Price delegation and salesforce contract design with asymmetric risk aversion coefficient of sales agents

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Abstract

An important issue that has attracted the interest of academics and practitioners in both marketing and operations is, should pricing decisions be made by the firm or delegated to the salesforce? This problem has been addressed in the research literature based on the assumption that the exact risk aversion coefficients of the sales agents are known to the firm, which may not be true in most applications. In this paper, we study this problem but assuming that the risk aversion coefficients of agents are private information of the sales agents. For both centralized pricing and delegated pricing settings, the optimal compensation and pricing contracts are designed and the sensitivity analyses are conducted. An interesting finding is that the risk aversion and effort valuation have substitutable impacts on the pricing policy preference of the firm and the agents. Either strong risk aversion or high effort valuation can drive the firm and the agents to favor centralized pricing over delegated pricing.

Key words: delegation; salesforce incentive; asymmetric information; mechanism design.

1 Introduction

An important question that has attracted the interest of academics and practitioners in both marketing and operations is, should pricing decisions be made by the firm or delegated to the salesforce? There appears to be no unconditional answer to this question from practical and theoretical perspectives, because examples of both pricing policies can be found in marketing practice and there are theoretical works favoring both pricing policies, e.g., Lal (1986), Weinberg (1975), and Mishra and Prasad (2004), among others. The problem is complicated by the risk preference of the firm and the agents, the type of information asymmetry, and the sequence of events. In these studies, the risk aversion coefficient of sales agent is modeled as a parameter in the utility function and it is assumed to be common information. In real world applications, however, it is very difficult for one to observe the exact risk preference of another player (Tsay, 2002; Xiao and Yang, 2009). This motivates us to consider the case that a salesperson's risk aversion coefficient is private information to the salesperson that can only be partially observed by the firm, and we examine the impact of salesperson's asymmetric risk aversion on the firm's pricing decision. We formulate a model composed of multiple risk-averse agents with private risk aversion coefficients and examine both pricing delegation and risk aversion issues under the framework of salesforce contract design. Specifically, we are interested in addressing the following questions: (1) How does the asymmetric information on salesperson's risk aversion coefficient affect the firm's pricing decision? (2) How do prices and contracts vary under centralized pricing and delegated pricing, respectively? (3) Which pricing policy is preferred by the firm? And which one is beneficial to the agents?

To study these issues, we build a principal-agent model with one risk-neutral firm and multiple risk-averse agents, where the agents have private risk-averse coefficients and make sales effort unobservable to the firm to maximize their expected utilities. The firm offers a menu of compensation contracts to allow each agent to self-select the actual contract. We analyze both centralized pricing, i.e., the price is determined by the firm, and delegated pricing, i.e., the pricing authority is delegated to each individual agent. This paper aims to examine how the asymmetric information on salesperson's risk aversion coefficient affects the firm's pricing decision under both centralized pricing and delegated pricing. For both pricing policies, a closed-form linear contract is designed which simultaneously induces every risk-averse agent to select a unique contract from it that maximizes the firm's expected profit. For both single-agent and multi-agent cases, we derive the sufficient

condition for centralized pricing to outperform price delegation from the perspectives of both the firm and the agents. It shows that when the agents are highly risk-averse and have high effort valuation, both the firm and the agents favor centralized pricing over price delegation.

Delegating pricing responsibility to the salesforce has attracted the interest of many researchers in marketing (Bhardwaj, 2001; Stephenson et al., 1979; Joseph, 2001; Lal, 1986; Weinberg, 1975). There are papers favoring price delegation (e.g., Lal, 1986; Weinberg, 1975). Lal (1986) shows under certain situations with demand information asymmetry, it is more profitable for the firm to delegate pricing authority to the salesforce than to centrally control it, since the agents have more regional knowledge. In contrast, Mishra and Prasad (2004) find that when the salesperson's private information can be revealed to the firm through contracting, centralized pricing performs at least as well as price delegation. Further, they show that for a broad class of situations it is no worse for the firm to set prices than to delegate the pricing responsibility to the salesforce. Our paper is different from Mishra and Prasad (2004) which assume that the salesperson has a quasi-linear utility function and the firm is free to design an optimal compensation plan. In contrast, we focus on the linear compensation contract with the presence of information asymmetry. Meanwhile, we pursue the investigation further by comparing the pricing policies from the perspectives of both the firm and the agents. Most importantly, the asymmetric information in our study is the risk aversion coefficient of the salesperson. We believe that the risk aversion coefficient of any salesperson is a private information that is only known to the salesperson himself, other parties only have a partial observation and/or estimation of a salesperson's risk aversion coefficient. We show that the agents' risk aversion coefficient and effort valuation have substitutable impacts on the pricing policy preference of the agents and the firm.

