Monitoring the market or the salesperson? The value of information in a multi-layer supply chain*

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Abstract

We study a supply chain in which a manufacturer relies on a salesperson to sell the products to the consumers. The sales outcome is determined by a random market condition and the salesperson's service level, both of which are privately observed by the salesperson. Apart from them, there are two types of resellers: a knowledgeable reseller observes the market condition, whereas a diligent reseller can monitor the service level. While delegating to a reseller enhances information acquisition, it may also result in double marginalization and supply chain inefficiency. We identify several operating regimes in which double marginalization can be eliminated via simple contracts and establish the benefit of monitoring the salesperson over monitoring the market. Our dominance result is not prone to our model characteristics regarding the complementarity of market condition and sales effort, the relative importance of adverse selection and moral hazard, and the contract form. We then generalize our model and re-establish the dominance result in the presence of reseller's risk aversion or private monitoring expertise. We also quantify the performance gaps among different selling schemes under various scenarios.

Keywords: multi-layer supply chain, partner selection, salesforce compensation, information asymmetry.

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1 Introduction

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 example, the Taiwanese computer manufacturer Acer and the Korean manufacturer Samsung both sell their products in the United States and Europe. Furthermore, they delegate the sales business to large-scale national *resellers,* such as importers, wholesalers, and retailers, in order to run this global business. These independently-managed resellers purchase products from the manufacturer and sell those products to consumers through local salespeople. In the case of computers and consumer electronics, Best Buy is one of the most important partners of Acer and Samsung in North America. It helps these overseas manufacturers to distribute products through its retail stores and salespeople. Manufacturers, national resellers, and local salespeople together form a global supply chain.

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, incentives may be misaligned as they optimize their own objectives. This results in the well-documented double marginalization problem, 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. One generally recognized reason to include a reseller is because they can better manage local salespeople, who face end consumers directly and may increase the sales outcome by offering better services. In the absence of resellers, the sales outcome is usually the only instrument available for the overseas manufacturer to measure the service level. However, the sales outcome is determined not only by the service level but also by the market condition. The manufacturer who looks solely at 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 a lower effort level and bring a bad service 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 service level. Due to the close contact with the target market and those local salespeople, resellers are able to achieve more precise demand forecasting and performance measurement than the manufacturer. Because the manufacturer would collaborate with a reseller who can create the higher sales quantity by delivering better services, resellers commonly develop their monitoring expertise to increase their chance of being delegated. This makes Business Intelligence (BI) systems, which generally provide demand forecasting and performance measurement as the main components, popular among large-scale resellers.[1] For 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. In general, BI systems allow these resellers to obtain more precise information and design a more accurate compensation scheme than the manufacturer. Resellers can thus better manage local salespeople and deliver more satisfactory services to end consumers. This helps the supply chain attract more consumers and allows the manufacturer to reach a higher sales volume.

This paper investigates the strategic impacts of resellers on such a global supply chain from the informational perspective. To this end, we study a three-layer supply chain with a manufacturer, a reseller, and a salesperson. In the absence of the reseller, the manufacturer implements direct sales and faces two well-documented 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 service level (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. As there are two distinct functions of the contemporary BI systems – demand forecasting and performance measurement, we consider two types of resellers in our model: The "*knowledgeable*" reseller who can predict the market condition with an advanced demand forecasting system, and the "*diligent*" reseller who is able to measure the salesperson's service level with her performance measurement expertise.[2] Convoluted with the reseller's salesforce compensation problem, our main research question is the manufacturer's partner selection problem: *Which type of reseller is more beneficial?*[3]

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[1]One example is SAS Retail Intelligence, the BI solution developed by SAS for the retailing industry (http://www.sas.com/industry/retail/ris.html).

[2]Although 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.

[3]In practice some resellers lie in between the two extreme types: They can predict demand and measure services,

The three-layer supply chain in our paper is distinct from the existing literature. First, due to the decentralized nature, the manufacturer makes the partner selection decision and the reseller makes the salesforce compensation decision. Compared with the conventional centralized setting, this decentralized scenario seems to fit better to our global supply chain context and apparently leads to more challenging issues from both theoretical and practical aspects. Second, we should emphasize that from the manufacturer's perspective, including a reseller with a specific monitoring ability may be *different* from having this ability by itself. This is because the reseller will apply her monitoring expertise in her own interest rather than for the manufacturer or the supply chain. As the manufacturer can only indirectly acquire the private information through the reseller, it also faces a contract design problem. If their objectives are not aligned, including the reseller results in double marginalization and lowers the manufacturer's expected profit.

We study those factors that allow or disallow the manufacturer to align the reseller's and its objectives. Specifically, we start with the basic setting in which the manufacturer faces no information asymmetry vis-a-vis the reseller and both of them are risk-neutral. Under this setting, we show that *the diligent reseller is more beneficial* for the manufacturer for the following two reasons. First, because in the manufacturer-reseller relationship the risk attitudes are identical, the manufacturer is able to align their objectives and completely "sell the business" to both types of resellers through the optimal two-part tariff. This optimal contract passes all the risk to the reseller and completely eliminates double marginalization even if the reseller is endowed with her own informational expertise. Second, in motivating the salesperson, the diligent reseller induces a better service than the knowledgeable reseller does, as performance measurement is more direct in inducing a higher service level than demand forecasting. Interestingly, no matter which reseller to delegate, *indirect sales outperforms direct sales.* This shows that a reseller's monitoring helps the manufacturer mitigate information asymmetry vis-a-vis the salesperson. Moreover, this result holds for different degrees of complementarity of service level and market condition, different relative importance of adverse selection and moral hazard, and multiple contract forms.

