commission rate offered to the type- (B, k) salesperson (as seen in $N_{Fk} > N_{Uk}$ and $\beta_U^* < v_t$). In general, it can be verified that N_{Fk}^2/N_{Uk}^2 increases in λ_A and Y_k decreases in λ_A for $k \in \{G, B\}$. As the salesperson becomes more accurate, she will be more optimistic when seeing a favorable signal. This explains why a larger distortion is required to achieve better differentiation.

Now we consider the manufacturer's problem in designing $\{(u_G, v_G), (u_B, v_B)\}$. Once the manufacturer sees that the contract (u_k, v_k) is chosen, it knows that the reseller has observed $s_R = k$. In this case, the conditional expectation of sales is

$$\mathbb{E}[x|s_R = k] = \sum_{j \in \{F, U\}} \bar{P}_{jk} a_{jk}^* = \bar{P}_{Fk} N_{Fk}^2 v_k + \bar{P}_{Uk} N_{Uk}^2 Y_k v_k = Z_k v_k \quad (5.4)$$

and the manufacturer's expected profit is $(1 - v_k)Z_k v_k - u_k$. With our assumption $\gamma = \frac{1}{2}$, simple derivations show that the manufacturer will see each type of reseller with probability $\frac{1}{2}$. The manufacturer's contract design problem is thus formulated as

$$\mathcal{M} \equiv \max_{\substack{u_G \text{ urs.}, v_G \geq 0, \\ u_B \text{ urs.}, v_B \geq 0}} \sum_{k \in \{G, B\}} \frac{1}{2} \left[(1 - v_k)Z_k v_k - u_k \right] \quad (5.5)$$

$$\text{s.t.} \quad \mathcal{R}_G \geq 0, \quad \mathcal{R}_B \geq 0, \quad (5.6)$$

$$\mathcal{R}_G \geq \mathcal{R}_G(B), \quad \mathcal{R}_B \geq \mathcal{R}_B(G). \quad (5.7)$$

The two IR constraints in (5.6) guarantee the reseller's participation while the two IC constraints in (5.7) ensure truth-telling. The objective function (5.5) is to maximize the manufacturer's expected profit. The optimal solution to the manufacturer's problem is summarized in the following lemma.

Lemma 9. *It is optimal for the manufacturer to offer*

$$v_G^* = 1, \quad v_B^* = \frac{Z_B}{Z_G}, \quad u_G^* = \frac{(v_B^*)^2}{2} (Z_G - Z_B) - \frac{1}{2} Z_G, \quad \text{and} \quad u_B^* = -\frac{(v_B^*)^2}{2} Z_B$$

to the reseller. The manufacturer's expected profit under the optimal contract is

$$\mathcal{M} = \frac{1}{4} \left[Z_G + \frac{Z_B^2}{Z_G} \right].$$

The reseller receives $\mathcal{R}_B = 0$ if she observes a bad signal, $\mathcal{R}_G = \frac{1}{2}(Z_G - Z_B)(\frac{Z_B}{Z_G})^2$ if she observes a good signal, and $\mathcal{R} = \frac{1}{2}(\mathcal{R}_G + \mathcal{R}_B) = \frac{1}{4}(Z_G - Z_B)(\frac{Z_B}{Z_G})^2$ in expectation.

The same as what we have observed in the reseller-salesperson relationship, the manufacturer also distorts downwards the sales bonus offered to the type- B reseller unless $\lambda_R = \frac{1}{2}$. This eventually lowers the sales effort and introduces inefficiency when delegating to a type- B reseller. To understand this downward distortion, note that the manufacturer relies on the reseller to motivate the salesperson and the manufacturer cannot observe the reseller's demand signal s_R . If there is only a single contract, the reseller should always claim that the signal is bad because achieving a high expected sales outcome under a bad signal is more costly and should be compensated more. To induce a type- G reseller to report truthfully, the manufacturer must make (u_B^*, v_B^*) sufficiently unattractive to her. This is accomplished by cutting down the sales bonus v_B^* because a type- G reseller prefers a large sales bonus. It can be verified that $Z_G > Z_B$ if and only if $\lambda_R > \frac{1}{2}$. Thus, the informational advantage possessed by the type- G reseller helps her earn a positive information rent (\mathcal{R}_G) as long as she can do better than the manufacturer in demand forecasting. On the contrary, a type- B reseller earns nothing.

Because resellers of different types will offer different contracts in equilibrium, we denote the contract intended for the type- (j, k) sales agent as $(\alpha_{jk}^*, \beta_{jk}^*)$ in the sequel. Combining the above two lemmas, we have $\beta_{FG}^* = 1$, $\beta_{UG}^* = Y_G$, $\beta_{FB}^* = v_B^*$, and $\beta_{UB}^* = Y_B v_B^*$. To facilitate the discussions below, we will refer to v_B^* as the upstream distortion factor, which appears when the reseller observes a bad signal. Similarly, we refer to Y_k as the downstream distortion factor, which is present when the salesperson observes an unfavorable signal. There is a larger distortion with a smaller v_B^* or Y_k . There is no distortion only when both the reseller and the salesperson are optimistic (i.e., $s_A = F$ and $s_R = G$). This is the case with $\beta_{FG}^* = 1$.

So far we have characterized the optimal menus offered by the manufacturer and the reseller, the induced effort level, and the resulting expected profits. We now proceed to discuss the impact of the reseller's forecasting accuracy.

5.2.2 Supply chain performance and the reseller's accuracy

We start the discussion from the supply chain's perspective. To examine the supply chain performance, we focus on the expected sales quantity $\mathbb{E}[x]$, as this represents the total revenue generated by the supply chain. The analysis starts from demonstrating its convexity in the following proposition. Figure 5.2 illustrates one particular example, in which the expected sales is *nonmonotone*: it is first decreasing and then increasing as the reseller improves her forecasting accuracy. Most of the parameter combinations result in the same nonmonotonicity.⁶

Proposition 13. *The expected sales $\mathbb{E}[x]$ is convex on $\lambda_R \in [\frac{1}{2}, 1]$.*

⁶At the end of this subsection, we provide a sufficient condition for the expected sales to be monotone.

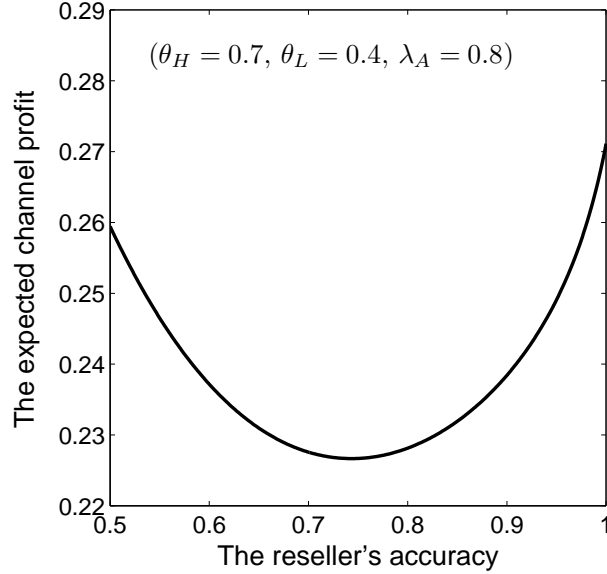


Figure 5.2: Nonmonotonicity of the expected sales.

The above proposition as well as our numerical experiments show that typically the expected sales decreases in the reseller's accuracy when the accuracy is low but increases when the accuracy is high. As we explain in detail below, improving the forecasting accuracy creates three different effects in our three-layer supply chain. How does the reseller's accuracy affect the expected sales then depends on the relative importance of these effects.

Improving the reseller's accuracy first introduces the conventional better-monitoring effect. As the reseller can better estimate the market condition, she can better infer the sales effort and design a more accurate compensation scheme. This will induce the salesperson to exert a higher sales effort and eventually result in a higher sales in expectation. To understand this effect, recall that the downstream distortion factor Y_k depends on $N_{Fk}^2/N_{Uk}^2 - 1$ (cf. Lemma 8), the degree of adverse selection in the reseller-salesperson relationship. While the salesperson can form different beliefs on the expected market condition (i.e., N_{Fk}^2 and N_{Uk}^2) upon observing different realizations of signal s_A , the reseller cannot do so because she cannot observe the salesperson's signal. The larger the difference between N_{Fk}^2 and N_{Uk}^2 , the more informational advantage the salesperson possesses relative to the reseller. If the reseller can improve her accuracy λ_R , intuitively this will make the salesperson's private signal s_A relatively less informative and reduce the degree of information asymmetry. Because the reseller sees the good signal and the bad signal with the same probability, the overall effect of adverse selection is captured by $\frac{1}{2}(N_{FG}^2/N_{UG}^2 - 1) + \frac{1}{2}(N_{FB}^2/N_{UB}^2 - 1)$, the expectation of the two degrees of adverse selection. It can then be verified that

$N_{FG}^2/N_{UG}^2 + N_{FB}^2/N_{UB}^2$ is indeed decreasing in λ_R . In short, the better-monitoring effect reduces the lower-level information asymmetry and brings positive benefits to the supply chain.

However, in the reseller-salesperson relationship, changing the reseller's accuracy also modifies the probability for the reseller to see a certain type of salesperson and introduces the belief-altering effect. If the type- k reseller expects to see the type- (F, k) salesperson more likely, it is more important to limit his information rents through a larger downward distortion on β_{Uk}^* (i.e., a smaller Y_k). This introduces the well-documented rent-extraction efficiency trade-off (cf. [28]) and creates inefficiency in our supply chain. When the reseller observes the bad signal, her belief on having the salesperson observing the favorable signal is \bar{P}_{FB} , which decreases in λ_R . Therefore, improving the reseller's accuracy reduces the level of distortion and improves supply chain performance. On the contrary, when the type- G reseller improves her accuracy, she believes that more likely the salesperson will observe the favorable signal (as \bar{P}_{FG} increases in λ_R) and thus creates a larger distortion. The overall impact on the supply chain performance of the belief-altering effect may thus be either positive or negative.

The next lemma indicates that the joint effect will eventually be positive, i.e., the downstream distortion factor Y_k will go up, when the reseller's accuracy is sufficiently high. In the lemma, we rule out the case with $\lambda_A = \frac{1}{2}$, which implies that $Y_k = 1$ for all λ_R .

Lemma 10. *For each combination of $k \in \{G, B\}$, $\lambda_A \in (\frac{1}{2}, 1]$, θ_H , and θ_L , there exists a unique threshold $\bar{\lambda}_R(k, \lambda_A, \theta_H, \theta_L) \in [\frac{1}{2}, 1)$ such that Y_k is increasing in λ_R when $\lambda_R \geq \bar{\lambda}_R(k, \lambda_A, \theta_H, \theta_L)$.*

While it is possible that Y_k decreases in λ_R when λ_R is small, this never happens when λ_R is close to 1. To understand this, we examine the better-monitoring effect in more detail. When the reseller possesses low accuracy, the salesperson has a huge informational advantage. In this case, a small improvement in the reseller's accuracy is relatively unimportant. However, as the reseller becomes more accurate, the same amount of accuracy improvement becomes relatively more significant. Once the reseller's accuracy achieves a certain threshold, further improvements make the better-monitoring effect strong enough to enhance efficiency in the reseller-salesperson relationship. This is irrespective of the possibly negative impact brought by the belief-altering effect. Note that the threshold may sometimes be $\frac{1}{2}$, in which case the joint effect is positive for all λ_R .

Now we turn to the manufacturer-reseller relationship. Because the manufacturer is always uninformed, improving the reseller's accuracy unambiguously aggravates information asymmetry between the manufacturer and the reseller. As the reseller's signal s_R becomes more informative, she is able to earn a larger information rent upon observing a good signal. In order to pay fewer rents, the manufacturer has the incentive to cut down the bonus for the reseller observing the bad signal (note that Z_F increases in λ_R , Z_U decreases in λ_R , and thus v_U^* decreases in λ_R). This rent-extraction

effect then allows the manufacturer to better differentiate different reseller types and extract more rents from the reseller. Nevertheless, it also aggravates the downward distortion in the manufacturer-reseller relationship, creates additional efficiency loss, and drives down the effort level as well as the sales outcome in expectation.

In summary, the better-monitoring, belief-altering, and rent-extraction effects together decide the shape of the expected sales as a function of the reseller's accuracy. When the accuracy is low and the information asymmetry between the manufacturer and the reseller is small, any accuracy improvement enlarges the manufacturer's informational disadvantage substantially. In other words, the rent-extraction effect is strong. At the same time, the accuracy improvement only helps the reseller resolve a relatively small part of her informational disadvantage; this suggests that the better-monitoring effect is weak. Therefore, the rent-extraction effect is dominant in the supply chain and the expected sales decreases when the reseller improves her accuracy. On the contrary, if the reseller has already been highly accurate, in most cases the negative rent-extraction effect will be only marginal while the positive better-monitoring effect is more significant. The supply chain performance is thus improved when the reseller further improves her high accuracy.

We finally note that the convexity of the expected sales does not necessarily imply nonmonotonicity. In particular, when the salesperson's accuracy λ_A is low and the market condition ratio $\eta \equiv \frac{\theta_H}{\theta_L}$ is close to 1, the expected sales can be monotonically decreasing in the reseller's accuracy. To see this, first note that when the salesperson's accuracy is low, the information asymmetry in the reseller-salesperson relationship is small and the better-monitoring effect is insignificant. Moreover, when the good market condition is just slightly better than the bad one, the benefit of distinguishing them is also small and being accurate is not valuable. Therefore, the negative rent-extraction effect dominates other positive effects and the expected sales is decreasing even when the reseller's accuracy is high. The next proposition formalizes the above discussion.

Proposition 14. *Let $\eta_1 \approx 1.3954$ be the unique greater-than-one root of the polynomial $\eta^5 - \eta^4 - 2\eta^2 + \eta = -1$. For each market condition ratio $\eta < \eta_1$, there exists a unique threshold $\hat{\lambda}_A(\eta) \in (\frac{1}{2}, 1]$ such that $\mathbb{E}[x]$ decreases in $\lambda_R \in [\frac{1}{2}, 1]$ if $\lambda_A < \hat{\lambda}_A(\eta)$.*

5.2.3 System-optimal reseller's accuracy and supply chain structure

As we have established in Proposition 13, the expected sales $\mathbb{E}[x]$ is convex on $\lambda_R \in [\frac{1}{2}, 1]$. Therefore, from the supply chain's perspective, the supply chain should include either the uninformed reseller with $\lambda_R = \frac{1}{2}$ or the precise reseller with $\lambda_R = 1$. Because the reseller in our supply chain does nothing but demand forecasting, including the uninformed reseller is equivalent to operating a direct supply chain with only the manufacturer and the salesperson. Therefore, our analysis in this section

also allows us to determine whether the direct supply chain outperforms the indirect one.