Besides the monopoly markets analyzed by above papers, price delegation in competitive settings has also been studied. Bhardwaj (2001) considers the competition of price and sales agents' effort with symmetric demand information and show that, for several linear and nonlinear contracts, there exist parameter values where centralized pricing by each firm is the unique equilibrium, and other parameter values where price delegation by each firm is the unique equilibrium. Mishra and Prasad (2005) also examine the price delegation issue with two competitive firms using standard agent theory but with both symmetric and asymmetric demand information. Under symmetric information they find that the optimal contract allows managers to reach the upper bound on

firm's profit by using either centralized or delegated pricing. Under asymmetric information they find that there always exists an equilibrium where all firms use centralized pricing. Different from these papers, we consider one firm and multiple agents and study the contract design for risk-averse salesforce with private risk aversion coefficients. Bhardwaj (2001) and Mishra and Prasad (2005) focus on the decision of competing firms, while we obtain closed-form solutions to compare the utilities of both the firm and the agents under both centralized pricing and delegated pricing. We find that both the firm and the agents prefer centralized pricing to delegated pricing when the agents are very risk-averse and value their efforts highly.

The analytical underpinnings for our work are provided by the principal-agent paradigm, and the model in this paper is a combination of moral hazard and adverse selection. Another closely related literature stream is salesforce incentive, which has been widely studied in the marketing literature (Coughlan, 1993). Many works study the compensation incentives to induce salespeople to disclose their private information about the market (Gonik, 1978; Mantrala and Raman, 1990). Recently, Chen (2005) compares Gonik's solution with a menu of linear contracts. And Chen (2000) proposes a compensation package to induce the salespeople to exert effort in a way that actually smooths the demand process. Similar to this paper, Jullien et al. (2007) analyze a model composed of one principal and multiple risk-averse agents, where the agents' risk aversion can be public or private information. In Jullien et al. (2007), the risks faced by the agents are binomial income risk: success or failure, and the principal motivates the agents simply by offering a higher payment for success. In contrast, in our setting, the firm makes pricing decisions and offers the base salary and the commission rate to motivate the sales agents. We contribute to this growing body of research literature by examining the pricing decision in the informational and contracting framework of agent theory.

Finally, since our model relates to risk-aversion, we review this stream of literature. There is a considerable literature studying inventory decisions of a single risk-averse agent, e.g., Eeckhoudt, Gollier and Schlesinger (1995), Chen and Federgruen (2000), and Gaur and Seshadri (2005). There have also been a few studies of supply chains consisting of one or more risk-averse agents, e.g., Lau and Lau (1999), Agrawal and Seshadri (2000a), Tsay (2002) and Yoo (2014). A number of papers are devoted to the study of coordination in supply chains involving risk-averse agents (Gan et al., 2004; Van Mieghem, 2003). Gan et al. (2004) generalize the coordination solution in the

risk-neutral case by defining it as one that results in a Pareto-optimal solution acceptable to each agent and develop coordination contracts for many scenarios with risk-averse players. In a recent work, Xu et al., (2014) consider a manufacturer that produces a single product and distributes it through her wholly owned direct channel and through an independent retail channel, which also sells the product to the customers. They propose a two-way revenue sharing contract to coordinate the dual-channel supply chain with risk aversion formulated under a mean-variance model. As a summary, Choi, Ruszczynski and Zhao (2011) present a table categorizing the literature on risk-averse inventory models. Our paper is different from the papers mentioned above in that the analytical underpinnings for our work are in the principal-agent paradigm rather than supply chains and our goal is to examine both pricing delegation and risk aversion issues under the framework of salesforce contract design. Our paper contributes to this line of research by considering a contract design problem when the agents' risk-averse coefficients are asymmetric information.

A number of papers are devoted to analyze the impact of risk aversion on other decisions besides inventory. For example, taking into account the strategic claim behavior and risk attitudes, Gallego et al., (2015) apply ideas from stochastic optimal control theory to design and price residual value warranties to maximize expected profits. Borgonovo and Peccati (2009) discuss the effect of risk measure selection in the determination of inventory policies. Avinadav, Chernonog and Perlman (2015) focus on analyzing how risk-sensitive behavior of supply chain members affects chain performance. The equilibrium strategies are derived when the members have different risk preference: averse, neutral and seeking. Xiao and Yang (2008) consider uncertainty and risk sensitivity under the price and service competition structure of two independent chains, each consisting of one risk-neutral supplier and one risk-averse retailer. They find that the higher the risk sensitivity of one retailer, the lower her optimal service level and retail price, while the impacts of the rival's risk sensitivity on her decisions depend on the substitutability between the two products. In a later work, Xiao and Yang (2009) analyze a supply chain consisting of a one risk-neutral manufacturer and one risk-averse retailer facing an outside integrated competitor, where the risk sensitivity of the retailer is private information. They investigate how the manufacturer designs a wholesale price-order quantity contract to induce the retailer to report his risk sensitivity information truthfully and study the effect of the risk-sharing rule on the revelation mechanism under demand uncertainty. They find that the strategic interaction significantly impacts in the effect of risk sensitivity on the order quantity and when the fraction of the risk cost shared by the manufacturer is sufficiently large