It should be noted that in our model the manufacturer can never observe the salesperson's private information directly. This assumption is adopted to make our model fit the practical situations: It is extremely difficult, if not impossible, for overseas manufacturers to collect information

both imperfectly. We choose to study the binary accuracy decision because such a novel comparison allows us to draw clear managerial implications. In addition, if the accuracy decision is continuous, it will be a trivial trade-off of the marginal cost/benefit of the two abilities. Since improving accuracy becomes more expensive when the monitoring is more accurate, a reseller should invest in one function if and only if it is still cost-effective. Even if the two functions are dependent, the problem just changes from two one-dimensional searches to a two-dimensional search.

in local markets. Nevertheless, it is still natural to ask whether direct monitoring brings any additional benefit to the manufacturer. By allowing the manufacturer to see those private information under direct sales, we may investigate the benefit of direct monitoring. Under our basic setting, we show that direct monitoring is equivalent to indirect monitoring, i.e., becoming a "knowledgeable (resp., diligent) manufacturer" generates the same expected sales as delegating to a knowledgeable (resp., diligent) reseller. This implies that delegation does not introduce any inefficiency. Therefore, the manufacturer needs not invest a lot in building its own monitoring expertise and should simply delegate the selling business to the reseller instead. This result thus offers a justification for the prevalence of indirect sales in practice.

To isolate the above dominance result and the elimination of double marginalization, we introduce a select set of model frictions and investigate our research question in three different extended scenarios. Specifically, we consider three cases in which the monitoring expertise is not observable, the reseller is risk-averse with a negative exponential utility function, and the reseller is protected by limited liability. In each of these cases, sell-out contracts cannot be used to facilitate the first-best outcome: resellers' private information forces the information rent left by the manufacturer, risk aversion avoids the manufacturer from passing all the risks to the reseller, and limited liability protects the reseller from paying a high franchise fee. In the presence of the above frictions, it is a priori unclear whether the intuitive arguments from the conventional two-layer supply chain can be directly applied. Nevertheless, our results give an *affirmative* answer as well: Including the diligent reseller is still more beneficial than including the knowledgeable one or direct sales in all the extended scenarios. This rather surprising conclusion provides a managerial implication to the manufacturer's partner selection decision and suggests how resellers should build their monitoring abilities.

Our three-layer supply chain is analytically different from a two-layer one, as it allows us to incorporate the aforementioned resller-related issues in the three-layer setting. We further investigate the performance gaps among direct sales and the two ways of delegation under various situations. Because in practice different fixed costs may be needed in implementing different strategies, quantifying these gaps helps the manufacturer choose the optimal supply chain configuration. Through analytical derivations and numerical experiments, we find that the gap between the two resellers decreases when adverse selection becomes relatively more important, the reseller becomes more risk-averse, or demands and services become complementary and the market size goes down. Interestingly, because the efficiency of direct sales does not depend on the reseller, direct sales may outperform both indirect selling schemes when the reseller is highly risk-averse. It is thus critical for the manufacturer to take these issues into consideration when designing the selling scheme.

The multi-layer supply chain design considered in our paper 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., Baron and Besanko (1992), Melumad et al. (1992), and the survey paper Mookherjee (2006)). 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 in Faure-Grimaud et al. (2000), Kessler (2000), Felli and Villas-Boas (2000), McAfee and McMillan (1995), and Strausz (1997). However, Faure-Grimaud et al. (2000) and McAfee and McMillan (1995) assume that the middleman is as uninformed as the principal. Consequently, the principal is worse off when the middleman is either risk-averse or faces a limited liability constraint. As in our paper, Kessler (2000), Felli and Villas-Boas (2000), and Strausz (1997) assume that the middleman is able to monitor the agent's action (effort). Nevertheless, their focus was on either the commitment or collusion issue. Moreover, since we include both the knowledgeable and diligent resellers, we go beyond these studies to compare between monitoring the agent's hidden information (market condition) and hidden action (service level).

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 (Villas-Boas (2004)), managerial compensation schemes (Chen (2005)), supply chain contracting (Cachon and Zhang (2006), Iyer et al. (2005), and Taylor and Xiao (2009)), and auctions (Huh and Park (2010), Li and Debo (2009), Vulcano et al. (2002), Wan and Beil (2009) and Zhou et al. (2009)). In strict 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). There have been some recent papers that investigate different formats of incentive structures such as the stair-step (threshold) sales incentive used in the automotive industry. For example, Sohoni et al. (2011) consider the scenario in which the dealer is paid on a per unit basis when the total sales exceeds a threshold value; a fixed bonus may also be offered. In a dynamic setting, Sohoni et al. (2010) investigate the hockey stick phenomenon commonly observed in practice. Specifically, they argue that the stair-step sales incentive may give rise to an intrinsic incentive for the dealer to exert a large effort at the end period in order to boost the sales and meet the threshold. The three-tier channel structure studied in our paper is not explored in these papers.