We state our main result regarding the system-optimal reseller's accuracy in the following proposition. Let

$$\lambda_R^* \equiv \operatorname{argmax}_{\lambda_R \in [\frac{1}{2}, 1]} \mathbb{E}[x]$$

be the system-optimal reseller's accuracy.⁷ As we demonstrate in the proposition, λ_R^* is determined by the market condition ratio η , which measures how θ_H differs from θ_L , and the salesperson's accuracy λ_A .

Proposition 15. *Let η_1 be defined in Proposition 14 and $\eta_2 \approx 2.2695$ be the unique greater-than-one root of the polynomial $\eta^4 - 2\eta^3 - \eta^2 = -2$. Then*

- for $\eta \in (1, \eta_1)$, $\lambda_R^* = \frac{1}{2}$ for all λ_A ;
- for $\eta \in [\eta_1, \eta_2]$, there exists a unique $\bar{\lambda}_A(\eta) \in [\frac{1}{2}, 1]$ such that $\lambda_R^* = \frac{1}{2}$ if $\lambda_A < \bar{\lambda}_A(\eta)$, $\lambda_R^* = 1$ if $\lambda_A > \bar{\lambda}_A(\eta)$, and $\lambda_R^* = \{\frac{1}{2}, 1\}$ if $\lambda_A = \bar{\lambda}_A(\eta)$; and
- for $\eta \in (\eta_2, \infty)$, $\lambda_R^* = 1$ for all λ_A .

We visualize the above proposition in Figure 5.3, in which $\bar{\lambda}_A(\eta)$ is illustrated by the curve as a function of η on the interval $[\eta_1, \eta_2]$. λ_R^* is different in the two regions separated by the curve. The first determinant of λ_R^* is the market condition ratio $\eta \equiv \frac{\theta_H}{\theta_L}$. Recall that θ_H and θ_L are the two possible realizations of θ , the random market condition. When $\eta < \eta_1$, the difference between θ_H and θ_L is small, and naturally the benefit of distinguishing the two realizations is only marginal: A wrong estimate does not deviate from the actual state too much. Therefore, the strength of the precise reseller is limited and the uninformed reseller is preferred. When $\eta > \eta_2$, the result is opposite and the precise reseller is preferred. This is because distinguishing the two quite different realizations now becomes more important.

The problem is more interesting when η is moderate, i.e., it is between the two cutoffs. In this case, the salesperson's accuracy plays a critical role. According to Proposition 15, $\lambda_R^* = \frac{1}{2}$ when λ_A is small and $\lambda_R^* = 1$ when λ_A is large. To understand this result, it is easier to treat including an uninformed reseller as operating a direct supply chain and consider whether to include the precise reseller into a direct supply chain. While the main benefit of including the reseller is brought by the better-monitoring effect, the rent-extraction effect creates efficiency loss. Because the rent-extraction effect appears in the manufacturer-reseller relationship, it harms the supply chain in the same way regardless of the salesperson's accuracy. On the contrary, the amount of benefits generated by the better-monitoring effect critically depends on

⁷In general, λ_R^* is a set (of two possible elements $\frac{1}{2}$ and 1) instead of a scalar. However, for ease of exposition, when λ_R^* is a singleton, we will use $\lambda_R^* = z$ instead of the more rigorous expression $\lambda_R^* = \{z\}$. Throughout the paper, the same idea applies to any set of accuracy when the set is almost always a singleton.

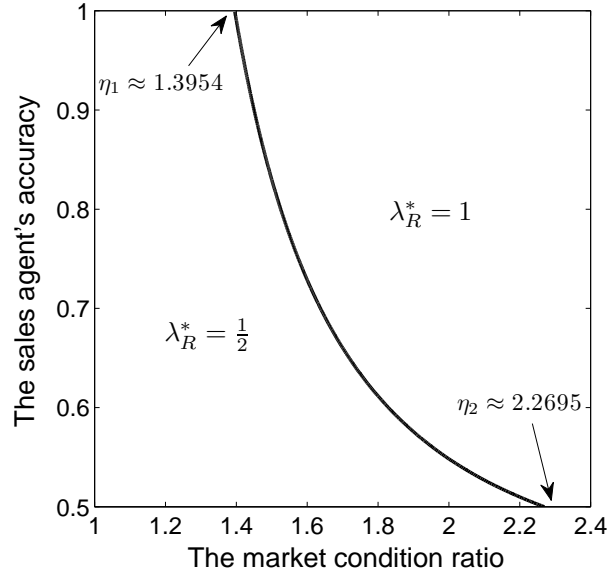


Figure 5.3: System-optimal reseller's accuracy.

how accurate the salesperson is. In a direct supply chain with a salesperson having low accuracy, the adverse selection problem faced by the manufacturer is not that serious. The better-monitoring effect is thus of little value and the direct supply chain performs better. When the salesperson is highly accurate, however, the manufacturer must find a way to mitigate the issue of asymmetric information. It is then beneficial to include the reseller and construct an indirect supply chain. As we observe in Figure 5.3, when the salesperson becomes more accurate (i.e., when λ_A increases), the range of η for the indirect supply chain to be preferred (i.e., $\lambda_R^* = 1$) enlarges. This verifies the above intuitive arguments.

5.2.4 Profit splitting and supply chain coordination

Now we switch our attention from supply chain performance to individual members' profitability. As the reseller can determine her own forecasting accuracy and the manufacturer may sometimes affect the reseller's accuracy decision through contractual agreements, bargaining, or collaborative forecasting, we first concentrate on these two players and discuss whether their incentives are aligned with each other. The following proposition characterizes the manufacturer's expected profit \mathcal{M} and shows that the manufacturer can extract exactly one half of the supply chain's expected sales revenue.

Proposition 16. $\mathcal{M} = \frac{1}{2}\mathbb{E}[x]$.

Proposition 16 immediately implies that, to maximize its own expected profit, the

manufacturer should try to maximize the supply chain performance. Therefore, if the manufacturer is allowed to decide the reseller's accuracy (e.g., by choosing the appropriate reseller to delegate to), it will maximize the expected sales and benefit the entire supply chain. The reseller will either be uninformed or precise.

In most business environments, however, the reseller's accuracy is determined by the reseller herself. Because the reseller will select her accuracy to maximize her own expected profit \mathcal{R} , we now investigate whether the accuracy chosen by the reseller optimizes supply chain performance. By denoting

$$\lambda'_R \equiv \operatorname{argmax}_{\lambda_R \in [\frac{1}{2}, 1]} \mathcal{R}$$

as the accuracy that maximizes the reseller's expected profit, we present a necessary condition for supply chain coordination, i.e., $\lambda'_R = \lambda_R^*$, in our next proposition.

Proposition 17. $\lambda'_R = \lambda_R^*$ only if $\eta \in [\eta_1, \sqrt{2}]$ and $\lambda_A \geq \max\{\bar{\lambda}_A(\eta), \tilde{\lambda}_A(\eta)\}$, where η_1 and $\bar{\lambda}_A(\eta)$ are defined in Proposition 15 and $\tilde{\lambda}_A(\eta) \equiv \frac{2\eta^3 - 3\eta - \sqrt{-\eta(2\eta^2 - 3)(\eta^2 - 2)}}{2\eta^3 + \eta^2 - 3\eta - \eta}$ for $\eta \in [\eta_1, \sqrt{2}]$. Whenever $\lambda'_R = \lambda_R^*$, we have $\lambda'_R = \lambda_R^* = 1$.

The proposition shows that supply chain coordination is possible only when η is moderate and λ_A is large. Moreover, if the supply chain is coordinated, it must be coordinated at $\lambda_R = 1$. Figure 5.4 provides an illustration for Proposition 17. The solid curve representing $\bar{\lambda}_A(\eta)$ comes from Figure 5.3, which separates the two regions having different λ_R^* : $\lambda_R^* = \frac{1}{2}$ in the left-hand side and $\lambda_R^* = 1$ in the right-hand side. The dashed curve depicts $\tilde{\lambda}_A(\eta)$ as a function of η . To the right of the dashed curve, we have $\lambda'_R < 1$. The tiny shaded area that is above both curves is the only region that the supply chain may be coordinated.⁸

We explain the result in two steps. First, because the reseller in our model can do nothing but demand forecasting, the ability of alleviating information asymmetry is her only instrument to earn profits. In fact, as we demonstrate in the proof, the reseller is expected to earn zero profit if $\lambda_R = \frac{1}{2}$. Therefore, the reseller *never* prefers herself to be uninformed. It then follows that there is always incentive misalignment when the supply chain and the manufacturer prefers the uninformed reseller (i.e., the direct supply chain). For the whole region that the uninformed reseller outperforms the precise reseller, the supply chain is not coordinated. This is the region to the left of the solid curve in Figure 5.4. The above intuition also explains why the supply chain can only be coordinated at $\lambda_R = 1$.

Now consider the dashed curve $\tilde{\lambda}_A(\eta)$. As shown in the proof of this proposition, we have $\lambda'_R < 1$ in the region that is to the right of the dashed curve. To understand why a large value of η will discourage the reseller from being precise, recall

⁸Inside the shaded region, indeed we observe supply chain coordination in some cases. For example, when $\eta = 1.4$ and $\lambda_A = 1$, it can be verified that $\lambda_R^* = \lambda'_R$.

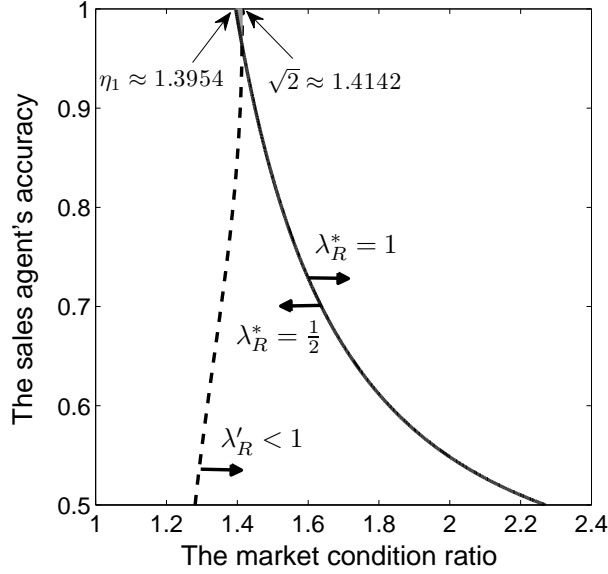


Figure 5.4: Incentive misalignment.

that an improvement in the reseller's accuracy introduces multiple effects. From the supply chain's perspective, the better-monitoring and rent-extraction effects are conflicting. However, from the reseller's perspective, both effects are detrimental: the better-monitoring effect drives up the salesperson's sales bonus (as the downstream distortion factor Y_k increases in λ_R) and the rent-extraction effect lowers the reseller's sales bonus (as the upstream distortion factor v_B^* decreases in λ_R). The reseller thus faces a trade-off between creating a larger pie and owning a smaller share of the pie. Interestingly, while the latter depends on the aggregation of the two effects, the former impacts the supply chain based on the difference between the two effects. When η is large, the benefit of distinguishing the two market condition realizations is large and thus the reseller's accuracy is important. In this case, both the better-monitoring effect and the rent-extraction effect are strong. However, as both effects become stronger, enlarging η only marginally increases the difference of the two effects. Therefore, the detrimental impact of having a smaller share will eventually dominate the beneficial impact of creating a large pie if η is large enough.

When η is moderate, we also need to take the salesperson's accuracy λ_A into account. Consider the case when λ_A decreases. On one hand, the manufacturer-reseller relationship is unchanged and the rent-extraction effect retains its impacts. On the other hand, the reseller-salesperson relationship becomes different and the better-monitoring effect becomes weaker. The benefit of enlarging the total pie is thus reduced a lot. However, the cost of having a smaller share, though it is also reduced, remains substantial as the rent-extraction effect is still significant. It then

follows that the reseller will not improve her accuracy to a too high level so that she can avoid the significant rent-extraction effect. This explains why we see $\lambda'_R < 1$ when λ_A is small.

Collectively, as we may observe in Figure 5.4, Proposition 17 implies that there is almost always incentive misalignment in the supply chain. When the supply chain prefers the uninformed reseller (i.e., when $\lambda_R^* = \frac{1}{2}$), the supply chain is never coordinated because the uninformed reseller earns nothing in expectation. This is the left-hand side of the solid curve in Figure 5.4. When the reseller prefers herself to be imprecise (i.e., when $\lambda'_R < 1$), the supply chain is also not coordinated because no intermediate accuracy is system-optimal. This is the right-hand side of the dashed curve. The only part that coordination is possible is the shaded region. As the shaded region is so small, most likely the supply chain will not be coordinated if the reseller can choose her own accuracy.

5.2.5 The salesperson's accuracy

Now we also accommodate the salesperson's accuracy decision. Our first result, which is in line with Proposition 13, establishes the convexity of expected sales with respect to the sales agent's accuracy.

Proposition 18. *The expected sales $\mathbb{E}[x]$ is convex on $\lambda_A \in [\frac{1}{2}, 1]$.*

Once the salesperson improves his accuracy, he can exert efforts in response to the market condition more accurately and make the supply chain more efficient. However, improving his accuracy also increases the information asymmetry in the reseller-salesperson relationship and hurts supply chain performance. Therefore, the expected sales is also convex and typically first decreasing and then increasing in the salesperson's accuracy. Proposition 18 is helpful for us to find the system-optimal accuracy mix, i.e., the combination of the reseller's and the salesperson's accuracy that optimizes supply chain performance. With the convexity of $\mathbb{E}[x]$ with respect to λ_A , it is immediate that λ_A must be either $\frac{1}{2}$ or 1 in any system-optimal accuracy mix. Naturally, one may conjecture that λ_A in a system-optimal accuracy mix can take different values under different conditions. Surprisingly, as we show in the following proposition, the conjecture is incorrect.

Proposition 19. *For all η , if $\lambda_A = 1$ in a system-optimal accuracy mix (λ_R, λ_A) , fixing λ_R but changing λ_A to $\frac{1}{2}$ is also system-optimal. Moreover, if $\eta < \eta_2$, any system-optimal accuracy mix satisfies $\lambda_A = \frac{1}{2}$.*

This proposition implies that, from the supply chain's perspective, it is (at least weakly) better for the salesperson to be uninformed rather than precise. To understand this, we should reinvestigate the consequences of improving the reseller's accuracy first. When the reseller's accuracy is improved, though the information

asymmetry between the manufacturer and the reseller is amplified, that between the reseller and the salesperson is alleviated. The latter effect enhances supply chain performance and makes the supply chain prefer the precise reseller in some cases. However, when the sales agent improves his accuracy, he only affects the reseller-salesperson relationship negatively. It is thus natural that the supply chain always prefers the sales agent to be uninformed. In fact, it can be verified that if $\lambda_A = 1$ in a system-optimal accuracy mix, it must be the case that $\lambda_R = 1$. In other words, it does not hurt for the salesperson to possess some accuracy only when his forecasting is completely irrelevant.