(small), the optimal wholesale price for the high risk-averse retailer is higher (lower) than that for the low risk-averse retailer. Similar to Xiao and Yang (2009), we also consider the case when the risk sensitivity of the retailer is private information. However, the basic formulation of our model is different. We analyze a principal-agent problem where the firm applies compensation incentives, which include a base salary and a commission rate, to induce salespeople to disclose their private information. In contrast, Xiao and Yang (2009) study a supply chain where the retailer actually purchases the product at a wholesale price from the manufacturer. Moreover, the research focuses are different. We compare the centralized pricing and delegated pricing policies in a system with one firm and multiple agents, while Xiao and Yang (2009) study the effect of the risk-sharing rule on the revelation mechanism when a one-manufacturer and one-retailer supply chain faces an outside integrated competitor.

The rest of this paper is organized as follows. In Section 2 we present the problem formulation. In Section 3 we analyze the contract design and pricing decision when there is a single agent and compare the results under centralized pricing and delegated pricing. In Section 4, we examine the case when there are multiple agents and compare the results with single agent case. In Section 5, we conduct a numerical study and discuss managerial insights. Finally, we conclude the paper in Section 6.

Throughout the paper, we use increasing and decreasing in non-strict sense, i.e., they represent non-decreasing and non-increasing respectively.

2 The Model

To obtain parsimony, we start with a single agent setting and analyze the multi-agent case in Section 4.

Consider the salesforce incentive problem with one risk-neutral firm and one risk-averse sales agent. The firm sells a product through the sales agent who interacts with customers. For convenience, we will refer to the firm as “she” and the agent as “he” hereafter. Similar to Chen (2005), the sales during the selling season for the agent is random and it depends on the agent’s sales effort.

Specifically, suppose the sales quantity, or demand, is

$$D = \mu(p) + a + \epsilon \quad (1)$$

where p is the selling price of the agent, $\mu(p)$ is the average sales quantity in the case without sales effort, a is the sales effort exerted by the agent, and random variable ϵ is normally distributed with mean 0 and variance σ^2 . As in other pricing papers, e.g., Agrawal and Seshadri (2000b), we assume $\mu(p)$ is decreasing and concave in p , which posits that the price has a diminishing positive effect on customer demand. Moreover, we assume that $\mu(p)$ is sufficiently large that the probability of D being negative is negligible.

The risk-neutral firm aims to maximize her expected profit by designing the compensation contract for the sales agent. Since the firm cannot directly observe the agent's effort level, the compensation to the agent must be based on the realized value of sales. We use $s(D)$ to denote the compensation the agent receives from the firm, which depends on his total sales D . Similar to Chen (2005), we consider a linear compensation contract (α, β) where the agent is compensated on his total sales $pD(p)$ (dollar value) using base salary β and commission rate α , i.e., $s(D) = \alpha pD(p) + \beta$. The firm's expected profit function can be written as

$$\pi = E[pD - s(D)]. \quad (2)$$

Suppose the sales agent's cost of effort level a is ta^2 , where t measures how sensitive the agent is toward the effort he exerts, which we refer to as the agent's valuation of his effort. Hence the agent's net value is $s(D) - ta^2$. The agent is risk-averse and aims to maximize his expected utility defined by

$$E[-e^{-\gamma(s(D)-ta^2)}],$$

where γ is the risk aversion coefficient of the agent. All parameters are common knowledge except the agent's risk aversion coefficient, γ , which is the private information of the agent. To the firm, the risk aversion coefficient of the agent is drawn from distribution F with density function f on a support $[\underline{\gamma}, \bar{\gamma}]$. We assume that $f(x)/F(x)$ is decreasing in x . This is the so-called log-concavity condition, i.e., $\log F(x)$ is concave in x . It is known that many distributions satisfy this property, e.g., Normal, uniform, exponential, Gamma, and power function distributions (see Bagnoli and Bergstrom 2005).