The rest of this paper is organized as follows. In Section 2, we describe the basic model setting.

Section 3 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 4. Performance gaps among different strategies under various environments are analyzed in Section 5. Finally, we draw conclusions in Section 6. All proofs are in the Appendix.

2 Model

We consider a supply chain in which a manufacturer (it) relies on the salesperson (he) to sell its products. The manufacturer has ample (unlimited) capacity of the product, and can deliver the products to the salesperson after demand is realized. Thus, the supply chain is operated in a "*make-to-order*" (MTO) manner. 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 service level a, and a random noise ϵ in the following additive form:

$$x = \theta + a + \epsilon, \tag{1}$$

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 service level and the market condition are independent. Another setting is that good services 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 3.5.1. We assume that the salesperson incurs a cost $V(a) = \frac{1}{2}a^2$ for choosing service 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 3.5.2 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 service 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, the manufacturer directly sees a reseller's expertise; the case with unobservable reseller's expertise is investigated in Section 4.1. 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 (1), the cost of services $\frac{1}{2}a^2$, 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. 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 and then generalize our results to risk-averse resellers in Section 4. In particular, we consider two ways to represent risk aversion: negative exponential utility functions (in Section 4.2) and limited liability (Section 4.3). 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, 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 merely a fixed franchise fee). Because wholesale contracts are also pervasive in industry, the relevant analysis is included in Section 4.3 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 (see, e.g., Chen (2005), Green and Stokey (1983), and Holmstrom and Milgrom (1991)). 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, see, e.g., Lal and Staelin (1986), Mishra and Prasad (2004), and Rao (1990).

3 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.

3.1 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 service 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 observed θ but has chosen the contract $(\alpha(\tilde{\theta}), \beta(\tilde{\theta}))$. By choosing service 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 $N\left(\alpha + \beta(\theta + a) - \frac{1}{2}a^2, \sigma^2\beta^2\right)$. Given $z(a)$, the salesperson's expected utility is $\mathbb{E}\left[-e^{-\rho z(a)}\right] = -e^{-\rho CE_S(\theta,\tilde{\theta}|a)}$, 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 solves

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

$$\text{s.t.} \quad CE_S(\theta) \geq CE_S(\theta, \tilde{\theta}), \quad \forall \theta, \tilde{\theta} \in (-\infty, \infty), \tag{2}$$

$$CE_S(\theta) \geq 0, \quad \forall \theta \in (-\infty, \infty), \tag{3}$$

where "*urs*" stands for "unrestricted in sign" as a commonly adopted convention of optimization literature. The incentive compatibility (IC) constraint (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) ensures the participation of the salesperson (because his reservation wage is zero). With $y^+ \equiv \max(0, y)$, 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 service level* $a^*(\theta) = \beta^*(\theta)$ *and receives an expected profit* $M^* = \mathbb{E}_\theta \left[\theta + \frac{\left[[1-H(\theta)]^+\right]^2}{2(1+\rho\sigma^2)} \right]$.

As indicated by Lemma 1, the mixture of adverse selection and moral hazard problems gives rise to an inefficient service 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 service level as well as a liability for the manufacturer (as seen from its expected profit M^*). Note that $\beta^*(\theta)$ may be 0 when θ is small enough such that $H(\theta) \geq 1$. In this case, the induced effort level will be 0, which means the salesperson will not exert any effort. In situations that a minimum service level is required, the degree of downward distortion should be limited.

3.2 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 service 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 service 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 service 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

$$R^K(\theta) = \max_{\alpha \text{ urs}, \beta \geq 0} \left\{ u - \alpha + (v - \beta)(\theta + \beta) \;\middle|\; \text{s.t. } \alpha + \beta\theta + \frac{1}{2}\beta^2(1 - \rho\sigma^2) \geq 0 \right\},$$

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 service 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 provide services. 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 provide better services. Notably, this quantity decreases as the cost of inducing better services 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 service 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

$$M^K = \max_{u \text{ urs}, v \geq 0} \Big\{ (1-v)(\mu + \frac{1}{1+\rho\sigma^2}v) - u \;\Big|\; \text{s.t. } u + v\mu + \frac{1}{2(1+\rho\sigma^2)}v^2 \geq 0 \Big\}.$$

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 3.5.3. 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 service 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 service 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 service 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.