Proposition 19 has an important implication on supply chain coordination. Suppose now both the reseller and the salesperson choose their accuracy to maximize their own expected profits. Proposition 17 has shown that the supply chain cannot be coordinated at the reseller's side for $\eta \geq \eta_2$. For $\eta < \eta_2$, to optimize the supply chain performance, Proposition 19 requires the salesperson to be uninformed, which is never preferred by the salesperson because this leaves himself a zero expected profit. We thus establish the following corollary.

Corollary 3. *If both the reseller and the salesperson can choose their forecasting accuracy, the supply chain is never coordinated.*

5.3 Extensions

5.3.1 Privatization of the reseller's signal

So far all our conclusions are based on the assumption that the salesperson can observe the reseller's demand signal. Suppose the reseller's demand signal is now private and cannot be observed by the salesperson. This creates the *informed principal* problem studied in the economics literature. We now argue that privatizing the reseller's signal does not affect any of our results.

When the reseller's signal s_R is private, the contracting process between the reseller and the salesperson is altered to the following *three-stage* game proposed by [36, 37]. First, the reseller privately observes her signal and proposes a mechanism to the salesperson. In order to benefit from the privatization, the reseller should not propose different mechanisms upon observing different values of s_R ; otherwise, the salesperson will be able to identify the reseller's type based on the proposed mechanisms. Therefore, the two types of resellers should pool and propose one pooling mechanism; this pooling mechanism requires both players to report their signals simultaneously and specify a contract (i.e., a pair of fixed payment and sales bonus) accordingly. As both players' private signals have two possible realizations, there are four scenarios corresponding to the four combinations of signal observations. The mechanism, which is contingent on the two signals, should thus consist of four contracts. In the second stage, the salesperson determines whether to accept the mechanism. Finally, after

the mechanism is accepted, both players report simultaneously, a contract is selected, the salesperson determines his effort level accordingly, and the sales outcome is realized.⁹ It should be emphasized that, though the reseller will only offer one pooling mechanism, the ex post selection of a contract differs in all four scenarios.

Because the reseller’s signal is hidden from the salesperson, the sales agent forms a belief on the reseller’s type and decides whether to accept the proposed mechanism based on his belief. In particular, because the sales agent is unsure which type of reseller he is facing (and thus which contract will be selected), the mechanism only needs to satisfy the salesperson’s participation and truth-telling constraints *in expectation*. One particular way to do this is to let the reseller combine the two optimal menus, one for each reseller’s type, obtained in Lemma 8 when the reseller’s signal is not private. Because the salesperson’s participation and truth-telling must be induced only in expectation, the reseller may modify the mechanism and try to increase her expected payoff. As suggested by [36, 37], this is as if different types of resellers engage in a fictitious exchange market and trade the “slacks” of the sales agent’s incentive problem with each other. However, trading the slack does not necessarily lead to a strictly positive benefit for the mechanism designer. In our reseller-salesperson relationship, because both players have quasilinear utility functions, the reseller’s gain in one type by trading the slacks will be exactly offset by the loss in the other type (cf. [36, 37]). Therefore, the combination of the two optimal observable-signal menus is an optimal pooling mechanism. Even though the internal interaction in the reseller-salesperson relationship is more complicated than that in our basic model, the two players’ equilibrium behaviors remain identical from an outside observer’s point of view. All our results thus follow.

5.3.2 Limited liability of the salesperson

Suppose the salesperson is now protected by limited liability and cannot afford a too large payment to the reseller. More precisely, in the reseller’s contract design problem defined in (5.1)–(5.3), we now include the limited liability constraints

$$\alpha_G \geq -C, \quad \alpha_B \geq -C, \tag{5.8}$$

where $C \in [0, \infty)$ is the highest amount of fixed payment that the salesperson is willing to pay to the reseller. From now on, we focus on the extreme case in which the salesperson cannot pay any positive fixed payment to the reseller, i.e., $C = 0$. We will discuss the general case with $C > 0$ at the end of this section.

With the salesperson’s limited liability in mind, we still apply backward induction to characterize the three players’ equilibrium behaviors. Consider the salesperson’s

⁹Note that when the reseller’s signal is observable by the salesperson, such a four-contract mechanism reduces to only two contracts, and one contract is then selected by having the salesperson reports his type. Therefore, the contracting process is identical to that in our basic model.

effort decision first. While the salesperson's limited liability affects how he selects a contract, it has no effect on how he chooses his effort level for a given contract. Therefore, the salesperson will make his effort decision as if there is no limited liability. The reseller's contract design problem can thus be formulated by adding the limited liability constraint (5.8) into her original problem defined in (5.1)–(5.3). The solution to the reseller's new problem is summarized in the following lemma. We use superscript L to distinguish the results obtained with limited liability from those in Section 5.2.

Lemma 11. *Suppose the reseller's contract design problem is subject to the salesperson's limited liability constraints in (5.8). If the type- k reseller has chosen the contract (u_t, v_t) , it is optimal for her to offer $\beta_F^L = \beta_U^L = \frac{1}{2}v_t$ and $\alpha_F^L = \alpha_U^L = 0$ to the sales agent. The reseller's expected profit is $\mathcal{R}_k^L(t) = u_t + \frac{1}{2}W_k v_t^2$, where $W_k \equiv \frac{1}{2}(\bar{P}_{Fk} N_{Fk}^2 + \bar{P}_{Uk} N_{Uk}^2)$.*

When the salesperson has limited liability, the reseller's optimal menu significantly differs from that in our basic model. First, because fixed payments have no effect in incentivizing the salesperson to work hard, there is no reason for the reseller to offer a positive fixed payment. Therefore, the optimal fixed payments are zero. More interestingly, the reseller finds it optimal to offer a *single* contract to both types of salesperson. In fact, limited liability makes it impossible to distinguish the two types of the salesperson: As the reseller cannot use the fixed payment to extract rents, offering different sales bonuses elucidates no information because both types of the salesperson will choose the higher bonus. It is thus natural that offering multiple contracts does not make the reseller better off and a single contract is optimal.

Now consider the manufacturer's contract design problem. Note that $\mathcal{R}_k^L(t)$ is in the same form as $\mathcal{R}_k(t)$ (cf. Lemma 8 for the case with no limited liability) and can be obtained by substituting Z_k by W_k in $\mathcal{R}_k(t)$. This implies that the manufacturer's problem can be formulated by simply replacing Z_k by W_k in (5.5)–(5.7). It then follows that the manufacturer's optimal menu can also be derived by substituting Z_k by W_k in Lemma 9. In particular, the optimal sales bonuses are $v_G^L = 1$ and $v_B^L = \frac{W_B}{W_G}$. While the salesperson's limited liability affects the reseller-salesperson relationship and results in a uniform downward distortion for both types of salesperson, it does not affect the manufacturer-reseller relationship qualitatively. There is still no distortion for a type- G reseller but a downward distortion for a type- B reseller. However, as the degree of distortion for the type- B reseller now depends on different parameters (as W_k replaces Z_k in v_B^L), a change in the salesperson still have indirect effects on the manufacturer.

Having characterized the optimal contracts, we now reinvestigate those results we obtained in Section 5.2. The next proposition shows that the limited liability does not change the shape of the expected sales but has a significant impact on the system-optimal reseller's accuracy.

Proposition 20. *When the salesperson is protected by limited liability:*

- the manufacturer's expected profit \mathcal{M} is one half of the expected sales revenue;
- the expected sales $\mathbb{E}[x]$ is convex in the reseller's accuracy; and
- the expected sales $\mathbb{E}[x]$ is strictly higher with the uninformed reseller than with the precise one.

With the presence of limited liability, the expected sales and the manufacturer's expected profit are still convex and generally first decreasing and then increasing in the reseller's accuracy. However, unlike the case with no limited liability, the uninformed reseller strictly *dominates* the precise reseller from the supply chain's and the manufacturer's perspectives. To understand these results, it is helpful to reconsider those conflicting effects introduced by improving the reseller's accuracy. The negative rent-extraction effect remains in the manufacturer-reseller relationship, which is qualitatively unaffected by the salesperson's limited liability. For the reseller-salesperson relationship, however, because the reseller cannot distinguish the two types of the salesperson, the belief-altering and better-monitoring effects no longer exist. While the salesperson can still exert efforts more efficiently with higher accuracy, the lack of the two effects in the reseller-salesperson relationship greatly reduces the benefit of improving the reseller's accuracy. The rent-extraction effect is thus dominant and the uninformed reseller is strictly preferred. In short, because it is impossible to mitigate the information asymmetry in the reseller-salesperson relationship due to the salesperson's limited liability, it is optimal to eliminate the information asymmetry in the manufacturer-reseller relationship by keeping the reseller uninformed.

The dominance result has a direct implication on supply chain coordination. Because the reseller never prefers herself to be uninformed, the supply chain is never coordinated when the salesperson has limited liability, even if the accuracy decision is decentralized only at the reseller's side. Again, this also results from the fact that the salesperson's limited liability disallows the reseller to alleviate her informational disadvantage with respect to the salesperson.

Finally, we discuss the more general setting with $C > 0$. How the degree of limited liability affects the supply chain depends on the two optimal fixed payments charged by the reseller defined in Lemma 8, α_F^* and α_U^* . When $-C \geq \alpha_U^*$, the fixed payments α_F^L and α_U^L change from 0 to $-C$ but the sales bonuses β_F^L and β_U^L are still $\frac{1}{2}v_k^L$ when the reseller observes signal $s_R = k \in \{G, B\}$. All our results established in this section hold. When $-C \in (\alpha_F^*, \alpha_U^*)$, the reseller offers a menu of contracts and brings the better-monitoring effect back. However, if C is sufficiently close to α_U^* , the better-monitoring effect is marginal and thus the uninformed reseller still always dominates the precise reseller. The precise reseller may generate a higher expected sales if $-C$ is close enough to α_F^* . Finally, when $-C \leq \alpha_F^*$, the optimal menu without limited liability is acceptable by the salesperson and all the results in Section 5.2 hold. In this case, all players interact as if the salesperson does not have limited liability.

5.3.3 General levels of pessimism

So far we have restricted our analysis to the case that the level of pessimism $\gamma \equiv \Pr(\theta = \theta_L) = 1/2$. We now remove this assumption by allowing γ to be any number within the interval $(0, 1)$ and reinvestigate our findings in Section 5.2 under general levels of pessimism.

The procedure of deriving the optimal contracts when $\gamma \neq \frac{1}{2}$ is almost identical to that when $\gamma = \frac{1}{2}$. For the reseller-salesperson relationship, generalizing γ only affects the three quantities N_{jk} , \bar{P}_{jk} , and Z_k . As long as we generalize these quantities to $N_{jk}(\gamma)$, $\bar{P}_{jk}(\gamma)$, and $Z_k(\gamma)$, i.e., functions of γ , the reseller's optimal menu characterized in Lemma 8 still applies. For the manufacturer-reseller relationship, the generalization of γ changes the manufacturer's belief on the distribution of the two types of resellers. Let $q_k(\gamma) \equiv P(s_R = k|\gamma)$ be the probability for the reseller to see signal k when the level of pessimism is γ .¹⁰ The manufacturer then maximizes the modified objective function

$$\sum_{k \in \{G, B\}} q_k(\gamma) \left[(1 - v_k) Z_k(\gamma) v_k - u_k \right]$$

subject to the original constraints in (6) and (7) (with the reseller's expected profits being generalized to functions of γ). Following the same argument in the proof of Lemma 9, we can show that it is optimal for the manufacturer to offer the sales bonuses

$$v_G^*(\gamma) = 1 \quad \text{and} \quad v_B^*(\gamma) = \frac{q_B(\gamma) Z_B(\gamma)}{q_B(\gamma) Z_B(\gamma) + q_G(\gamma) [Z_G(\gamma) - Z_B(\gamma)]}.$$

Clearly, the downward distortion for the type- B reseller still exists for any level of pessimism.

Having derived the three players' equilibrium behaviors, we now examine our findings in this more general setting. Unfortunately, the generalization of γ greatly complicates our three-layer supply chain and prevents us from obtaining clear analytical results. Therefore, we resort to numerical experiments to generate insights. Our first observation demonstrates how the reseller's accuracy affects the expected sales. The observation suggests that the convexity result in Proposition 13 holds for all levels of pessimism.

Observation 6. *For any value of γ , the expected sales $\mathbb{E}[x]$ is either first decreasing and then increasing or monotonically decreasing in the reseller's accuracy $\lambda_R \in [\frac{1}{2}, 1]$. In particular, $\mathbb{E}[x]$ tends to be nonmonotone when γ is low but monotonically decreasing when γ is high.*

¹⁰We have $q_G(\gamma) = (1 - \gamma)\lambda_R + \gamma(1 - \lambda_R)$ and $q_B(\gamma) = (1 - \gamma)(1 - \lambda_R) + \gamma\lambda_R$.

While generalizing the level of pessimism destroys the convexity of the expected sales in general, it qualitatively preserves the relationship between the expected sales and the reseller's accuracy. This is because those conflicting effects still exist under any value of γ and thus the shape of the expected sales remains similar. More interestingly, we find that when γ approaches 1, it is more likely that the expected sales is monotonically decreasing in the reseller's accuracy. In Figure 5.5, we depict five curves for five values of γ . For each curve, the expected sales $\mathbb{E}[x]$ is monotonically decreasing in λ_R at the left-hand side but nonmonotone at the right-hand side. When γ increases, the left-hand side enlarges, i.e., the expected sales is more likely to be monotonically decreasing.

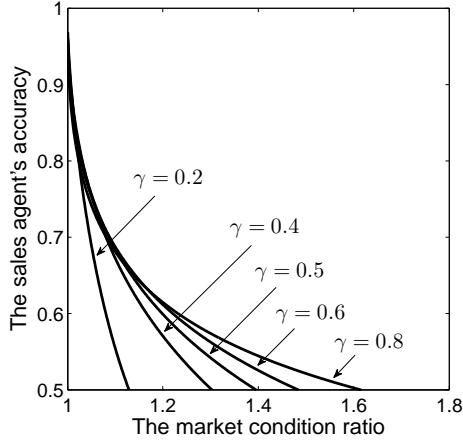


Figure 5.5: Monotonicity of the expected sales with various levels of pessimism.

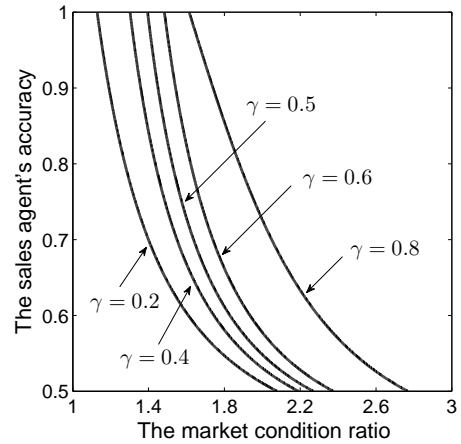


Figure 5.6: System-optimal reseller's accuracy with various levels of pessimism.