The sales agent has a minimum utility value for him to accept a contract. In this paper, without loss of generality, we normalize it to -1. Note that for other values, we can slightly modify the base salary, and the main results in this paper still hold. Thus, for the agent to accept a contract, that has to maximize his expected utility among his choices and the expected utility value has to be at least -1 , i.e.,

$$-E[e^{-\gamma(s(D)-ta^2)}] = -e^{-CE[s(D)-ta^2]} \geq -1,$$

this is equivalent to $CE[s(D) - ta^2] \geq 0$.

The firm's problem is to design a menu of compensation contracts for the sales agent, when the prices are determined by herself or delegated to the agent, that maximize her expected total profit. She is also interested in comparing her expected maximum profits under the two pricing policies.

3 Contract Design for a Single Agent

3.1 Centralized Pricing

This section analyzes the contract design for centralized pricing. The sequence of events for centralized pricing is as follows: (1) The firm offers a menu of contracts $(\alpha(\gamma), \beta(\gamma))$ for the agent to pick; (2) the agent decides whether or not to participate and if so, which contract to sign based on his private risk attitude; (3) finally, the firm determines the price and the agent exerts the effort under a signed contract.

Recall that the agent's problem is to maximize his utility function

$$E[-e^{-\gamma(\alpha p D(p) + \beta - ta^2)}].$$

By the certainty equivalence principle, this is equivalent to maximizing

$$\gamma \left((r(p) + pa)\alpha + \beta - ta^2 - \frac{1}{2}\gamma\sigma^2\alpha^2p^2 \right).$$

where $r(p) = p\mu(p)$ is the revenue function.

For the agent with private risk aversion coefficient γ , if he chooses contract $(\alpha(\gamma'), \beta(\gamma'))$, the firm will think the agent's type is γ' and therefore will set a selling price $p(\gamma')$. Hence the expected

utility of the agent modified by the certainty equivalence principle is

$$u(\gamma, \gamma') = \gamma \left((r(p(\gamma')) + p(\gamma')a)\alpha(\gamma') + \beta(\gamma') - ta^2 - \frac{1}{2}\gamma\sigma^2\alpha^2(\gamma')p^2(\gamma') \right).$$

Therefore the optimal effort level is $a = \frac{\alpha(\gamma')p(\gamma')}{2t}$. Substituting this into the utility function we obtain

$$u(\gamma, \gamma') = \gamma \left(r(p(\gamma'))\alpha(\gamma') + \beta(\gamma') + \frac{\frac{1}{2t} - \gamma\sigma^2}{2}\alpha^2(\gamma')p^2(\gamma') \right).$$

For notational convenience, we use $u(\gamma)$ to represent $u(\gamma, \gamma)$, and we have

$$\frac{u(\gamma)}{\gamma} = r(p(\gamma))\alpha(\gamma) + \beta(\gamma) + \frac{\frac{1}{2t} - \gamma\sigma^2}{2}\alpha^2(\gamma)p^2(\gamma).$$

The incentive compatibility condition yields

$$\left(\frac{u(\gamma)}{\gamma} \right)'_{\gamma} = -\frac{1}{2}\sigma^2\alpha^2(\gamma)p^2(\gamma)$$

and

$$\frac{u(\gamma)}{\gamma} = \frac{\sigma^2}{2} \int_{\gamma}^{\bar{\gamma}} \alpha^2(z)p^2(z)dz. \quad (3)$$

Note that we obtain (3) since $u(\bar{\gamma})/\bar{\gamma} = 0$ must hold in the optimal contract. This can easily be proved by contradiction: If this is not true, there exists another contract that is also accepted by the agent and leads to a higher profit for the firm. For equation (3), the incentive compatibility condition requires $\frac{\partial^2 u(\gamma)}{\partial \gamma^2} \leq 0$, which leads to Proposition 1. Equation (3) ensures that $u(\gamma) \geq 0$ for all $\gamma \in [\underline{\gamma}, \bar{\gamma}]$. This individual rationality constraint guarantees participation of the sales agent with any risk aversion coefficient in signing a contract.

Proposition 1 *For a menu of contracts $(\alpha(\gamma), \beta(\gamma), p(\gamma)), \gamma \in [\underline{\gamma}, \bar{\gamma}]$ to be implementable, $\alpha(\gamma)p(\gamma)$ has to be decreasing in γ .*