3.3 Diligent reseller

Recall that a diligent reseller is able to observe the service level and therefore can specify the required service 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 service 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

$$CE_S^D(\theta,\tilde{\theta}) = \alpha(\tilde{\theta}) + \beta(\tilde{\theta})(\theta + a(\tilde{\theta})) - \frac{1}{2}[a(\tilde{\theta})]^2 - \frac{1}{2}\rho\sigma^2[\beta(\tilde{\theta})]^2 \tag{4}$$

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

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

$$\text{s.t.} \quad CE_S^D(\theta) \geq CE_S^D(\theta,\tilde{\theta}) \quad \forall \theta, \tilde{\theta} \in (-\infty,\infty) \tag{5}$$

$$CE_S^D(\theta) \geq 0 \quad \forall \theta \in (-\infty,\infty). \tag{6}$$

The IC constraint (5) requires truth-telling and the IR constraint (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 service level v and compensate the salesperson just his cost of providing services ($\frac{1}{2}v^2$). 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 service level as long as he receives a sufficient fixed payment, the reseller can implement the first-best service level. Finally, due to the additive form of sales outcome (1), the marginal cost/benefit of providing service 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

$$M^K = \max_{u \text{ urs}, v\geq 0} \left\{ (1-v)\,(\mu + v) - u \;\middle|\; \text{s.t. } u + v\mu + \frac{1}{2}v^2 \geq 0 \right\},$$

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.

[4]When the effects of service level and market condition are not independent, the optimal contract will no longer be a single contract. In Section 3.5.1 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 4.2, when the reseller is risk-averse, zero commission rate will not be optimal and her risk attitude will affect the contract offered.

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 service 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 service level (1) for the whole supply chain. Also note that in the reseller-salesperson relationship, no service 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.

3.4 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 better services. 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.

Note that the diligent reseller is more effective than the knowledgeable reseller in inducing better services. 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 service distortion arises. Though the hidden market condition amplifies service 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 service level will be distorted downwards. Since the overall supply chain performance is determined by the service level, the dominance of $a^D(\theta)$ over $a^K(\theta)$ implies that delegating to a diligent reseller is more beneficial from the system's perspective.

This distortion on service 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 double marginalization argument (see, e.g., Coughlan et al. (2001), Jeuland and Shugan (1983), Lee and Staelin (1997), and Spengler (1950)). 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 better service 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.*

3.5 Discussions

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

3.5.1 Complementarity between demand and services

In certain scenarios, it is possible that a better service 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 better services becomes higher as well (cf. the marginal benefit of offering better services is independent of the market condition in the additive form (1)). Thus, monitoring the market allows the knowledge reseller to evaluate how effective the salesperson's services are, whereas the diligent reseller can only enforce appropriate services 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 service 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 $\frac{1}{2}E_\theta\left[\theta^2\right]$, 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.

3.5.2 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 providing services by setting $V(a) = \frac{1}{2k}a^2$, where $k \in (0, \infty)$. When k is scaled up from 1, the efficient service level increases since the cost decreases. Therefore, inducing better services 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 service level becomes more costly and less effective; on the extreme case, the service 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 service level and obtain a higher profit if contracting with the diligent reseller. 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 service 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 service level. The dominance result thus continues to be valid.

[5] Another 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 providing better services.

3.5.3 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 service 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.

3.5.4 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 Mirrlees (1974), 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 service 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.

3.5.5 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 3.1 and allow the manufacturer to directly observe either the market or the service 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 (resp., service level) directly, the manufacturer generates the same expected profit as delegating to the knowledgeable (resp., diligent) reseller.*[6]

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.

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[6]We use "resp." as the abbreviation for "respectively" throughout this paper.

4 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 should be reinvestigated. Remarkably, in all these variants, we still establish the clear-cut preference on the diligent reseller.

4.1 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:

$$u_s^K + v_s^K \mu + \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2 \geq u_s^D + v_s^D \mu + \frac{1}{2(1+\rho\sigma^2)}(v_s^D)^2, \tag{7}$$

$$u_s^D + v_s^D \mu + \frac{1}{2}(v_s^D)^2 \geq u_s^K + v_s^K \mu + \frac{1}{2}(v_s^K)^2. \tag{8}$$

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:

$$u_s^K + v_s^K \mu + \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2 \geq 0, \tag{9}$$

$$u_s^D + v_s^D \mu + \frac{1}{2}(v_s^D)^2 \geq 0. \tag{10}$$

In equilibrium, the manufacturer's menu of contracts must induce the reseller's truth-telling. While delegating to the knowledgeable reseller, the induced service 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 service level is v_s^D; the expected sales and the manufacturer's expected profit are $\mu+v_s^D$ and $(1-v_s^D)\left(\mu+v_s^D\right)-u_s^D$, 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:

$$\max_{\substack{u_s^K \text{ urs, } v_s^K \geq 0,\\ u_s^D \text{ urs, } v_s^D \geq 0}} \quad p\Big[(1-v_s^K)(\mu+\tfrac{1}{1+\rho\sigma^2}v_s^K)-u_s^K\Big]+(1-p)\Big[(1-v_s^D)(\mu+v_s^D)-u_s^D\Big]$$

$$\text{s.t.} \quad (7)\text{ - }(10),$$

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*

$$v_s^K=\frac{1}{1+(1-p)\rho\sigma^2/p}, \qquad u_s^K=-v_s^K\mu-\frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2,$$
$$v_s^D=1, \qquad \textit{and} \;\; u_s^D=-\mu-\frac{1}{2}+\left[\frac{1}{2}-\frac{1}{2(1+\rho\sigma^2)}\right](v_s^K)^2$$

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 service 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 the 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 service level, since it calls for the celebrated double marginalization problem. As a result, upon delegating to the knowledgeable reseller, now the induced service 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 service 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 service level. Hence, a diligent reseller is awarded some information rents in return.