Generalizing γ introduces some new effects. When the reseller improves her accuracy, she will make the correct prediction with a higher probability. When $\gamma < \frac{1}{2}$, usually the market condition will be good (i.e., $\theta = \theta_H$). If the reseller improves her accuracy in this case, she will observe the good signal more often. As the reseller is more likely to be optimistic, the expected sales will be increased. In short, lowering γ creates the positive *optimism effect* and helps drive the expected sales up when λ_R is high. On the contrary, if $\gamma > \frac{1}{2}$, the reseller will more likely be pessimistic once she becomes more accurate. This brings in the negative *pessimism effect* and hurts the supply chain performance. The level of pessimism γ thus plays a role in determining the shape of the expected sales. We also observe that the sales agent's accuracy impacts the shape of the expected sales similarly.

Our next step is to investigate how different values of γ affect the system-optimal reseller's accuracy λ_R^* . In Proposition 15 and Figure 5.3 we characterize and visualize the two-dimensional cutoff structure when $\gamma = \frac{1}{2}$. As we summarize in the next observation, the same structure still applies to other values of γ . This observation is

visualized in Figure 5.6, where we depict several cutoff curves under various values of γ . For each curve, the system-optimal reseller's accuracy is $\lambda_R^* = \frac{1}{2}$ at the left-hand side and $\lambda_R^* = 1$ at the right-hand side. It is clear that all these curves have similar shapes and the insight we obtained for the special case $\gamma = \frac{1}{2}$ is still valid.

Observation 7. *For any $\gamma \in (0, 1)$, the expected sales $\mathbb{E}[x]$ is maximized at $\lambda_R^* = \frac{1}{2}$ (respectively, $\lambda_R^* = 1$) if η and λ_A are both small (respectively, large) enough. Moreover, it is more likely that $\lambda_R^* = \frac{1}{2}$ (respectively, $\lambda_R^* = 1$) when γ increases (respectively, decreases).*

The second part of Observation 7 delivers more messages to us regarding the impact of the level of pessimism γ on the system-optimal reseller's accuracy λ_R^* . As γ increases, the pessimism effect mitigates the benefit of improving the reseller's accuracy. Therefore, the cutoff curve moves to the right and it is more likely to see $\lambda_R^* = \frac{1}{2}$. On the contrary, decreasing γ introduces the optimism effect, moves the cutoff curve to the left, and makes the supply chain prefer the precise reseller more. Interestingly, even if γ is extremely close to 0, it is still possible that delegating to an uninformed reseller attains supply chain optimality. The following proposition provides an analytical support.

Proposition 21. *For any $\gamma \in (0, 1)$ and $\eta < 2$, there exists a threshold $\hat{\lambda}_A(\gamma, \eta) \in (\frac{1}{2}, 1]$ such that delegating to the uninformed reseller uniquely maximizes the expected sales if $\lambda_A < \hat{\lambda}_A(\gamma, \eta)$.*

Lastly, we discuss the impact of generalizing γ on supply chain coordination. When γ approaches 1, the uninformed reseller is more preferred from the supply chain's perspective. As the reseller never makes herself uninformed, it is less possible for the supply chain to be coordinated when γ is closer to 1. When γ approaches 0, the supply chain prefers the precise reseller more. However, we find that the reseller tends to possess moderate accuracy in this case. We thus obtain the following observation.

Observation 8. *The supply chain can be coordinated only if γ is around $\frac{1}{2}$.*

5.4 Summary

In this chapter, we consider a three-layer supply chain with a manufacturer, a reseller, and a salesperson. While the manufacturer is uninformed about the realization of the random market condition, both the reseller and the salesperson can conduct demand forecasting to estimate the realized market condition. We show that the supply chain performance as well as the manufacturer's profitability are hurt when the reseller or the sales agent improves her/his low accuracy. When the accuracy is high, however, an improvement may enhance supply chain performance and allow the manufacturer to earn more in expectation. From the supply chain's and the

manufacturer's perspectives, when the market condition ratio and the salesperson's forecasting accuracy are both low, the uninformed reseller is preferred; when these two parameters are both high, delegating to the precise reseller is optimal. We also find that the supply chain may be coordinated when the reseller can choose her accuracy but never coordinated if the salesperson also has the discretion to choose his own accuracy.

Chapter 6

Conclusions

In this study, we consider a three-layer supply chain under information asymmetry. While the manufacturer is uninformed about the market condition and the sales effort, the salesperson observes both (or can estimate the market condition in Chapter 5). This creates both the adverse selection problem and the moral hazard problem in the supply chain. The reseller, who serves as a middleman in the supply chain, can monitor some of these asymmetric information through various monitoring strategies.

In Chapter 3, we consider the case that the reseller may either observe the market condition or sales effort, i.e., eliminate one of the adverse selection and moral hazard problems. We show that monitoring the sales effort is more direct and effective. In Chapter 4, we allow the reseller to choose an accuracy mix that allows her to monitor both aspects imperfectly. While she faces the physical restrictions and budget constraint, we show that focusing on one side is generally better than balancing between the two sides and the optimal strategy is nontrivially determined by those constraints. Finally, in Chapter 5, we examine the scenario that the reseller cannot monitor the sales effort. Regarding her decision about choosing her forecasting accuracy, we show that improving her forecasting accuracy may hurt the supply chain and the manufacturer, especially when the accuracy is low. All our results together give the reseller and the supply chain insightful suggestions for building the monitoring strategy.

This study certainly has its limitations. First, we assume that the selling price is exogenously given. If the price is endogenized, the manufacturer and the reseller may distort the price or include it in the menu to induce better truth-telling. Price and commission rate can therefore serve as complementary screening tools. Moreover, we exclude the effect of competition from other manufacturers, which may be inappropriate in some contexts. Introducing the competition between manufacturers creates a common agency problem, as these manufacturers may compete in contract offers in order to earn the collaboration opportunity with a specific reseller. This issue calls for future investigations. Finally, when the manufacturer delegates to the reseller, we assume that the manufacturer cannot communicate directly with the salesperson. While our three-layer indirect supply chain is pervasive in practice, there are also

situations where the salesperson is hired or can also be directly compensated by the manufacturer. New insights may be found under this alternative setting.

Bibliography

- [1] E. Anderson and R. Oliver. Perspectives on behavior-based versus outcome-based salesforce control systems. *The Journal of Marketing*, 51(4):76–88, 1987.
- [2] Y. Aviv. The effect of collaborative forecasting on supply chain performance. *Management Science*, 47(10):1326–1343, 2001.
- [3] M. Bagnoli and T. Bergstrom. Log-concave probability and its applications. *Economic Theory*, 26(2):445–469, 2005.
- [4] D. Baron and D. Besanko. Information, control, and organizational structure. *Journal of Economics and Management Strategy*, 1(2):237–275, 1992.
- [5] G. Cachon and M. Fisher. Supply chain inventory management and the value of shared information. *Management Science*, 46(8):1032–1048, 2000.
- [6] G. Cachon and M. Lariviere. Contracting to assure supply: How to share demand forecasts in a supply chain. *Management Science*, 47(5):629–646, 2001.
- [7] G. Cachon and F. Zhang. Procuring fast delivery: Sole-sourcing with information asymmetry. *Management Science*, 52(6):881–896, 2006.
- [8] G. Cai, X. Chao, and J. Li. Optimal reserve prices in name-your-own-price auctions with bidding and channel options. *Production and Operations Management*, 18(5):653–671, 2009.
- [9] F. Chen. Information sharing and supply chain coordination. In S. Graves and T. de Kok, editors, *Supply Chain Management: Design, Coordination and Operation*, volume 11 of *Handbooks in Operations Research and Management Science*, pages 341–421, Amsterdam, Kingdom of the Netherlands, 2003. Elsevier.
- [10] F. Chen. Salesforce incentives, market information, and production/inventory planning. *Management Science*, 51(1):60–75, 2005.
- [11] Y.J. Chen and W. Xiao. Impact of reseller’s forecasting accuracy on channel member performance. Forthcoming in *Production and Operations Management*, 2012.

- [12] A. Coughlan, E. Anderson, L. Stern, and A. EL-Ansary. *Marketing Channels*. Pearson Education, Inc., USA, 2001.
- [13] A. Faure-Grimaud, J. Laffont, and D. Martimort. A theory of supervision with endogenous transaction costs. *Annals of Economics and Finance*, 1:231–263, 2000.
- [14] L. Felli and J.M. Villas-Boas. Renegotiation and collusion in organizations. *Journal of Economics and Management Strategy*, 9(4):453–483, 2000.
- [15] S. Gavirneni, R. Kapuscinski, and S. Tayur. Value of information in capacitated supply chains. *Management Science*, 45(1):16–24, 1999.
- [16] J. Gonik. Tie salesmen’s bonuses to their forecasts. *Harvard Business Review*, 56(3):116–123, 1978.
- [17] J. Green and N. Stokey. A comparison of tournaments and contracts. *Journal of Political Economy*, 91(6):349–364, 1983.
- [18] B. Holmstrom and P. Milgrom. Multitask principal-agent analyses: Incentive contracts, asset ownership, and job design. *Journal of Law, Economics, and Organization*, 7(3):24–52, 1991.
- [19] W.T. Huh and K.S. Park. A sequential auction-bargaining procurement model. *Naval Research Logistics*, 57(1):13–32, 2010.
- [20] A. Iyer, V. Deshpande, and Z. Wu. Contingency management under asymmetric information. *Operations Research Letters*, 33(6):572–580, 2005.
- [21] A. Iyer, L. Schwarz, and S. Zenios. A principal-agent model for product specification and production. *Management Science*, 51(1):106–119, 2005.
- [22] A. Jeuland and S. Shugan. Managing channel profits. *Marketing Science*, 2(3):239–272, 1983.
- [23] K. Joseph and A. Thevaranjan. Monitoring and incentives in sales organizations: An agency-theoretic perspective. *Marketing Science*, 17(2):107–123, 1998.
- [24] A. Kessler. On monitoring and collusion in hierarchies. *Journal of Economic Theory*, 91(2):280–291, 2000.
- [25] M. Krafft. An empirical investigation of the antecedents of sales force control systems. *Marketing Science*, 63(3):120–134, 1999.
- [26] H. Krishnan, R. Kapuscinski, and D.A. Butz. Coordinating contracts for decentralized supply chains with retailer promotional effort. *Management Science*, 50(1):48–63, 2004.

- [27] J. Laffont and D. Martimort. *The Theory of Incentives: The Principal-Agent Model*. Princeton University Press, Princeton Township, New Jersey, USA, 2002.
- [28] J. Laffont and J. Tirole. *A Theory of Incentives in Procurement and Regulation*. MIT Press, Cambridge, Massachusetts, USA, 1993.
- [29] R. Lal and R. Staelin. Salesforce compensation plans in environments with asymmetric information. *Marketing Science*, 5(3):179–198, 1986.
- [30] E. Lazear. The power of incentives. *American Economic Review*, 90(2):410–14, 2000.
- [31] E. Lee and R. Staelin. Vertical strategic interaction: Implications for channel pricing strategy. *Marketing Science*, 16(3):185–207, 1997.
- [32] H. Lee, C. So, and C. Tang. The value of information sharing in a two-level supply chain. *Management Science*, 46(5):626–643, 2000.
- [33] C. Li and L.G. Debo. Strategic dynamic sourcing from competing suppliers with transferable capacity investment. *Naval Research Logistics*, 56(6):540–562, 2009.
- [34] M. Mantrala and M. Raman. Analysis of a sales force incentive plan for accurate sales forecasting and performance. *International Journal of Research in Marketing*, 7(2–3):189–202, 1990.
- [35] M.K. Mantrala, S. Albers, F. Caldieraro, O. Jensen, K. Joseph, M. Krafft, C. Narasimhan, S. Gopalakrishna, A. Zoltners, R. Lal, and L. Lodish. Sales force modeling: State of the field and research agenda. *Marketing Letters*, 21(3):255–272, 2010.
- [36] E. Maskin and J. Tirole. The principal-agent relationship with an informed principal: The case of private values. *Econometrica*, 58(2):379–409, 1990.
- [37] E. Maskin and J. Tirole. The principal-agent relationship with an informed principal, ii: Common values. *Econometrica*, 60(1):1–42, 1992.
- [38] R. McAfee and J. McMillan. Organizational diseconomies of scale. *Journal of Economics & Management Strategy*, 4(3):399–426, 1995.
- [39] N. Melumad, D. Mookherjee, and S. Reichelstein. A theory of responsibility centers. *Journal of Accounting and Economics*, 15(4):445–484, 1992.
- [40] J. Mirrlees. Notes on welfare economics, information and uncertainty. In M. Balch, D. McFadden, and S.Y. Wu, editors, *Essays on Economic Behavior under Uncertainty*, pages 243–261, Amsterdam, Kingdom of the Netherlands, 1974. Elsevier.

- [41] B. Mishra and A. Prasad. Centralized pricing versus delegating pricing to the salesforce under information asymmetry. *Marketing Science*, 23(1):21–28, 2004.
- [42] J. Miyaoka and W.H. Hausman. How improved forecasts can degrade decentralized supply chains. *Manufacturing & Service Operations Management*, 10(3):547–652, 2008.
- [43] D. Mookherjee. Decentralization, hierarchies, and incentives: A mechanism design perspective. *Journal of Economic Literature*, 44(2):367–390, 2006.
- [44] C. Prendergast. The tenuous trade-off between risk and incentives. *Journal of Political Economy*, 110(5):1071–1102, 2002.
- [45] J. Raju and V. Srinivasan. Quota-based compensation plans for multiterritory heterogeneous salesforces. *Management Science*, 42(4):1454–1462, 1996.
- [46] R. Rao. Compensating heterogeneous salesforces: Some explicit solutions. *Marketing Science*, 9(4):319–341, 1990.
- [47] H. Shin and T. Tunca. The effect of competition on demand forecast investments and supply chain coordination. *Operations Research*, 58(6):1592–1610, 2010.
- [48] J. Spengler. Vertical integration and antitrust policy. *The Journal of Political Economy*, 58(4):347–352, 1950.
- [49] R. Strausz. Delegation of monitoring in a principal-agent relationship. *Review of Economic Studies*, 64(3):337–357, 1997.
- [50] T. Taylor and W. Xiao. Incentives for retailer forecasting: Rebates vs. returns. *Management Science*, 55(10):1654–1669, 2009.
- [51] T. Taylor and W. Xiao. Does a manufacturer benefit from selling to a better-forecasting retailer? *Management Science*, 56(9):1584–1598, 2010.
- [52] J.M. Villas-Boas. Communication strategies and product line design. *Marketing Science*, 23(3):304–316, 2004.
- [53] G. Vulcano, G. van Ryzin, and C. Maglaras. Optimal dynamic auctions for revenue management. *Management Science*, 48(11):1388–1407, 2002.
- [54] Z. Wan and D.R. Beil. Rfq auctions with supplier qualification screening. *Operations Research*, 57(4):934–949, 2009.
- [55] R. Zhao. All-or-nothing monitoring. *American Economic Review*, 98(4):1619–1628, 2008.