The firm aims to maximize her expected profit, which is

$$\begin{aligned}
& E[pD(p) - \alpha pD(p) - \beta] \\
&= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[(1 - \alpha(\gamma))(r(p(\gamma)) + \frac{1}{2t}\alpha(\gamma)p^2(\gamma)) - \beta(\gamma) \right] dF(\gamma) \\
&= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[(1 - \alpha(\gamma))(r(p(\gamma)) + \frac{1}{2t}\alpha(\gamma)p^2(\gamma)) - \frac{u(\gamma)}{\gamma} \right. \\
&\quad \left. + \alpha(\gamma)r(p(\gamma)) + \frac{\frac{1}{2t} - \gamma\sigma^2}{2}\alpha^2(\gamma)p^2(\gamma) \right] dF(\gamma) \\
&= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[r(p(\gamma)) + \frac{1}{2t}\alpha(\gamma)p^2(\gamma) - \frac{\sigma^2}{2} \int_{\underline{\gamma}}^{\bar{\gamma}} \alpha^2(z)p^2(z)dz - \frac{\frac{1}{2t} + \gamma\sigma^2}{2}\alpha^2(\gamma)p^2(\gamma) \right] f(\gamma)d\gamma \\
&= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[r(p(\gamma)) + \frac{1}{2t}\alpha(\gamma)p^2(\gamma) - \left(\frac{1}{4t} + \frac{1}{2}\sigma^2 \frac{F(\gamma)}{f(\gamma)} + \frac{1}{2}\gamma\sigma^2 \right) \alpha^2(\gamma)p^2(\gamma) \right] f(\gamma)d\gamma,
\end{aligned}$$

where the last equation follows from switching the order of integration:

$$\begin{aligned}
\int_{\underline{\gamma}}^{\bar{\gamma}} \int_{\underline{\gamma}}^{\bar{\gamma}} \alpha^2(z)p^2(z)dz f(\gamma)d\gamma &= \int_{\underline{\gamma}}^{\bar{\gamma}} \int_{\underline{\gamma}}^z \alpha^2(z)p^2(z)f(\gamma)d\gamma dz \\
&= \int_{\underline{\gamma}}^{\bar{\gamma}} \alpha^2(z)p^2(z)F(z)dz \\
&= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[\alpha^2(\gamma)p^2(\gamma) \frac{F(\gamma)}{f(\gamma)} \right] f(\gamma)d\gamma.
\end{aligned}$$

Define

$$H(\alpha, p, \gamma) = r(p(\gamma)) + \frac{1}{2t}\alpha(\gamma)p^2(\gamma) - \left(\frac{1}{4t} + \frac{1}{2}\sigma^2 \frac{F(\gamma)}{f(\gamma)} + \frac{1}{2}\gamma\sigma^2 \right) \alpha^2(\gamma)p^2(\gamma),$$

and let $\alpha(\gamma)$ be the maximizer of $H(\alpha, p, \gamma)$ for given γ on $0 \leq \alpha \leq 1$. This is a quadratic concave function, and the optimal commission rate is

$$\alpha(\gamma) = \frac{1}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))}. \quad (4)$$

Substituting (4) in $H(\alpha, p, \gamma)$ and slightly abusing the notation, we obtain

$$H(p, \gamma) = r(p(\gamma)) + p^2 \frac{\frac{1}{4t}}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))}. \quad (5)$$

It follows that

$$\begin{aligned}
\frac{\partial H(p, \gamma)}{\partial p} &= r'(p(\gamma)) + p(\gamma) \frac{\frac{1}{2t}}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))} \\
&= p(\gamma) \left(\frac{\mu(p(\gamma))}{p(\gamma)} + \mu'(p(\gamma)) + \frac{\frac{1}{2t}}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))} \right)
\end{aligned}$$

Since $\mu(p(\gamma))$ is concave decreasing in $p(\gamma)$, we know that

$$\frac{\mu(p(\gamma))}{p(\gamma)} + \mu'(p(\gamma)) + \frac{\frac{1}{2t}}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))}$$

is decreasing in $p(\gamma)$. Therefore, $H(p, \gamma)$ is quasi-concave in p , and optimal p is the solution of

$$r'(p(\gamma)) + p(\gamma) \frac{\frac{1}{2t}}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))} = 0 \quad (6)$$

In the following analysis, let us focus on the linear demand $\mu(p) = 1 - p$. In this case, $r(p) = p - p^2$ and $r'(p) = 1 - 2p$. And we have the following theorem.

Theorem 1 *When there is a single agent, the optimal contract $(\alpha(\gamma), \beta(\gamma))$ and the optimal central price are given as*

$$\alpha(\gamma) = \frac{1}{1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))}, \quad (7)$$

$$\beta(\gamma) = \frac{\sigma^2}{2} \int_{\gamma}^{\bar{\gamma}} \alpha^2(z) p^2(z) dz - \alpha(\gamma) r(p(\gamma)) - \frac{\frac{1}{2t} - \gamma\sigma^2}{2} \alpha^2(\gamma) p^2(\gamma), \quad (8)$$

$$p(\gamma) = \frac{1}{2 - \frac{1}{2t}\alpha(\gamma)} = \frac{1}{2 - \frac{1}{2t(1 + 2t(\gamma\sigma^2 + \sigma^2 F(\gamma)/f(\gamma))}}. \quad (9)$$