4.2 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 service 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

$$CE_R^K(\theta) = \max_{\alpha \text{ urs},\beta\geq 0} \left\{ u - \alpha + (v - \beta)(\theta + \beta) - \frac{1}{2}r(v - \beta)^2\sigma^2 \;\middle|\; \text{s.t. } CE_S(\theta) \geq 0 \right\}.$$

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

$$M_A^K(r) = \max_{u \text{ urs},v\geq 0} \left\{ \mathbb{E}_\theta \left[(1 - v)\left(\theta + \beta_A^K(\theta)\right) - u\right] \;\middle|\; \text{s.t. } \mathbb{E}_\theta \left[CE_R^K(\theta)\right] \geq 0 \right\},$$

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 service 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 service 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 service 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 (4), her problem is

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

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* $\overline{M}_A^D(r) = \mu + \frac{1}{2(1+r\sigma^2)}$*, 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 service 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 service level $a_A^D(\theta)$, the manufacturer obtains the same expected profit $\overline{M}_A^D = (1 - \bar{v}_A^D)(\mu + a_A^D(\theta)) - \bar{u}_A^D$ 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 $\overline{M}_A^D$ is a lower bound of the manufacturer's maximum expected profit. Finally, $\overline{M}_A^D = \mu + \frac{1}{2(1+r\sigma^2)}$ 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

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

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 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 5.2, 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. Figure 1 summarizes the relationship among expected profits the manufacturer may gain, where an arc (i, j) indicates that i is always larger than j.

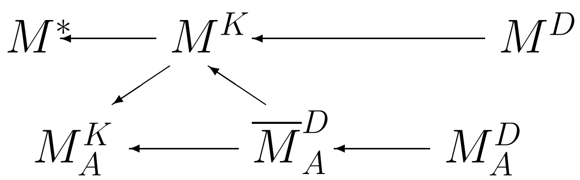

Figure 1: Relationship among manufacturer's expected profits

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.

4.3 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 a 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 service level is still $\frac{1}{1+\rho\sigma^2}v$. Therefore, the manufacturer's problem while contracting with the knowledgeable reseller becomes

$$M_L^K(B) = \max_{u \text{ urs}, \, v \geq 0} \Big\{(1-v)(\mu + \frac{1}{1+\rho\sigma^2}v) \;\Big|\; \text{s.t. } u + v\mu + \frac{1}{2(1+\rho\sigma^2)}v^2 \geq 0, u \geq B\Big\} \qquad (11)$$

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

$$M_L^D(B) = \max_{u \text{ urs}, \, v \geq 0} \Big\{(1-v)(\mu + v) \;\Big|\; \text{s.t. } u + v\mu + \frac{1}{2}v^2 \geq 0, u \geq B\Big\}. \qquad (12)$$

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 (11), there exists a feasible solution for (12) that leads to a better outcome. This is clearly true: The feasible region for (11) is a subset of that for (12) and any feasible solution for (11) generates a smaller objective value for (11) than for (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.

5 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 services.

5.1 Relative importance of adverse selection and moral hazard

When the salesperson's cost of exerting service level a is $V(a) = \frac{1}{2k}a^2$ (cf. Section 3.5.2), 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 $M^*(k) = \mu + \mathbb{E}\left[\frac{\left[[k-H(\theta)]^+\right]^2}{2(k+\rho\sigma^2)}\right]$ 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

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

which implies that the performance gaps diminish as k approaches 0. Roughly speaking, as the service 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.

5.2 Negative exponential utility functions

Recall that we define $r \in (0, \rho]$ as the resellers' coefficient of absolute risk aversion in Section 4.2. 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 $M_A^K(r)$, $M_A^D(r)$, and M^* in Figure 2. The difference $M_A^D(r) - M_A^K(r)$ is drawn in Figure 3. This example contains all those interesting observations discussed below.

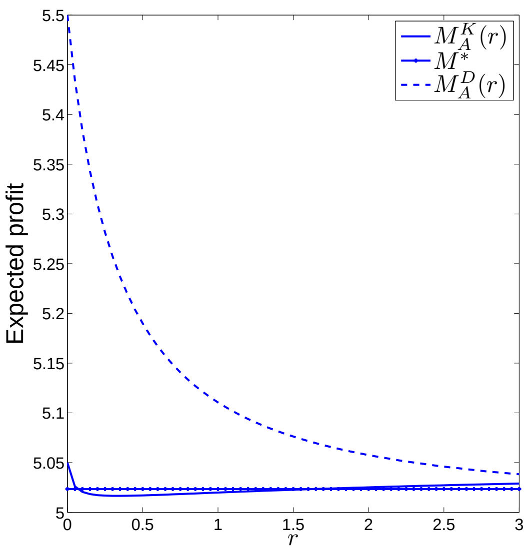

Figure 2: $M_A^D(r)$, $M_A^K(r)$, and M^*

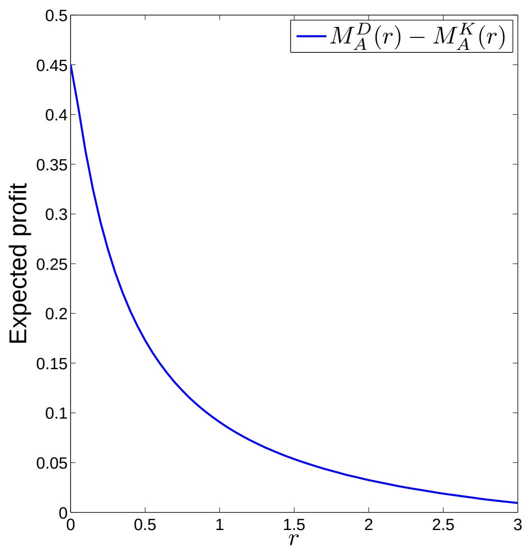

Figure 3: $M_A^D(r) - M_A^K(r)$

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 4.2, $M_A^K(r)$ 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.