Appendix A

Appendix for Chapter 3

Proof of Lemma 1. It follows from the first-order necessary condition of the IC constraint (3.2) that $\frac{d}{d\theta} CE_S(\theta) = \beta(\theta) \geq 0$ for all $\theta \in (-\infty, \infty)$, which implies that $CE_S(\theta)$ is nondecreasing in θ . The IR constraint (3.3) implies that $CE_S(-\infty) = 0$ at the optimal solution. Consequently, $CE(\theta) = \int_{-\infty}^{\theta} \beta(y) dy$ and the binding IR constraint lead to

$$\begin{aligned} \alpha(\theta) &= -\beta(\theta)\theta - \frac{1}{2}(1 - \rho\sigma^2) [\beta(\theta)]^2 + CE_S(\theta) \\ &= -\beta(\theta)\theta - \frac{1}{2}(1 - \rho\sigma^2) [\beta(\theta)]^2 + \int_{-\infty}^{\theta} \beta(y) dy. \end{aligned}$$

Replace the $\alpha(\theta)$ in the objective function and ignore the IC constraint for a moment, we reduce the problem to

$$\begin{aligned} M^* &= \max_{\{\beta(\theta) \geq 0\}} \mathbb{E}_{\theta} \left[\theta + \beta(\theta) - \frac{1}{2}(1 + \rho\sigma^2) [\beta(\theta)]^2 - \int_{-\infty}^{\theta} \beta(y) dy \right] \\ &= \max_{\{\beta(\theta) \geq 0\}} \mathbb{E}_{\theta} \left[\theta + [1 - H(\theta)]\beta(\theta) - \frac{1}{2}(1 + \rho\sigma^2) [\beta(\theta)]^2 \right], \end{aligned}$$

where the second equality comes from integration by parts. Maximizing the integrand pointwise yields $\beta^*(\theta) = \frac{[1-H(\theta)]^+}{1+\rho\sigma^2}$, and the maximum objective value M can be calculated by plugging $\beta^*(\theta)$ back. The IC constraint can be easily verified and is omitted. \square

Proof of Lemma 2. We first observe that the constraint must be binding at the optimal solution. If this is not the case, the reseller can reduce the fixed payment α by a sufficiently small amount such that the objective value increases while the constraint is still satisfied. Thus, the problem reduces to maximizing a quadratic function of β :

$$R^K(\theta) = \max_{\beta \geq 0} \left\{ u + (v - \beta)(\theta + \beta) + \beta\theta + \frac{1}{2}\beta^2(1 - \rho\sigma^2) \right\}.$$

It follows that it is optimal for the reseller to choose $\beta^K(\theta) = \frac{1}{1+\rho\sigma^2}v \geq 0$. This determines the induced effort level $a^K(\theta) = \frac{1}{1+\rho\sigma^2}v$. Consequently, $R^K(\theta) = u + v\theta + \frac{1}{2(1+\rho\sigma^2)}v^2$. \square

Proof of Lemma 3. Observing that at optimality the constraint must be binding, we can replace u by $-v\mu - \frac{1}{2(1+\rho\sigma^2)}v^2$ in the objective and reduce the problem into

$$M^K = \max_{v \geq 0} \left\{ \mu + \frac{1}{1+\rho\sigma^2}v - \frac{1}{2(1+\rho\sigma^2)}v^2 \right\}.$$

This implies that the optimal commission rate is $v^K = 1$ and $M^K = \mu + \frac{1}{2(1+\rho\sigma^2)}$ by the first-order condition. The corresponding induced effort level is $\frac{1}{1+\rho\sigma^2}$, regardless of θ . \square

Proof of Lemma 4. It follows from the first-order necessary condition of the IC constraint that $\frac{d}{d\theta}CE_S(\theta) = \beta(\theta) \geq 0$ for all $\theta \in (-\infty, \infty)$, which implies that $CE_S(\theta)$ is nondecreasing in θ . The (IR) constraint implies that $CE_S(-\infty) = 0$ at the optimal solution. Consequently, $CE_S(\theta) = \int_{-\infty}^{\theta} \beta(y)dy$. Moreover, from (3.4), we have

$$\alpha(\theta) = -\beta(\theta)\theta - \beta(\theta)a(\theta) + \frac{1}{2}[a(\theta)]^2 + \frac{1}{2}(1-\rho\sigma^2)[\beta(\theta)]^2 + \int_{-\infty}^{\theta} \beta(y)dy.$$

Substituting $\alpha(\theta)$ in the objective with the right hand side and ignoring the (IC) constraint for a while, the reseller's problem can be rewritten as

$$R^D = \max_{\{\beta(\theta) \geq 0, a(\theta) \geq 0\}} \mathbb{E}_{\theta} \left\{ u + v\theta + va(\theta) - \frac{1}{2}[a(\theta)]^2 - \frac{1}{2}\rho\sigma^2[\beta(\theta)]^2 - \beta(\theta)H(\theta) \right\},$$

where the equality follows from integration by parts. Since the integrand is strictly decreasing in $\beta(\theta)$, the optimal commission rate is $\beta^D(\theta) = 0$. The corresponding optimal effort level is $a^D(\theta) = v$, and the reseller's maximum expected payoff is $R^D = u + v\mu + \frac{1}{2}v^2$. Given the commission rate $\beta^D(\theta) = 0$, the corresponding fixed payment is $\alpha^D(\theta) = \frac{1}{2}[a^D(\theta)]^2 = \frac{1}{2}v^2$, which is independent of θ . Since the reseller only offers a single contract, the IC constraint is satisfied. \square

Proof of Lemma 5. At optimality, the constraint should be binding. Thus, the manufacturer's problem reduces to $M^D = \max_{v \geq 0} \left\{ \mu + v - \frac{1}{2}v^2 \right\}$, which gives rise to the optimal commission rate is $v^D = 1$ and $M^D = \mu + \frac{1}{2}$. The corresponding effort level is 1. \square

Proof of Proposition 2. Recall that the salesperson under a knowledgeable reseller gets payoff $\alpha + \beta x - \frac{1}{2}a^2$ by setting his effort level to a . The corresponding certainty equivalent $CE_S(\theta|a) = \alpha + \beta\theta a - \frac{1}{2}a^2 - \frac{1}{2}\rho\sigma^2\beta^2$ is then maximized by $a^K = \beta\theta$ as $CE_S(\theta) = \alpha + \frac{1}{2}(\theta^2 - \rho\sigma^2)\beta^2$. With effort level $\beta\theta$, the expected sales outcome is $\beta\theta^2$. The knowledgeable reseller is then solving

$$\begin{aligned} R^K(\theta) &= \max_{\alpha, \text{urs}, \beta \geq 0} u - \alpha + (v - \beta)\beta\theta^2 \\ \text{s.t.} \quad &\alpha + \frac{1}{2}(\theta^2 - \rho\sigma^2)\beta^2 \geq 0. \end{aligned}$$

At optimality, the constraint must be binding. Therefore, the problem reduces to $R^K(\theta) = \max_{\beta \geq 0} \left\{ u + \frac{1}{2}(\theta^2 - \rho\sigma^2)\beta^2 + v\theta^2\beta - \theta^2\beta^2 \right\}$. By the first-order condition, this is maximized by $\beta^K(\theta) = \frac{\theta^2}{\theta^2 + \rho\sigma^2}v$. We then have $a^K = \frac{\theta^3}{\theta^2 + \rho\sigma^2}v$ and $R^K(\theta) = u + \frac{\theta^4}{2(\theta^2 + \rho\sigma^2)}v^2$. Denoting $\mathbb{E}_\theta \left[\frac{\theta^4}{\theta^2 + \rho\sigma^2} \right]$ by γ , the manufacturer then solves

$$M^K = \max_{u, v \geq 0} \gamma(1-v)v - u$$

$$\text{s.t. } u + \frac{1}{2}\gamma v^2 \geq 0.$$

As the constraint must be binding at optimality, we can replace u in the objective function by $-\frac{1}{2}\gamma v^2$ and obtain that $M^K = \max_{\beta \geq 0} \left\{ \gamma v - \gamma v^2 + \frac{1}{2}\gamma v^2 \right\} = \frac{1}{2}\gamma = \frac{1}{2}\mathbb{E}_\theta \left[\frac{\theta^4}{\theta^2 + \rho\sigma^2} \right]$ with $v^K = 1$ as the maximizer.

Now consider the diligent reseller. Observing θ but choosing a contract by reporting $\tilde{\theta}$, the salesperson's certainty equivalent is now $CE_S(\tilde{\theta}, \theta) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta a(\theta)) - \frac{1}{2}a(\tilde{\theta})^2 - \frac{1}{2}\rho\sigma^2\beta(\tilde{\theta})^2$. With the definition $CE_S(\theta) = CE_S(\theta, \theta)$, the reseller's problem is

$$R^D = \max_{\substack{\{\alpha(\theta) \text{ urs,} \\ \beta(\theta) \geq 0, a(\theta) \geq 0\}}} \mathbb{E}_\theta \left[u - \alpha(\theta) + (v - \beta(\theta))\theta a(\theta) \right]$$

$$\text{s.t. } CE(\theta) \geq CE(\tilde{\theta}, \theta) \quad \forall \theta \in (-\infty, \infty)$$

$$CE(\theta) \geq 0 \quad \forall \theta \in (-\infty, \infty).$$

By the first order condition of the first constraint, we get $CE'(\theta) = \beta(\theta)a(\theta) \geq 0$ and thus $CE(-\infty) = 0$ and $CE(\theta) = \int_{-\infty}^{\theta} \beta(y)a(y)dy$ at optimality. The fact that the second constraint is binding then leads to

$$R^D = \max_{\{\beta(\theta) \geq 0, a(\theta) \geq 0\}} \mathbb{E}_\theta \left[u + v\theta a(\theta) - \frac{1}{2}a(\theta)^2 - \frac{1}{2}\rho\sigma^2\beta(\theta)^2 - \beta(\theta)a(\theta)H(\theta) \right]$$

according to integration by part. Since the integrand is non-increasing in $\beta(\theta)$, we have $\beta^D(\theta) = 0$. It then follows that $R^D = \max_{\{a(\theta) \geq 0\}} \mathbb{E}_\theta \left[u + v\theta a(\theta) - \frac{1}{2}a(\theta)^2 \right] = u + \frac{1}{2}\mathbb{E}[\theta^2]v^2$ with the maximizer $a^D(\theta) = v\theta$. With such R^D , the manufacturer's problem is

$$M^D = \max_{u, v \geq 0} (1-v)\mathbb{E}_\theta[\theta^2]v - u$$

$$\text{s.t. } u + \frac{1}{2}\mathbb{E}_\theta[\theta^2]v^2 \geq 0.$$

By the same way as in the knowledgeable reseller case, this problem can be solved with maximizers $v^D = 1$ and $u^D = -\frac{1}{2}\mathbb{E}_\theta[\theta^2]$. We then have $M^D = \frac{1}{2}\mathbb{E}_\theta[\theta^2] = \frac{1}{2}\mathbb{E}_\theta \left[\frac{\theta^4}{\theta^2} \right] \geq \frac{1}{2}\mathbb{E}_\theta \left[\frac{\theta^4}{\theta^2 + \rho\sigma^2} \right] = M^K$, which concludes that delegating to a diligent reseller is more profitable for the manufacturer. \square

Proof of Proposition 3. Consider the knowledgeable reseller. Given contract (α, β) , the salesperson's certainty equivalent is $CE(\theta|a) = \alpha + \beta(\theta + a) - \frac{1}{2k}a^2 - \frac{1}{2}\rho\sigma^2\beta^2$, which is maximized by $a(\theta) = \beta k$. In the reseller's optimal contract, the salesperson receives a zero certainty equivalent and therefore

$$R^K(\theta) = \max_{\beta \geq 0} \left\{ u + (v - \beta)(\theta + \beta k) + \beta\theta + \frac{1}{2}\beta^2(k - \rho\sigma^2) \right\} = u + v\theta + \frac{k^2}{2(k + \rho\sigma^2)}v^2,$$

where the optimal commission rate is $\beta^K(\theta) = \frac{k}{k + \rho\sigma^2}v$. With this, we can show that

$$M^K = \max_{v \geq 0} \left\{ \mu + \frac{k^2}{k + \rho\sigma^2}v - \frac{k^2}{2(k + \rho\sigma^2)}v^2 \right\} = \mu + \frac{k^2}{2(k + \rho\sigma^2)},$$

where the optimizer is $v^K = 1$.