Proof By (6), we have the optimal central price. And the base salary can be easily derived. ■

Proposition 2 *For centralized pricing,*

- (a) *commission rate $\alpha(\gamma)$ is decreasing in γ ; and*
- (b) *base salary $\beta(\gamma)$ is increasing in γ if $t \geq 1/2$; and*
- (c) *central selling price $p(\gamma)$ is decreasing in γ .*

Proof For the base salary, we have

$$\begin{aligned} \beta'(\gamma) &= -\frac{\partial r(p(\gamma))}{\partial \gamma} \alpha(\gamma) - r(p(\gamma)) \alpha'(\gamma) - \frac{1}{2} \left(\frac{1}{2t} - \gamma\sigma^2 \right) \frac{\partial \alpha^2(\gamma) p^2(\gamma)}{\partial \gamma} \\ &= \frac{8t^3 \sigma^2 \left(12t - 5 - 4t\gamma\sigma^2 + 8t^2 \left(\frac{F(\gamma)}{f(\gamma)} \sigma^2 + \gamma\sigma^2 \right) \right)}{\left(4t - 1 + 8t^2 \left(\frac{F(\gamma)}{f(\gamma)} \sigma^2 + \gamma\sigma \right) \right)^3}. \end{aligned}$$

We can derive that $\beta'(\gamma) > 0$ if $t \geq 1/2$. The proofs of other results are omitted. ■

Proposition 2 states that, when the agent becomes more risk-averse, the firm will offer him a lower commission rate and set a lower selling price, while the base salary is dependent on the effort valuation and is not guaranteed to be higher.

Conducting sensitivity analysis of effort valuation t , we have the following results.

Proposition 3 *For centralized pricing, commission rate $\alpha(\gamma)$ and central selling price $p(\gamma)$ are decreasing in effort valuation t , while base salary $\beta(\gamma)$ is not monotone in t .*

Proof It is obvious that commission rate $\alpha(\gamma)$ and central selling price $p(\gamma)$ are decreasing in t . Taking derivative of $\beta(\gamma)$ with respect to t and the result is straightforward. ■

Proposition 3 states that a low effort valuation alone does not guarantee a favorable contract. In other words, the effort valuation and the risk aversion coefficient jointly affect the profits of the agent and of the firm.

3.2 Price Delegation

We proceed to examine the case when the price setting responsibility is delegated to the agent. Similar to other papers on price delegation, e.g, Mishra and Prasad (2004), the sequence of events for delegating pricing is as follows: (1) The firm offers a menu of compensation contracts for the agent to pick; (2) the agent decides whether or not to participate and if so, which contract to sign based on his private risk attitude; (3) finally, the agent determines the price and then exerts the effort.

Let $(\alpha(\gamma), \beta(\gamma))$ be the menu offered. If the agent chooses a different contract γ' , his utility is

$$\frac{u(\gamma, \gamma')}{\gamma} = \alpha(\gamma')(r(p) + pa) + \beta(\gamma') - ta^2 - \frac{1}{2}\gamma\sigma^2\alpha^2(\gamma')p^2.$$

Hence, the optimal effort level of the agent is $a = \frac{\alpha(\gamma')p}{2t}$, and the corresponding utility is

$$\frac{u(\gamma, \gamma')}{\gamma} = r(p)\alpha(\gamma') + \beta(\gamma') + \frac{\frac{1}{2t} - \gamma\sigma^2}{2}\alpha^2(\gamma')p^2. \quad (10)$$

Note that the agent determines the selling price after signing the contract. First order condition shows that p is the solution of the following equation

$$r'(p) + (\frac{1}{2t} - \gamma\sigma^2)p\alpha(\gamma') = 0.$$

The solution depends on both γ and γ' . Same as before, we focus on the linear demand $\mu(p) = 1 - p$, which leads to

$$p(\gamma, \gamma') = \frac{1}{2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma')}.$$

Substituting this into (10), we obtain

$$\begin{aligned} \frac{u(\gamma, \gamma')}{\gamma} &= r(p(\gamma, \gamma'))\alpha(\gamma') + \beta(\gamma') + \frac{\frac{1}{2t} - \gamma\sigma^2}{2}(\alpha(\gamma')\tilde{p}(\gamma, \gamma'))^2 \\ &= \frac{\alpha(\gamma')}{2(2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma'))} + \beta(\gamma'). \end{aligned}$$

Following the same logic as in Section 3.1, we obtain

$$\begin{aligned} \frac{u(\gamma)}{\gamma} &= \frac{\sigma^2}{2} \int_{\underline{\gamma}}^{\bar{\gamma}} \frac{\alpha^2(z)}{(2 - (\frac{1}{2t} - z\sigma^2)\alpha(z))^2} dz \\ &= \frac{\sigma^2}{2} \int_{\underline{\gamma}}^{\bar{\gamma}} \alpha^2(z)p^2(z)dz, \end{aligned} \tag{11}$$

and, by the individual rationality constraint, this guarantees participation of the sales agent in signing a contract.