5.3 Limited liability

When the manufacturer is limited in the amount of franchise fee it can charge, we have shown in Section 4.3 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 (11) and (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 already dominated the knowledgeable one.

Proposition 8. *There exists a lower bound $\hat{\mu} > 0$ such that the following is true: 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 $u \geq L$ and result in less effective delegation. Direct sales will then become more profitable.

5.4 Complementarity between demand and services

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 services are complementary, different realizations of the market condition drive the salesperson to choose different service 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 and a fixed variance, $M^D - M^K$ increases in μ.*

When the manufacturer delegates to the diligent reseller in a big market, the complementarity allows her to induce a high service 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.

6 Conclusions

In this paper, 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 service 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.

Our study certainly has its limitations. In our study, 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 in order to induce better truth-telling. Price and commission rate can therefore serve as complementary screening tools. Another possible extension is to investigate a variety of contract forms (e.g., buy-back contracts, advance purchase contracts, and quantity flexibility contracts) and see how they affect the strategic decisions of the manufacturer and resellers. 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, since these manufacturers may compete in contract offers in order to earn the collaboration opportunity with a specific reseller. This issue calls for future investigations.

Appendix

Proof of Lemma 1. It follows from the first-order necessary condition of the IC constraint (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) 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. □

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 service level $a^K(\theta) = \frac{1}{1+\rho\sigma^2}v$. Consequently, $R^K(\theta) = u + v\theta + \frac{1}{2(1+\rho\sigma^2)}v^2$. □

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 service level is $\frac{1}{1+\rho\sigma^2}$, regardless of θ. □

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 (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 service 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. □

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 service level is 1. □

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 service 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 service level $\beta\theta$, the expected sales outcome is $\beta\theta^2$. The knowledgeable reseller is then solving

$$R^K(\theta) = \max_{\alpha \text{ urs}, \beta\geq 0} \left\{ u - \alpha + (v-\beta)\beta\theta^2 \;\middle|\; \text{s.t. } \alpha + \frac{1}{2}(\theta^2 - \rho\sigma^2)\beta^2 \geq 0 \right\}.$$

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

$$M^K = \max_{u \text{ urs}, v\geq 0} \left\{ \gamma(1-v)v - u \;\middle|\; \text{s.t. } u + \frac{1}{2}\gamma v^2 \geq 0 \right\}.$$

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

With the definition $CE_S(\theta) = CE_S(\tilde{\theta}, \theta)$, the reseller's problem is

$$\begin{aligned} R^D = \max_{\{\alpha(\theta) \text{ urs}, \beta(\theta)\geq 0, a(\theta)\geq 0\}} \quad & \mathbb{E}_\theta \Big\{ u - \alpha(\theta) + (v - \beta(\theta))\theta a(\theta) \Big\} \\ \text{s.t.} \quad & CE(\theta) \geq CE(\tilde{\theta}, \theta) \quad \forall \theta \in (-\infty, \infty) \\ & CE(\theta) \geq 0 \quad \forall \theta \in (-\infty, \infty). \end{aligned}$$

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 $R^D = \max_{\{a(\theta)\geq 0\}} \mathbb{E}_\theta \left[u + v\theta a(\theta) - \frac{1}{2}a(\theta)^2 \right] = u + \frac{1}{2}E[\theta^2]v^2$ with the maximizer $a^D(\theta) = v\theta$. With such R^D, the manufacturer's problem is

$$M^D = \max_{u \text{ urs}, v\geq 0} \Big\{ (1 - v)\mathbb{E}_\theta[\theta^2]v - u \;\Big|\; \text{s.t. } u + \frac{1}{2}\mathbb{E}_\theta[\theta^2]v^2 \geq 0 \Big\}.$$

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 $M^D = \frac{1}{2}\mathbb{E}_\theta \left[\theta^2\right] = \frac{1}{2}\mathbb{E}_\theta \left[\frac{\theta^4}{\theta^2}\right] \geq \frac{1}{2}\mathbb{E}_\theta \left[\frac{\theta^4}{\theta^2 + \rho\sigma^2}\right] = M^K$, which concludes that delegating to a diligent reseller is more profitable for the manufacturer. □

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 $R^D = \mathbb{E}_\theta\left[u + v\theta + \frac{k}{2}v^2\right]$ 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, we have $M^D = \mu + \frac{k}{2} \geq \mu + \frac{k^2}{2(k+\rho\sigma^2)} = M^K$. □