Suppose the salesperson observes a market condition θ but chooses the contract $(\alpha(\tilde{\theta}), \beta(\tilde{\theta}), a(\tilde{\theta}))$ from the diligent reseller, his certainty equivalent is $CE(\tilde{\theta}, \theta) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a(\tilde{\theta})) - \frac{1}{2k}[a(\tilde{\theta})]^2 - \frac{1}{2}\rho\sigma^2[\beta(\tilde{\theta})]^2$. Define $CE(\theta) \equiv CE(\theta, \theta)$. Again, the first order condition of the IC constraint and $CE(-\infty) = 0$ imply that $CE(\theta) = \int_{-\infty}^{\theta} \beta(y)dy$. Ignore the IC constraint for a moment, we rewrite the problem as

$$R^D = \max_{\{\beta(\theta) \geq 0, a(\theta) \geq 0\}} \mathbb{E}_{\theta} \left[u + v\theta + va(\theta) - \frac{1}{2k}[a(\theta)]^2 - \frac{1}{2}\rho\sigma^2[\beta(\theta)]^2 - \beta(\theta)H(\theta) \right].$$

$\beta^D(\theta) = 0$ and $a^D(\theta) = vk$ optimizes this problem and result in $R^D = \mathbb{E}_{\theta} [u + v\theta + \frac{k}{2}v^2]$ as the reseller's maximum expected payoff. With $R^D = 0$ at optimality, we have

$$M^D = \max_{v \geq 0} \left\{ \mu + vk - \frac{k}{2}v^2 \right\} = \mu + \frac{k}{2},$$

where the optimizer is $v^D = 1$. Collectively, $M^D = \mu + \frac{k}{2} \geq \mu + \frac{k^2}{2(k + \rho\sigma^2)} = M^K$. \square

Proof of Proposition 4. We start with the first case in which the manufacturer can observe the market condition θ . In this case, the manufacturer's problem is equivalent to the knowledgeable reseller's problem in Section 3.2.2 with $u = 0$ and $v = 1$. By substituting u by 0 and v by 1 in Lemma 2, we can conclude that the manufacturer will receive $\mu + \frac{1}{2(1 + \rho\sigma^2)}$ in expectation. Similarly, if the manufacturer can observe the effort level a , its problem is equivalent to the diligent reseller's problem in Section 3.2.3 with $u = 0$ and $v = 1$. It then follows that the manufacturer will receive $\mu + \frac{1}{2}$ in expectation if we replace u by 0 and v by 1 in Lemma 4. \square

Proof of Lemma 6. We first solve the reseller's problem. At optimality, the constraint is binding, so the problem becomes

$$CE_R^K(\theta) = \max_{\beta \geq 0} \left\{ u + v\theta + v\beta - \frac{1}{2}r(v - \beta)^2\sigma^2 - \frac{1}{2}(1 + \rho\sigma^2)\beta^2 \right\}.$$

By the first order condition, $\beta_A^K = \frac{1+r\sigma^2}{1+\rho\sigma^2+r\sigma^2}v$ solves the problem. It then follows that $a_A^K(\theta) = \frac{1+r\sigma^2}{1+\rho\sigma^2+r\sigma^2}v$ and $CE_R^K(\theta) = u + v\theta + \frac{1+r\sigma^2}{2(1+\rho\sigma^2+r\sigma^2)}v - \frac{1}{2}rv^2\sigma^2$. Now consider the manufacturer, who will set $\mathbb{E}_\theta [CE_R^K(\theta)] = 0$ at any optimal solution and reduce her problem to

$$M_A^K = \max_{v \geq 0} \left\{ \mu + \left(\frac{1+r\sigma^2}{1+\rho\sigma^2+r\sigma^2} \right) (1-v)v + \frac{1+r\sigma^2}{2(1+\rho\sigma^2+r\sigma^2)}v - \frac{1}{2}rv^2\sigma^2 \right\}.$$

With the optimizer $v_A^K = \frac{1+r\sigma^2}{1+r\sigma^2+r\rho\sigma^2}$, M_A^K , β_A^K , and $a_A^K(\theta)$ can be derived accordingly. \square

Proof of Lemma 7. First we must solve the reseller's problem and derive the optimal menu $\{(\alpha_A^D(\theta), \beta_A^D(\theta), a_A^D(\theta))\}$. Applying the first order condition on the IC constraint, we obtain $\frac{d}{d\theta} CE_S(\theta) = \beta(\theta) \geq 0$. Ignoring the IC constraint for a moment, it is clear that the IR constraint must be binding at $\theta = -\infty$ and thus $CE_S(\theta) = \int_{-\infty}^{\theta} \beta(y)dy$ at optimality. The problem then reduces to

$$CE_R^D = \max_{\substack{\beta(\theta) \geq 0, \\ a(\theta) \geq 0}} \mathbb{E}_\theta \left[u + v\theta + a(\theta)v - H(\theta)\beta(\theta) - \frac{r(v - \beta(\theta))^2\sigma^2 + [a(\theta)]^2 + \rho[\beta(\theta)]^2\sigma^2}{2} \right]. \quad (\text{A.1})$$

By pointwise optimization, we have $a_A^D(\theta) = v$ and $\beta_A^D(\theta) = \frac{[rv\sigma^2 - H(\theta)]^+}{(r+\rho)\sigma^2}$ solve this problem. The verification of the IC constraint is straightforward. Accordingly, $\alpha_A^D(\theta)$ can be computed by plugging $a^D(\theta)$ and $\beta^D(\theta)$ back into the binding IR constraint.

The diligent reseller using the optimal contract is said to be “strong”. However, we consider an alternative “weak” diligent reseller using a suboptimal contract $a_A^D(\theta) = v$ and $\beta^D(\theta) = 0$ for all θ . It is optimal for the weak diligent reseller to offer $\bar{\alpha}^D(\theta) = \frac{1}{2}v^2$ as the fixed payment. This single contract, though suboptimal, guarantees the participation of all-types of salesperson. She then obtains $\overline{CE}_R^D = u + v\mu + \frac{1}{2}v^2 - \frac{1}{2}rv^2\sigma^2$ as her certainty equivalent by plugging $\beta(\theta) = 0$ and $a(\theta) = v$ back into (A.1). To contract with the weak diligent reseller, the manufacturer solves

$$\begin{aligned} \overline{M}_A^D &= \max_{u, v, v \geq 0} (1-v)(\mu + v) - u \\ \text{s.t. } &\overline{CE}_R^D \geq 0. \end{aligned} \quad (\text{A.2})$$

At optimality, the binding constraint reduces her problem to $\max_{v \geq 0} \left\{ \mu + v - \frac{1}{2}(1+r\sigma^2)v^2 \right\}$. The manufacturer then receives $\overline{M}_A^D = \mu + \frac{1}{2(1+r\sigma^2)}$ with the maximizer $\bar{v}_A^D = \frac{1}{1+r\sigma^2}$.

The last step is to show that \overline{M}_A^D is a lower bound of the maximum expected profit M_A^D . To see this, note that the strong diligent reseller obtains CE_R^D . The

manufacturer will then solve

$$M_A^D = \max_{u \text{ urs}, v \geq 0} (1-v)(\mu+v) - u \quad \text{s.t.} \quad CE_R^D \geq 0. \quad (\text{A.3})$$

The fact $CE_R^D \geq \overline{CE}_R^D$ implies the feasible region of (A.3) is no smaller than that of (A.2). Since these two problems also have an identical objective function, we have $M^D \geq \overline{M}^D$. \square

Proof of Proposition 5. First we observe from (3.8) and (3.9) that

$$u_s^D + v_s^D \mu + \frac{1}{2}(v_s^D)^2 \geq u_s^K + v_s^K \mu + \frac{1}{2}(v_s^K)^2 \geq u_s^K + v_s^K \mu + \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2 \geq 0,$$

which implies that (3.10) is redundant. Furthermore, if we ignore (3.7) for a moment, the relaxed manufacturer's problem becomes:

$$\max_{\substack{u_s^K \text{ urs}, v_s^K \geq 0, \\ u_s^D \text{ urs}, v_s^D \geq 0}} p \left[(1-v_s^K) \left(\mu + \frac{1}{1+\rho\sigma^2} v_s^K \right) - u_s^K \right] \\ + (1-p) \left[(1-v_s^D) (\mu + v_s^D) - u_s^D \right] \quad (\text{A.4})$$

$$\text{s.t.} \quad u_s^D + v_s^D \mu + \frac{1}{2}(v_s^D)^2 \geq u_s^K + v_s^K \mu + \frac{1}{2}(v_s^K)^2, \quad (\text{A.5})$$

$$u_s^K + v_s^K \mu + \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2 \geq 0. \quad (\text{A.6})$$

We first observe that at optimality (A.6) must be binding; otherwise, decreasing u_s^K a bit yields a higher expected payoff for the manufacturer while relaxing (A.5). Likewise, we can show that (A.5) must be binding as well, for otherwise decreasing u_s^D would be profitable for the manufacturer. Thus, we can replace u_s^K and u_s^D by

$$u_s^K = -v_s^K \mu - \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2, \\ u_s^D = -v_s^D \mu - \frac{1}{2}(v_s^D)^2 + \left(\frac{1}{2} - \frac{1}{2(1+\rho\sigma^2)} \right) (v_s^K)^2,$$

in the manufacturer's objective and get the maximizers

$$v_s^D = 1, \text{ and } v_s^K = \frac{1}{1 + (1-p)\rho\sigma^2/p}.$$

The corresponding fixed payments are $u_s^K = -v_s^K \mu - \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2$ and $u_s^D = -\mu - \frac{1}{2} + \left(\frac{1}{2} - \frac{1}{2(1+\rho\sigma^2)} \right) (v_s^K)^2$. The knowledgeable reseller receives zero expected payoff since (A.6) is binding, whereas the diligent reseller obtains an information rent $u_s^D +$

$v_s^D \mu + \frac{1}{2}(v_s^D)^2 = (\frac{1}{2} - \frac{1}{2(1+\rho\sigma^2)})(v_s^K)^2$. It is then straight forward to verify that (3.7) is satisfied under this menu of contracts. Finally, the induced effort levels $a_s^K(\theta)$ and $a_s^D(\theta)$ follow from Propositions 3 and 5. \square

Proof of Proposition 7. Given B , it is straightforward to show that the optimal solutions for (3.11) is

$$(u^K(B), v^K(B)) = \begin{cases} (-\mu - \frac{\eta}{2}, 1) & \text{if } B \leq -\mu - \frac{\eta}{2} \\ \left(B, \max \left\{ \frac{\eta - \mu}{2\eta}, \frac{-\mu + \sqrt{\mu^2 - 2\eta B}}{\eta} \right\} \right) & \text{otherwise} \end{cases},$$

where $\eta \equiv \frac{1}{1+\rho\sigma^2} \in (0, 1]$. Similarly, the optimal solution for (3.12) is

$$(u^D(B), v^D(B)) = \begin{cases} (-\mu - \frac{1}{2}, 1) & \text{if } B \leq -\mu - \frac{1}{2} \\ \left(B, \max \left\{ \frac{1-\mu}{2}, -\mu + \sqrt{\mu^2 - 2B} \right\} \right) & \text{otherwise} \end{cases},$$

Now we discuss three cases: $B \in (-\infty, \leq -\mu - \frac{1}{2}]$, $B \in (-\mu - \frac{1}{2}, \leq -\mu - \frac{\eta}{2}]$, and $B \in (-\mu - \frac{\eta}{2}, 0)$. In the first case, because $M_L^K(B) = M^K$ and $M_O^D(B) = M^D$, $M_L^D(B) - M_L^K(B)$ is unaffected by B . In the second case, we still have $M_L^K(B) = M^K$, but now $M_L^D(B)$ is not M^D because the constraint $u \geq B$ is binding at the optimal solution. In this case, it is clear that $M_L^D(B)$ is decreasing in B , and thus $M_L^D(B) - M_L^K(B)$ is decreasing in B . In the last case, we have

$$\begin{aligned} & M_L^D(B) - M_L^K(B) \\ &= (1 - \mu)v^D(B) - (v^D(B))^2 - (\eta - \mu)v^K(B) + \eta(v^K(B))^2. \end{aligned} \quad (\text{A.7})$$

Note that depending on the values of μ and B , there are four combinations of $v^K(B)$ and $v^D(B)$. We will first show that (A.7) is nondecreasing in three combinations and then show that the last combination is not possible.

Suppose $v^K(B) = \frac{-\mu + \sqrt{\mu^2 - 2\eta B}}{\eta}$ and $v^D(B) = -\mu + \sqrt{\mu^2 - 2B}$, then $\frac{\partial}{\partial B}(M_L^D(B) - M_L^K(B)) = \frac{-1-\mu}{\sqrt{\mu^2 - 2B}} + \frac{\eta + \mu}{\sqrt{\mu^2 - 2\eta B}} \leq 0$ because the second term is increasing in η .

Suppose $v^K(B) = \frac{-\mu + \sqrt{\mu^2 - 2\eta B}}{\eta}$ and $v^D(B) = \frac{1-\mu}{2}$, then $\frac{\partial}{\partial B}(M_L^D(B) - M_L^K(B)) = \frac{\eta + \mu}{\sqrt{\mu^2 - 2\eta B}} - 2$, which is nonnegative if and only if $\frac{\eta - \mu}{2\eta} \leq \frac{-\mu + \sqrt{\mu^2 - 2\eta B}}{\eta}$. Because this

is required by the fact that $v^K(B) = -\mu + \sqrt{\mu^2 - 2B}$, the desired result holds in this case. Suppose $v^K(B) = \frac{\eta - \mu}{2\eta}$ and $v^D(B) = \frac{1-\mu}{2}$, then $\frac{\partial}{\partial B}(M_L^D(B) - M_L^K(B)) = 0$.

Finally, it is impossible to have $v^K(B) = \frac{\eta - \mu}{2\eta}$ and $v^D(B) = -\mu + \sqrt{\mu^2 - 2B}$. To see this, note that $v^D(B) = -\mu + \sqrt{\mu^2 - 2B}$ implies $\frac{1-\mu}{2} \leq -\mu + \sqrt{\mu^2 - 2B}$, which then implies $\frac{\eta - \mu}{2\eta} \leq \frac{-\mu + \sqrt{\mu^2 - 2\eta B}}{\eta}$ due to $-\mu + \sqrt{\mu^2 - 2B} \leq \frac{-\mu + \sqrt{\mu^2 - 2\eta B}}{\eta}$ (as the right-hand side decreases in η) and $\frac{1-\mu}{2} \geq \frac{\eta - \mu}{2\eta}$. It then follows that $v^K(B)$ cannot be $\frac{\eta - \mu}{2\eta}$. \square

Proof of Proposition 8. For any $\mu \geq 1$, it can be easily verified that $v^D(0) = 0$ and thus $M_L^D(0) = \mu$. However, M^* is always greater than μ , so $M^* > M_L^D(0)$. The existence and uniqueness of $\hat{B}(\mu)$ then follows from the monotonicity of $M_L^D(B)$ and the fact that $M_L^D(-\infty) > M^*$. We may thus set $\hat{\mu} = 1$ to complete the proof. For different combinations of parameters, better lower bounds may be found. \square

Proof of Proposition 9. When θ is uniformly distributed with mean μ and variance ξ^2 , we have $M^D = \frac{1}{2}E_\theta[\theta^2] = \frac{1}{2}(\xi^2 + \mu^2)$ and

$$M^K = \frac{1}{2}E_\theta \left[\frac{\theta^4}{\theta^2 + \rho\sigma^2} \right] = \frac{1}{2(2\sqrt{3}\xi)} \int_a^b \frac{w^4}{w^2 + \rho\sigma^2} dw,$$

where $a = \mu - \sqrt{3}\xi$ and $b = \mu + \sqrt{3}\xi$. It then follows that

$$\begin{aligned} \frac{d}{d\mu}(M^D - M^K) &= \mu - \frac{1}{4\sqrt{3}\xi} \left(\frac{b^4}{b^2 + \rho\sigma^2} - \frac{a^4}{a^2 + \rho\sigma^2} \right) \\ &= \frac{8\sqrt{3}\xi\mu(b^2 + \rho\sigma^2)(a^2 + \rho\sigma^2) - b^4(a^2 + \rho\sigma^2) + a^4(b^2 + \rho\sigma^2)}{4\sqrt{3}\xi(b^2 + \rho\sigma^2)(a^2 + \rho\sigma^2)} \\ &= \frac{\mu\rho^2\sigma^4}{(b^2 + \rho\sigma^2)(a^2 + \rho\sigma^2)}. \end{aligned}$$