The firm designs the contract aiming to maximize her expected profit, which is

$$\begin{aligned} &E[pD(p) - \alpha pD(p) - \beta] \\ &= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[(1 - \alpha(\gamma))(r(p(\gamma)) + \frac{\alpha(\gamma)p^2(\gamma)}{2t}) - \beta(\gamma) \right] dF(\gamma) \\ &= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[(1 - \alpha(\gamma))(r(p(\gamma)) + \frac{\alpha(\gamma)p^2(\gamma)}{2t}) - \frac{u(\gamma)}{\gamma} + \alpha(\gamma)r(p(\gamma)) + \frac{\frac{1}{2t} - \gamma\sigma^2}{2}\alpha^2(\gamma)p^2(\gamma) \right] dF(\gamma) \\ &= \int_{\underline{\gamma}}^{\bar{\gamma}} \left[r(p(\gamma)) + \frac{\alpha(\gamma)p^2(\gamma)}{2t} - \frac{1}{2} \left(\frac{1}{2t} + \gamma\sigma^2 + \sigma^2 \frac{F(\gamma)}{f(\gamma)} \right) \alpha^2(\gamma)p^2(\gamma) \right] f(\gamma)d\gamma \\ &= \int_{\underline{\gamma}}^{\bar{\gamma}} \frac{1 + \gamma\sigma^2\alpha(\gamma) - \frac{1}{2} \left(\frac{1}{2t} + \gamma\sigma^2 + \sigma^2 \frac{F(\gamma)}{f(\gamma)} \right) \alpha^2(\gamma)}{(2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma))^2} d\gamma. \end{aligned}$$

Define function $H(\alpha, \gamma)$ as follows

$$H(\alpha, \gamma) = \frac{1 + \gamma\sigma^2\alpha(\gamma) - \frac{1}{2} \left(\frac{1}{2t} + \gamma\sigma^2 + \sigma^2 \frac{F(\gamma)}{f(\gamma)} \right) \alpha^2(\gamma)}{(2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma))^2}, \tag{12}$$

then the optimal contract $\alpha(\gamma)$ can be obtained by maximizing $H(\alpha, \gamma)$ for given γ .

Theorem 2 *For delegated pricing with a single agent, when $t \geq 1/4$, the optimal contract $(\alpha(\gamma), \beta(\gamma))$*

and the delegated price are given by

$$\begin{aligned}
\alpha(\gamma) &= \frac{1}{1 + (2t - \frac{1}{2})\gamma\sigma^2 + t\gamma^2\sigma^4 + 2t\sigma^2 F(\gamma)/f(\gamma)}, \\
\beta(\gamma) &= \frac{\sigma^2}{2} \int_r^{\bar{r}} \frac{\alpha^2(z)}{(2 - (\frac{1}{2t} - z\sigma^2)\alpha(z))^2} dz - \frac{\alpha(\gamma)}{2(2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma))}, \\
p(\gamma) &= \frac{1}{2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma)} = \frac{1}{2 - \frac{\frac{1}{2t} - \gamma\sigma^2}{1 + (2t - \frac{1}{2})\gamma\sigma^2 + t\gamma^2\sigma^4 + 2t\sigma^2 F(\gamma)/f(\gamma)}}.
\end{aligned} \tag{13}$$

Proof Taking first derivative of $H(\alpha, \gamma)$ with respect to α , we have

$$(H(\alpha, \gamma))'_\alpha = \frac{2 - \alpha(\gamma) \left(2 + 4t\sigma^2 \frac{F(\gamma)}{f(\gamma)} + (4t - 1)\gamma\sigma^2 + 2t\gamma^2\sigma^4 \right)}{2t(2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma))^3}$$

Since $2t(2 - (\frac{1}{2t} - \gamma\sigma^2)\alpha(\gamma))^3$ is positive and

$$2 - \alpha(\gamma) \left(2 + 4t\sigma^2 \frac{F(\gamma)}{f(\gamma)} + (4t - 1)\gamma\sigma^2 + 2t\gamma^2\sigma^4 \right)$$

is decreasing in α when $t \geq 1/4$, we know that $H(\alpha, \gamma)$ is quasi-concave in α , and therefore the optimal commission rate can be obtained by first order condition. And other results can be easily derived. ■

Proposition 4 For price delegation, when $t \geq 1/4$,

- (a) commission rate $\alpha(\gamma)$ is decreasing in γ ; and
- (b) base salary $\beta(\gamma)$ is increasing in γ ; and
- (c) delegated selling price $p(\gamma)$ is decreasing in γ .