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 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 service level a, its problem is equivalent to the diligent reseller's problem in Section 3.3 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. □

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 $\mathbb{E}_\theta\left[CE_R^K(\theta)\right] = 0$ at optimality 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. □

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

$$CE_R^D = \max_{\substack{\{\beta(\theta)\geq 0,\\ a(\theta)\geq 0\}}} \mathbb{E}_\theta\left[u + v\theta + a(\theta)v - \frac{1}{2}\left[r(v-\beta(\theta))^2\sigma^2 + [a(\theta)]^2 + \rho[\beta(\theta)]^2\sigma^2 \right] - H(\theta)\beta(\theta) \right]. \quad (13)$$

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 $\bar{\beta}^D(\theta) = 0$ 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 (13). To contract with the weak diligent reseller, the manufacturer solves

$$\overline{M}_A^D = \max_{u \text{ urs}, v \geq 0} \left\{ (1-v)(\mu+v) - u \;\middle|\; \overline{CE}_R^D \geq 0 \right\}. \tag{14}$$

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

$$M_A^D = \max_{u \text{ urs}, v \geq 0} \left\{ (1-v)(\mu+v) - u \;\middle|\; CE_R^D \geq 0 \right\}. \tag{15}$$

The fact $CE_R^D \geq \overline{CE}_R^D$ implies the feasible region of (15) is no smaller than that of (14). Since these two problems also have an identical objective function, we have $M^D \geq \overline{M}^D$. □

Proof of Proposition 5. First we observe from (8) and (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 (10) is redundant. Furthermore, if we ignore (7) for a moment, the relaxed manufacturer's problem becomes:

$$\begin{aligned}
\max_{\substack{u_s^K \text{ urs}, v_s^K \geq 0,\\ u_s^D \text{ urs}, v_s^D \geq 0}} \quad & p\Big(1 - v_s^K)(\mu + \frac{1}{1+\rho\sigma^2}v_s^K) - u_s^K\Big] + (1-p)\Big[(1-v_s^D)(\mu+v_s^D) - u_s^D\Big] && (16)\\
\text{s.t.} \quad & u_s^D + v_s^D\mu + \frac{1}{2}(v_s^D)^2 \geq u_s^K + v_s^K\mu + \frac{1}{2}(v_s^K)^2, && (17)\\
& u_s^K + v_s^K\mu + \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2 \geq 0. && (18)
\end{aligned}$$

We first observe that at optimality (18) must be binding; otherwise, decreasing u_s^K a bit yields a higher expected payoff for the manufacturer while relaxing (17). Likewise, we can show that (17) 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

$$\begin{aligned}
u_s^K &= -v_s^K\mu - \frac{1}{2(1+\rho\sigma^2)}(v_s^K)^2,\\
u_s^D &= -v_s^D\mu - \frac{1}{2}(v_s^D)^2 + (\frac{1}{2} - \frac{1}{2(1+\rho\sigma^2)})(v_s^K)^2,
\end{aligned}$$

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 $u_s^D = -\mu - \frac{1}{2} + (\frac{1}{2} - \frac{1}{2(1+\rho\sigma^2)})(v_s^K)^2$. The knowledgeable reseller receives zero expected payoff since (18) 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 (7) is satisfied under this menu of contracts. Finally, the induced service levels $a_s^K(\theta)$ and $a_s^D(\theta)$ follow from Propositions 3 and 5. □

Proof of Proposition 7. Given B, it is straightforward to show that the optimal solutions for (11) is $(u^K(B), v^K(B)) = (-\mu-\frac{\eta}{2}, 1)$ if $B \le -\mu-\frac{\eta}{2}$ and $\left(B, \max\left\{\frac{\eta-\mu}{2\eta}, \frac{-\mu+\sqrt{\mu^2-2\eta B}}{\eta}\right\}\right)$ otherwise, where $\eta \equiv \frac{1}{1+\rho\sigma^2} \in (0,1]$. Similarly, the optimal solution for (12) is $(u^D(B), v^D(B)) = (-\mu-\frac{1}{2}, 1)$ if $B \le -\mu - \frac{1}{2}$ and $\left(B, \max\left\{\frac{1-\mu}{2}, -\mu+\sqrt{\mu^2-2B}\right\}\right)$ otherwise. Now we discuss three cases: $B \in (-\infty, \le -\mu-\frac{1}{2}]$, $B \in (-\mu-\frac{1}{2}, \le -\mu-\frac{\eta}{2}]$, 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 $u \ge B$ 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

$$M_L^D(B) - M_L^K(B) = (1-\mu)v^D(B) - (v^D(B))^2 - (\eta-\mu)v^K(B) + \eta(v^K(B))^2. \quad (19)$$