The result then holds given that $\mu \geq 0$ and $\rho \geq 0$. \square

Appendix B

Appendix for Chapter 4

Proof of Proposition 10. Since $CE'(\theta) = \beta \geq 0$, $CE(\theta)$ is nondecreasing in θ . Therefore, to satisfy the (IR) constraint (4.4), at optimality we must have $CE(-\infty) = 0$ and $CE(\theta) = \int_{-\infty}^{\theta} \beta(y)dy$. We then have

$$-\alpha(\theta) = \beta(\theta)\theta + \frac{[\beta + w(\theta)]^2}{2} - \frac{1}{2}\rho[\beta(\theta)]^2\sigma_\epsilon^2 - \frac{1}{2}\rho[w(\theta)]^2\sigma_\xi^2 - \int_{-\infty}^{\theta} \beta(y)dy$$

at optimality according to $CE(\theta)$ in (4.1). Ignoring the (IC) constraint reduces the reseller's problem to

$$\max_{\{\beta(\theta) \geq 0, w(\theta) \geq 0\}} \mathbb{E}_{\theta|s} \left[\theta + \beta(\theta) + w(\theta) - \frac{[\beta(\theta) + w(\theta)]^2}{2} - \frac{1}{2}\rho \left([\beta(\theta)]^2\sigma_\epsilon^2 + [w(\theta)]^2\sigma_\xi^2 \right) - H(\theta|s)\beta(\theta) \mid s \right] \quad (\text{B.1})$$

with integration by part applied on the last term. Because this objective function is concave on $\beta(\theta)$ and $w(\theta)$, the first-order condition is sufficient and at any optimal solution we have

$$\begin{aligned} 1 &= [\beta^*(\theta) + w^*(\theta)] + \rho\beta^*(\theta)\sigma_\epsilon^2 + H(\theta|s) \text{ and} \\ 1 &= [\beta^*(\theta) + w^*(\theta)] + \rho w^*(\theta)\sigma_\xi^2. \end{aligned}$$

The second equality leads to $w^*(\theta) = \frac{1-\beta^*(\theta)}{1+\rho\sigma_\xi^2}$. With $\beta^*(\theta) \geq 0$ in mind, we can then substitute $w^*(\theta)$ in the first equality by this and get $\beta^*(\theta) = \left[\frac{\rho\sigma_\xi^2 - (1+\rho\sigma_\xi^2)H(\theta|s)}{\rho\sigma_\xi^2 + (1+\rho\sigma_\xi^2)\rho\sigma_\epsilon^2} \right]^+$. Note that $\beta^*(\theta) \leq 1$, which implies $w^*(\theta) \geq 0$. With $\alpha^*(\theta)$ solved by plugging $\beta^*(\theta)$ and $w^*(\theta)$ in, we have derived the optimal menu of contract. Verifying the (IC) constraint (4.3) is trivial and ignored. \square

Proof of Proposition 11. Consider $\beta^*(\theta)$ first. Because $H(\theta)$ is strictly decreasing from infinity to 0, we define θ_0 as the unique value satisfying $H(\theta_0|s) = \frac{\rho\sigma_\xi^2}{1+\rho\sigma_\xi^2}$. It then follows that $\beta^*(\theta) = 0$ for all $\theta \leq \theta_0$ and $\beta^*(\theta) > 0$ for all $\theta > \theta_0$. Note that when σ_ξ^2 is increasing, we have $\frac{\rho\sigma_\xi^2}{1+\rho\sigma_\xi^2}$ increasing and thus θ_0 decreasing. This implies that $\beta^*(\theta)$ is weakly increasing in σ_ξ^2 for all $\theta \leq \theta_0$: It either remains 0 or becomes positive. For $\theta > \theta_0$, we have

$$\frac{\partial\beta^*(\theta)}{\partial\sigma_\xi^2} = \frac{\rho\sigma_\epsilon^2 + H(\theta|s)}{\rho(\sigma_\xi^2 + \sigma_\epsilon^2 + \rho\sigma_\xi^2\sigma_\epsilon^2)^2} > 0.$$

Therefore, we conclude that $\beta^*(\theta)$ decreases as σ_ξ^2 decreases for all θ . Because $w^*(\theta) = \frac{1-\beta^*(\theta)}{1+\rho\sigma_\xi^2}$, it is clear that $w^*(\theta)$ increases as σ_ξ^2 decreases for all θ . Finally, consider $a^*(\theta)$. We have $a^*(\theta) = \beta^*(\theta) + w^*(\theta) = \frac{1+\beta^*(\theta)\rho\sigma_\xi^2}{1+\rho\sigma_\xi^2}$. For $\theta \leq \theta_0$, $\beta^*(\theta) = 0$ and thus $a^*(\theta) = \frac{1}{1+\rho\sigma_\xi^2}$ increases as σ_ξ^2 decreases. For $\theta > \theta_0$, we have

$$\frac{\partial a^*(\theta)}{\partial\sigma_\xi^2} = \frac{\sigma_\xi^2[-\rho\sigma_\epsilon^2 - H(\theta|s)]}{(\sigma_\xi^2 + \sigma_\epsilon^2 + \rho\sigma_\xi^2\sigma_\epsilon^2)^2} < 0.$$

Therefore, $a^*(\theta)$ decreases as σ_ξ^2 decreases for all θ . The result for $\mathbb{E}[a^*(\theta)]$ then follows. \square

Proof of Proposition 12. Recall that in solving the contract design problem (4.2) – (4.4), the first step is to replace $\alpha(\theta)$ by $\beta(\theta)$ and $w(\theta)$ and obtain (B.1). Let

$$\begin{aligned} h(\beta(\theta), w(\theta), \sigma_\xi^2) \equiv & \theta + \beta(\theta) + w(\theta) - \frac{[\beta(\theta) + w(\theta)]^2}{2} \\ & - \frac{1}{2}\rho\left([\beta(\theta)]^2\sigma_\epsilon^2 + [w(\theta)]^2\sigma_\xi^2\right) - H(\theta|s)\beta(\theta) \end{aligned}$$

be the integrand in (B.1), we may express the expected profit as

$$R(\sigma_\tau^2, \sigma_\xi^2) = \mathbb{E}_s \left\{ \max_{\{\beta(\theta) \geq 0, w(\theta) \geq 0\}} \mathbb{E}_{\theta|s} \left[h(\beta(\theta), w(\theta), \sigma_\xi^2) \mid s \right] \right\},$$

i.e., for every realization of s , the reseller looks for $\beta(\theta)$ and $w(\theta)$ to maximize her expected profit. Because $h(\beta(\theta), w(\theta), \sigma_\xi^2)$ decreases in σ_ξ^2 if β and w are fixed, the expectation to be maximized, $\mathbb{E}_{\theta|s} \left[h(\beta(\theta), w(\theta), \sigma_\xi^2) \mid s \right]$, also decreases in σ_ξ^2 . Let $\bar{\sigma}_\xi^2 < \hat{\sigma}_\xi^2$ be two values of σ_ξ^2 , we know

$$\max_{\{\beta(\theta) \geq 0, w(\theta) \geq 0\}} \left\{ \mathbb{E}_{\theta|s} \left[h(\beta(\theta), w(\theta), \bar{\sigma}_\xi^2) \mid s \right] \right\} > \max_{\{\beta(\theta) \geq 0, w(\theta) \geq 0\}} \left\{ \mathbb{E}_{\theta|s} \left[h(\beta(\theta), w(\theta), \hat{\sigma}_\xi^2) \mid s \right] \right\}$$

since these two optimization problems have the same feasible region and the objective function of the former is larger than that of the latter for every feasible solution. In other words, for any given s , the reseller can do better in expectation with a smaller σ_ξ^2 . Since this is true for every realization of s , it is true for the expectation of s . Therefore, $R(\sigma_\tau^2, \bar{\sigma}_\xi^2) > R(\sigma_\tau^2, \hat{\sigma}_\xi^2)$ and we conclude that $R(\sigma_\tau^2, \sigma_\xi^2)$ strictly decreases in σ_ξ^2 . \square

Summary of the Numerical Studies.

K_ξ	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
FOE	432	432	412	324	218	115	52	23	10	2
Balancing	0	0	20	98	136	175	185	171	141	107
FOD	0	0	0	10	78	142	195	238	281	323

Table B.1: Impact of K_ξ (for Figure 4.3)

c_ξ	1	0.75	0.5	0.25	c_{joint}	5	7.5	10	12.5
FOE	475	495	516	534	FOE	646	511	448	415
Balancing	218	238	277	300	Balancing	217	302	289	225
FOD	387	347	287	246	FOD	217	267	343	440

Table B.2: Impact of c_ξ (for Figure 4.4) Table B.3: Impact of c_{joint} (for Figure 4.5)

Appendix C

Appendix for Chapter 5

Proof of Lemma 8. First, we can apply $\mathcal{A}_{Fk} \geq \mathcal{A}_{Fk}(U)$, $N_{Fk}^2 \geq N_{Uk}^2$, and $\mathcal{A}_{Uk} \geq 0$ to show that $\mathcal{A}_{Fk} \geq 0$ is redundant. If we ignore the constraint $\mathcal{A}_{Uk} \geq \mathcal{A}_{Uk}(F)$, the remaining two constraints will be binding at the optimal solution. Therefore, we can replace α_F and α_U by $\alpha_F = \frac{1}{2}\beta_U^2(N_{Fk}^2 - N_{Uk}^2) - \frac{1}{2}\beta_F^2 N_{Fk}^2$ and $\alpha_U = -\frac{1}{2}\beta_U N_{Uk}^2$ in the objective function. The problem then reduces to

$$\begin{aligned} \mathcal{R}_k(t) = \max_{\beta_F \geq 0, \beta_U \geq 0} & \bar{P}_{Fk} \left[\frac{1}{2} N_{Fk}^2 \beta_F^2 - \frac{1}{2} (N_{Fk}^2 - N_{Uk}^2) \beta_U^2 + N_{Fk}^2 (v_t - \beta_F) \beta_F \right] \\ & + \bar{P}_{Uk} \left[\frac{1}{2} N_{Uk}^2 \beta_U^2 + N_{Uk}^2 (v_t - \beta_U) \beta_U \right], \end{aligned} \quad (\text{C.1})$$

which is solved by $\beta_F^* = v_t$ and $\beta_U^* = \frac{\bar{P}_{Uk} N_{Uk}^2}{\bar{P}_{Uk} N_{Uk}^2 + \bar{P}_{Fk} (N_{Fk}^2 - N_{Uk}^2)} v_t$ through the first-order condition. Verifying the constraint $\mathcal{A}_{Uk} \geq \mathcal{A}_{Uk}(F)$ is trivial and omitted. The reseller's expected profit $\mathcal{R}_k(t)$ can be found by plugging β_F^* and β_U^* into (C.1). \square

Proof of Lemma 9. First, we can apply $\mathcal{R}_G \geq \mathcal{R}_G(B)$, $Z_G \geq Z_B$, and $\mathcal{R}_B \geq 0$ to show that $\mathcal{R}_G \geq 0$ is redundant. If we ignore the constraint $\mathcal{R}_B \geq \mathcal{R}_B(G)$, the remaining two constraints will be binding at the optimal solution. Therefore, we can replace u_G and u_B by $u_G = \frac{v_B^2}{2}(Z_G - Z_B) - \frac{v_G^2}{2} Z_G$ and $u_B = -\frac{v_B^2}{2} Z_B$ in the objective function. The problem then reduces to

$$\mathcal{M} = \max_{v_G \geq 0, v_B \geq 0} \left\{ \frac{1}{2} Z_G v_G^2 - \frac{1}{2} (Z_G - Z_B) v_B^2 + Z_G (1 - v_G) v_G + \frac{1}{2} Z_B v_B^2 + Z_B (1 - v_B) v_B \right\}, \quad (\text{C.2})$$

which is solved by $v_G^* = 1$ and $v_B^* = \frac{Z_B}{Z_G}$ through the first-order condition. Verifying the constraint $\mathcal{R}_B \geq \mathcal{R}_B(G)$ is trivial and omitted. The manufacturer's expected profit \mathcal{M} can be found by plugging v_G^* and v_B^* into (C.2). \square

Proof of Proposition 13. To show that $\mathbb{E}[x]$ is convex, we will show \mathcal{M} is convex and then rely on the fact $\mathcal{M} = \frac{1}{2}\mathbb{E}[x]$, which is demonstrated in Proposition 16. Below we prove the convexity of \mathcal{M} . First, we express the manufacturer's contract

design problem as the problem of determining the optimal sales bonus for the type- B reseller, i.e., $\mathcal{M} = \max_{v \in [0,1]} \left\{ \frac{Z_G}{8}(1-v^2) + \frac{Z_B}{4}v \right\}$. Therefore, \mathcal{M} will be convex if Z_G and Z_B are both convex. To prove the convexity of Z_k , note that the type- k reseller's expected profit $\mathcal{R}_k = u_t + Z_k v_k^2$ can also be expressed as the problem of determining the optimal amount of downward distortion of the sales bonus for the type- (B, k) salesperson, i.e.,

$$\mathcal{R}_k = u_t + \max_{y \in [0,1]} \left\{ \bar{P}_{Fk} N_{Fk}^2 (1-y^2) + \bar{P}_{Uk} N_{Uk}^2 (2y-y^2) + \bar{P}_{Fk} N_{Uk}^2 y^2 \right\} v_k^2.$$

This implies that Z_k is also the maximum of several functions. As all the coefficients are nonnegative with $y \in [0, 1]$, it suffices to show that $\bar{P}_{Fk} N_{Fk}^2$, $\bar{P}_{Uk} N_{Uk}^2$, and $\bar{P}_{Fk} N_{Uk}^2$ are all convex. Consider the case with $k = G$ first. It is straightforward to verify that $\frac{\partial^2}{\partial \lambda_R^2} \bar{P}_{FG} N_{FG}^2 = \frac{2\lambda_A^2(1-\lambda_A)^2(\theta_H - \theta_L)^2}{[\lambda_A \lambda_R + (1-\lambda_A)(1-\lambda_R)]^3} \geq 0$ and $\frac{\partial^2}{\partial \lambda_R^2} \bar{P}_{FG} N_{FG}^2 = \frac{2\lambda_A^2(1-\lambda_A)^2(\theta_H - \theta_L)^2}{[(1-\lambda_A)\lambda_R + \lambda_A(1-\lambda_R)]^3} \geq 0$. For $\bar{P}_{FG} N_{UG}^2$, we have $\frac{\partial^2}{\partial \lambda_R^2} \bar{P}_{FG} N_{UG}^2 = \frac{2\lambda_A(1-\lambda_A)(\theta_H - \theta_L)}{[(1-\lambda_A)\lambda_R + \lambda_A(1-\lambda_R)]^4} h(\lambda_A, \lambda_R)$, where

$$\begin{aligned} h(\lambda_A, \lambda_R) &= 2\lambda_R \theta_H - \lambda_A \left[\theta_H + 5\lambda_R \theta_H - 3(1-\lambda_R)\theta_L \right] \\ &\quad + \lambda_A^2 \left[(2 + \lambda_R)\theta_H + 7\lambda_R - 6 \right] + \lambda_A^3 (3\lambda_R - 1)(\theta_H - \theta_L), \end{aligned}$$

which is linear in λ_R . Therefore, to show that $h(\lambda_A, \lambda_R) \leq 0$ for all λ_A and λ_R , we only need to show that $h(\lambda_A, \frac{1}{2}) \leq 0$ and $h(\lambda_A, 1) \leq 0$ for all λ_A . As one may verify, $h(\lambda_A, \frac{1}{2})$ is quadratic and convex, so $h(\frac{1}{2}, \frac{1}{2}) = -\frac{1}{8}(\theta_H - \theta_L) < 0$ and $h(1, \frac{1}{2}) = -\theta_L < 0$ imply that $h(\lambda_A, \frac{1}{2}) < 0$ for all λ_A . For $h(\lambda_A, 1)$, which is a third-degree polynomial function of λ_A , because its smaller stationary point is negative, it is quasi-convex on $\lambda_A \in [\frac{1}{2}, 1]$. Then $h(\frac{1}{2}, 1) = 0$ and $h(1, 1) = -\frac{1}{8}(\theta_H - \theta_L) < 0$ imply that $h(\lambda_A, 1) \leq 0$ for all λ_A . This completes the proof for the case with $k = G$. The case with $k = B$ can be proved in the same way. \square

Proof of Lemma 10. For $k \in \{G, B\}$, we have $\frac{\partial}{\partial \lambda_R} Y_k|_{\lambda_R=1} = \frac{2(2\lambda_A-1)(\theta_H-\theta_L)}{(1-\lambda_A)^2\theta_H} > 0$. Because $\frac{\partial}{\partial \lambda_R} Y_k$ is continuous, it follows that when λ_R is sufficiently close to 1, $\frac{\partial}{\partial \lambda_R} Y_k$ will be positive. We may then define $\bar{\lambda}_k(\lambda_A, \theta_H, \theta_L)$ as $\max \left\{ \lambda_R \in (\frac{1}{2}, 1) \mid \frac{\partial}{\partial \lambda_R} Y_k = 0 \right\}$ if it exists or $\frac{1}{2}$ otherwise. \square

Proof of Proposition 14. When $\lambda_A = \frac{1}{2}$, we have $\frac{\partial}{\partial \lambda_R} \mathbb{E}[x]|_{\lambda_R=1} = \frac{\theta_L^2}{\eta^3}(\eta^5 - \eta^4 - 2\eta^2 + \eta + 1)$. If $\eta < \eta_1$, it is easy to verify that $\eta^5 - \eta^4 - 2\eta^2 + \eta + 1 < 0$ and thus $\frac{\partial}{\partial \lambda_R} \mathbb{E}[x]|_{\lambda_R=1} < 0$. The proposition then follows due to the continuity of $\frac{\partial}{\partial \lambda_R} \mathbb{E}[x]$. \square

Proof of Proposition 15. Let $\bar{x}(\lambda_A, \lambda_R)$ be the expected sales $\mathbb{E}[x]$ under λ_A and λ_R . We have $\bar{x}(\lambda_A, 1) = \frac{1}{2}(\theta_H^2 + \theta_L^4/\theta_H^2)$ and

$$\bar{x} \left(\lambda_A, \frac{1}{2} \right) = \frac{1}{2} \left\{ [\theta_L(1-\lambda_A) + \theta_H\lambda_A]^2 + \frac{[\theta_L\lambda_A + \theta_H(1-\lambda_A)]^4}{[\theta_L(1-\lambda_A) + \theta_H\lambda_A]^2} \right\}.$$

To compare $\bar{x}(\lambda_A, \frac{1}{2})$ and $\bar{x}(\lambda_A, 1)$, note that: (i) $\bar{x}(\lambda_A, 1)$ is constant for all λ_A ; (ii) $\bar{x}(\lambda_A, \lambda_R)$ is convex in λ_A for any given λ_R (proved in Proposition 18); and (iii)

$\bar{x}(1, \frac{1}{2}) = \bar{x}(1, 1)$. Due to these facts, we will have $\bar{x}(\lambda_A, \frac{1}{2}) > \bar{x}(\lambda_A, 1)$ for all λ_A if and only if

$$\frac{\partial}{\partial \lambda_A} \bar{x}(\lambda_A, \frac{1}{2})|_{\lambda_A=1} = \frac{\theta_L^5}{\theta_H^3} (\eta^5 - \eta^4 - 2\eta^2 + \eta + 1) < 0.$$

It can be verified that there is only one root of $\eta^5 - \eta^4 - 2\eta^2 + \eta + 1 = 0$ that is greater than 1, which is denoted by $\eta_1 \approx 1.3954$. It then follows that $\frac{\partial}{\partial \lambda_A} \bar{x}(\lambda_A, \frac{1}{2})|_{\lambda_A=1} < 0$ for all $\eta < \eta_1$. For $\eta \geq \eta_1$, we know $\bar{x}(\lambda_A, \frac{1}{2}) < \bar{x}(\lambda_A, 1)$ for all λ_A if and only if $\bar{x}(\frac{1}{2}, \frac{1}{2}) > \bar{x}(\frac{1}{2}, 1)$, i.e., $\eta^4 - 2\eta^3 - \eta^2 + 2 > 0$. It can be verified that there is only root of $\eta^4 - 2\eta^3 - \eta^2 + 2 = 0$ that is greater than 1, which is denoted by $\eta_2 \approx 2.2695$. It then follows that $\bar{x}(\frac{1}{2}, \frac{1}{2}) > \bar{x}(\frac{1}{2}, 1)$ for all $\eta > \eta_2$. For $\eta \in [\eta_1, \eta_2]$, the facts that $\bar{x}(\lambda_A, 1)$ is constant for all λ_A and $\bar{x}(\lambda_A, \lambda_R)$ is convex on λ_A imply that $\bar{x}(\lambda_A, \frac{1}{2}) > \bar{x}(\lambda_A, 1)$ for λ_A close to $\frac{1}{2}$ and $\bar{x}(\lambda_A, \frac{1}{2}) < \bar{x}(\lambda_A, 1)$ for λ_A close to 1. The cutoff is thus unique. \square

Proof of Proposition 16. Plugging v_G^* and v_B^* into (C.2) leads to $\mathcal{M} = \frac{1}{2} \left(\frac{1}{2} Z_G + \frac{Z_B^2}{2Z_G} \right) = \frac{1}{2} \left(\frac{1}{2} Z_G v_G^* + \frac{1}{2} Z_B v_B^* \right)$. From (5.4) we know $Z_k v_k^* = \mathbb{E}[x|s_R = k]$. Also $\Pr(s_R = k) = \frac{1}{2}$, so $\mathcal{M} = \frac{1}{2} \sum_{k \in \{G, B\}} \Pr(s_R = k) \mathbb{E}[x|s_R = k] = \frac{1}{2} \mathbb{E}[x]$. \square

Proof of Proposition 17. Because $Z_G = Z_B$ when $\lambda_R = \frac{1}{2}$, we know $\mathcal{R} = \frac{1}{4} (Z_G - Z_B) v_B^2 = 0$ when $\lambda_R = \frac{1}{2}$. The fact that $\mathcal{R} \geq 0$ (due to the IR constraints) then implies that $\lambda'_R > \frac{1}{2}$. This rules out the possibility of $\lambda'_R = \lambda_R^*$ when $\eta < \eta_1 \approx 1.3954$, because in this case $\lambda_R^* = \frac{1}{2}$. For $\eta \geq \eta_1$, the key quantity to investigate is $\frac{\partial}{\partial \lambda_R} \mathcal{R}|_{\lambda_R=1}$. As long as this is negative, we know $\lambda'_R < 1$ and thus $\lambda'_R \neq \lambda_R^*$. We have $\frac{\partial}{\partial \lambda_R} \mathcal{R}|_{\lambda_R=1} = \frac{-(\theta_H - \theta_L)\theta_L^3}{2(1-\lambda_A)\lambda_A\theta_H^5} g(\lambda_A)$, where

$$g(\lambda_A) = \lambda_A^2 \left(2\theta_H^3 + \theta_H^2 \theta_L - 3\theta_H \theta_L^2 - \theta_L^3 \right) + \lambda_A \left(-4\theta_H^3 + 6\theta_H \theta_L^2 \right) + 2\theta_H^3 + 3\theta_H \theta_L^2$$

is quadratic in λ_A . It can be verified that the coefficient of λ_A^2 is positive and $g(\lambda_A)$ is convex for $\eta > \eta_1$. Because the roots of $g(\lambda_A) = 0$ are $\frac{2\eta^3 - 3\eta \pm \sqrt{-\eta(2\eta^2 - 3)(\eta^2 - 2)}}{2\eta^3 + \eta^2 - 3\eta - \eta}$, they are complex if and only if $\eta < \sqrt{\frac{3}{2}} < \eta_1$ or $\eta > \sqrt{2}$. The convexity of $g(\lambda_A)$ then implies that $g(\lambda_A) > 0$ and thus $\frac{\partial}{\partial \lambda_R} \mathcal{R}|_{\lambda_R=1} < 0$ when $\eta > \sqrt{2}$. Now we can focus on the intermediate region $\eta \in [\eta_1, \sqrt{2}]$, in which the two roots are real. In this case, the smaller root $\tilde{\lambda}_A(\eta)$ is the only root that is within $[\frac{1}{2}, 1]$. The convexity of $g(\lambda_A)$ then implies that $\frac{\partial}{\partial \lambda_R} \mathcal{R}|_{\lambda_R=1} \geq 0$ if and only if $\lambda_A \geq \tilde{\lambda}_A(\eta)$. λ'_R may then be 1. If λ_A is also large enough so that $\lambda_R^* = 1$ (cf. Proposition 15), then it is possible for us to have $\lambda'_R = \lambda_R^*$. \square

Proof of Proposition 18. The proof is very similar to that of Proposition 13 and is omitted. \square

Proof of Proposition 19. We follow proposition 15 to prove this proposition. When $\eta \leq \eta_1$, $\bar{x}(\lambda_A, \frac{1}{2}) \geq \bar{x}(\lambda_A, 1)$ for all λ_A and the inequality is strict unless $\lambda_A = 1$. Therefore, $\bar{x}(\lambda_A, \lambda_R)$ is uniquely maximized at $(\frac{1}{2}, \frac{1}{2})$. When $\eta \in (\eta_1, \eta_2)$,

$\bar{x}(\lambda_A, \frac{1}{2}) > \bar{x}(\lambda_A, 1)$ for λ_A close enough to $\frac{1}{2}$. The fact that $\bar{x}(\lambda_A, 1)$ is a constant then implies that $\bar{x}(\lambda_A, \lambda_R)$ is also uniquely maximized at $(\frac{1}{2}, \frac{1}{2})$. Finally, when $\eta \geq \eta_2$, $\bar{x}(\lambda_A, \frac{1}{2}) \leq \bar{x}(\lambda_A, 1)$ for all λ_A and $\bar{x}(\lambda_A, \lambda_R)$ is maximized when $\lambda_R = \frac{1}{2}$, regardless of the value of λ_A . \square

Proof of Lemma 11. First, note that $\alpha_j \geq 0$ implies $\mathcal{A}_{jk} \geq 0$ and thus the IR constraints are both redundant. We then add the two IC constraints up and obtain the monotonicity condition $\beta_F \geq \beta_B$. Ignore the IC constraint $\mathcal{A}_{Uk} \geq \mathcal{A}_{Uk}(F)$ for a moment. Without this IC constraint, it is clear that $\alpha_B = 0$ is required for optimality. Now, monotonicity as well as $\alpha_G \geq 0$ together show the redundancy of $\mathcal{A}_{Fk} \geq \mathcal{A}_{Fk}(U)$, which further implies $\alpha_G = 0$ at optimality. The problem now becomes unconstrained and is optimized at $\beta_F = \beta_U = \frac{1}{2}$ by the first order condition. Such a single contract certainly satisfies the previously omitted IC constraint. \square

Proof of Proposition 20. To show the convexity of $\mathbb{E}[x]$, first note that $\mathcal{M} = \frac{1}{2}\mathbb{E}[x]$ according to the same argument we use in the proof of Proposition 16 (the only modification is to replace Z_k by W_k). We now show that \mathcal{M} is convex in λ_R . Following the same arguments in the proof of Proposition 13, the convexity of \mathcal{M} reduces to the convexity of W_G and W_B , which again reduces to the convexity of $\bar{P}_{jk}N_{jk}^2$, $j \in \{F, U\}$, $k \in \{G, B\}$. As this is verified in the proof of Proposition 13, the convexity of \mathcal{M} is established. Now consider the second part. Let $\bar{x}^L(\lambda_R)$ be the expected sales and $v_B^*(\lambda_R)$ be the sales bonus for the type- B reseller when the reseller's accuracy is λ_R . Through straightforward arithmetics, we can verify that

$$\begin{aligned} \bar{x}^L\left(\frac{1}{2}\right) &= \frac{1}{4} \left\{ N_{Fk}^2 + N_{Uk}^2 \right\} \\ &> \frac{1}{4} \left\{ N_{Fk}^2 [\lambda_A + v_B^*(1)(1 - \lambda_A)] + N_{Uk}^2 [(1 - \lambda_A) + v_B^*(1)\lambda_A] \right\} = \bar{x}^L(1), \end{aligned}$$

where the strict inequality follows from $v_B^*(1) < 1$ and $\lambda_A > 0$. \square

Proof of Proposition 21. Let $\bar{x}(\lambda_A, \lambda_R, \gamma)$ be the expected sales $\mathbb{E}[x]$ under λ_A , λ_R , and γ . We have $\bar{x}(\frac{1}{2}, \frac{1}{2}, \gamma) = \theta_L^2(\eta + \gamma - \eta\gamma)^2$ and $\bar{x}(\frac{1}{2}, 1, \gamma) = \theta_L^2 \left[\eta^2(1 - \gamma) + \frac{\gamma^2}{(\eta^2 - 1)(1 - \gamma) + \gamma} \right]$. Therefore,

$$\bar{x}\left(\frac{1}{2}, \frac{1}{2}, \gamma\right) - \bar{x}\left(\frac{1}{2}, 1, \gamma\right) = \frac{\gamma(1 - \gamma)\theta_L^2}{(\eta^2 - 1)(1 - \gamma) + \gamma} \left[\eta(2 - \eta)(\eta^2 - 1) + \gamma(\eta^2 - 2)(\eta - 1)^2 \right].$$

The term outside the square bracket is always positive. When $\eta < 2$, the first term inside the square bracket is also positive. If $\eta^2 \geq 2$, then the second term inside the bracket is nonnegative and $\bar{x}(\frac{1}{2}, \frac{1}{2}, \gamma) > \bar{x}(\frac{1}{2}, 1, \gamma)$. If $\eta^2 < 2$, the two terms inside the square bracket are jointly minimized at $\gamma = 1$ as $2(\eta - 1) > 0$. Therefore, we still have $\bar{x}(\frac{1}{2}, \frac{1}{2}, \gamma) > \bar{x}(\frac{1}{2}, 1, \gamma)$. The desired result then follows from the continuity of $\bar{x}(\lambda_A, \lambda_R, \gamma)$. \square