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 (19) 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 $\frac{\partial}{\partial B}(M_L^D(B) - M_L^K(B)) = \frac{-1-\mu}{\sqrt{\mu^2-2B}} + \frac{\eta+\mu}{\sqrt{\mu^2-2\eta B}} \le 0$ 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 $\frac{\eta-\mu}{2\eta} \le \frac{-\mu+\sqrt{\mu^2-2\eta B}}{\eta}$. 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 $\frac{1-\mu}{2} \le -\mu+\sqrt{\mu^2-2B}$, which then implies $\frac{\eta-\mu}{2\eta} \le \frac{-\mu+\sqrt{\mu^2-2\eta B}}{\eta}$ due to $-\mu+\sqrt{\mu^2-2B} \le \frac{-\mu+\sqrt{\mu^2-2\eta B}}{\eta}$ (as the right-hand side decreases in η) and $\frac{1-\mu}{2} \ge \frac{\eta-\mu}{2\eta}$. It then follows that $v^K(B)$ cannot be $\frac{\eta-\mu}{2\eta}$. □

Proof of Proposition 8. For any $\mu \ge 1$, 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. □

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

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

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

References

Baron, D., D. Besanko. 1992. Information, control, and organizational structure. *Journal of Economics and Management Strategy* **1** 237–275.

Cachon, G., F. Zhang. 2006. Procuring fast delivery: Sole-sourcing with information asymmetry. *Management Science* **52** 881–896.

Chen, F. 2005. Salesforce incentives, market information, and production/inventory planning. *Management Science* **51** 60–75.

Coughlan, A., E. Anderson, L. Stern, A. EL-Ansary. 2001. *Marketing Channels*. Pearson Education, Inc., USA.

Faure-Grimaud, A., J. Laffont, D. Martimort. 2000. A theory of supervision with endogenous transaction costs. *Annals of Economics and Finance* **1** 231–263.

Felli, L., J. M. Villas-Boas. 2000. Renegotiation and collusion in organizations. *Journal of Economics and Management Strategy* **9**(4) 453–483.

Green, J., N. Stokey. 1983. A comparison of tournaments and contracts. *Journal of Political Economy* **91**(6) 349–364.

Holmstrom, B., P. Milgrom. 1991. Multitask principal-agent analyses: Incentive contracts, asset ownership, and job design. *Journal of Law, Economics and Organization* **7** 24–52.

Huh, W.T., K.S. Park. 2010. A sequential auction-bargaining procurement model. *Naval Research Logistics* **57**(1) 13–32.

Iyer, A., V. Deshpande, Z. Wu. 2005. Contingency management under asymmetric information. *Operations Research Letters* **33**(6) 572–580.

Jeuland, A., S. Shugan. 1983. Managing channel profits. *Marketing Science* **2** 239–272.

Kessler, A. 2000. On monitoring and collusion in hierarchies. *Journal of Economic Theory* **91**(2) 280–291.

Lal, R., R. Staelin. 1986. Salesforce compensation plans in environments with asymmetric information. *Marketing Science* **5**(3) 179–198.

Lee, E., R. Staelin. 1997. Vertical strategic interaction: Implications for channel pricing strategy. *Marketing Science* **16**(3) 185–207.

Li, C., L.G. Debo. 2009. Strategic dynamic sourcing from competing suppliers with transferable capacity investment. *Naval Research Logistics* **56**(6) 540–562.

McAfee, R., J. McMillan. 1995. Organizational diseconomies of scale. *Journal of Economics & Management Strategy* **4**(3) 399–426.

Melumad, N., D. Mookherjee, S. Reichelstein. 1992. A theory of responsibility centers. *Journal of Accounting and Economics* **15** 445–484.

Mirrlees, J. 1974. Notes on welfare economics, information and uncertainty. *Essays on Economic Behavior under Uncertainty* 243–261.

Mishra, B., A. Prasad. 2004. Centralized pricing versus delegating pricing to the salesforce under information asymmetry. *Marketing Science* **23**(1) 21–28.

Mookherjee, D. 2006. Decentralization, hierarchies, and incentives: A mechanism design perspective. *Journal of Economic Literature* **44**(2) 367–390.

Rao, R. 1990. Compensating heterogeneous salesforces: Some explicit solutions. *Marketing Science* **9**(4) 319–341.

Sohoni, M.G., A. Bassamboo, S. Chopra, U. Mohan, N. Sendil. 2010. Threshold incentives over multiple periods and the sales hockey stick phenomenon. *Naval Research Logistics* **57**(6) 503–518.

Sohoni, M.G., S. Chopra, U. Mohan, N. Sendil. 2011. Threshold incentives and sales variance. Forthcoming in Production and Operations Management.

Spengler, J. 1950. Vertical integration and antitrust policy. *Journal of Political Economy* **58** 347.

Strausz, R. 1997. Delegation of monitoring in a principal-agent relationship. *Review of Economic Studies* **64**(3) 337–57.

Taylor, T.A., W. Xiao. 2009. Incentives for Retailer Forecasting: Rebates vs. Returns. *Management Science* **55**(10) 1654–1669.

Villas-Boas, J.M. 2004. Communication strategies and product line design. *Marketing Science* 304–316.

Vulcano, G., G. van Ryzin, C. Maglaras. 2002. Optimal dynamic auctions for revenue management. *Management Science* **48**(11) 1388–1407.

Wan, Z., D.R. Beil. 2009. RFQ auctions with supplier qualification screening. *Operations Research* **57**(4) 934–949.

Zhou, S. X., Z. Tao, N. B. Zhang, G. Cai. 2009. Reverse auction procurement with flexible non-competitive contracts. Working paper, Chinese University of Hong Kong.