Proof For the base salary, when $t \geq 1/4$, we have

$$\begin{aligned}
\beta'(\gamma) &= -r'(p(\gamma))p'(\gamma)\alpha(\gamma) - r(p(\gamma))\alpha'(\gamma) \\
&\quad - (\frac{1}{2t} - \gamma\sigma^2)(\alpha(\gamma)p^2(\gamma)\alpha'(\gamma) + \alpha^2(\gamma)p(\gamma)p'(\gamma)) \\
&= \frac{2t^2\sigma^2(-1 + 4t + 4t(\frac{F(\gamma)}{f(\gamma)})'_\gamma + 4t\gamma\sigma^2)}{(-1 + 4t + 4t^2\sigma^2(2\frac{F(\gamma)}{f(\gamma)} + 2\gamma + \gamma^2\sigma^2))^2} \\
&\geq 0.
\end{aligned}$$

Other proofs are obvious and are omitted. ■

Proposition 4 states that, when the agent becomes more risk-averse, he will set a lower selling price and will be offered a lower commission rate associated with a higher base salary by the firm.

Proposition 5 *For delegated pricing, commission rate $\alpha(\gamma)$ and central selling price $p(\gamma)$ are decreasing in effort valuation t , while base salary $\beta(\gamma)$ is not monotone in t .*

The proof is obvious and is omitted. Similarly to Proposition 3 in centralized pricing, although the commission rate and the central selling price are decreasing in the agent's effort valuation in delegated pricing, a low effort valuation alone does not guarantee a favorable contract. In other words, the effort valuation and the risk aversion coefficient jointly affect the profits of the agent and of the firm, and we will explore this joint effect further in sequel.

3.3 Comparison

A salient issue faced by the firm is, should pricing decisions be made by herself or delegated to the salesforce? Both pricing policies are valid when $t \geq 1/4$. In the sequel of this paper, we assume t is in this range. We now proceed to compare the results of two pricing policies. For notational convenience, we use superscripts C and D to denote the results of centralized pricing and delegated pricing, respectively.

We start with the commission rate and, by simple algebra, we obtain the following proposition.

Proposition 6 *Comparing the commission rates under centralized pricing and delegated pricing, we have if $\gamma\sigma^2 \geq \frac{1}{2t}$, $\alpha^C(\gamma) \geq \alpha^D(\gamma)$; otherwise, $\alpha^C(\gamma) < \alpha^D(\gamma)$.*

Proof Since

$$\frac{1}{\alpha^C(\gamma)} - \frac{1}{\alpha^D(\gamma)} = \gamma\sigma^2(1 - 2t\gamma\sigma^2)/2,$$

some simple algebra establishes the results. ■

Proposition 6 implies that the risk aversion coefficient and the effort valuation have joint impacts. It shows that, given the effort valuation, which pricing policy leads to a higher commission rate depends on the extent of the agent's risk aversion. When the agent is very risk-averse, price delegation leads to a lower commission rate than centralized pricing.

Proposition 7 *Comparing the selling prices under centralized and delegated pricing, when $t \geq 1/4$, the centralized price is larger than the delegated price.*

Proof We have

$$p^C(\gamma) - p^D(\gamma) = \frac{t\gamma\sigma^2(-1 + 4t + 2t(\gamma + 4t(F(\gamma)/f(\gamma) + \gamma))\sigma^2)}{(-1 + 4t + 8t^2(F(\gamma)/f(\gamma) + \gamma)\sigma^2)(-1 + 4t(1 + 2t(F(\gamma)/f(\gamma) + \gamma)\sigma^2 + t\gamma^2\sigma^4))}$$

and the result follows. ■

Proposition 7 implies that the firm tends to price higher than the agent, and this might partially due to the risk aversion of the agent and the risk neutrality of the firm.

Theorem 3 *For the single agent case, if $t \geq 1/4$, it is mutually beneficial for the firm and the agent to apply centralized pricing.*

Proof Compare the utility of the agent under the two pricing policies. By (3) and (11), we know that

$$\frac{u(\gamma)}{\gamma} = \frac{\sigma^2}{2} \int_{\gamma}^{\bar{\gamma}} \alpha^2(z) p^2(z) dz.$$

Namely, the agent's utility can be written as a function of the agent's effort level. Since

$$\begin{aligned} & \alpha^C(\gamma) p^C(\gamma) - \alpha^D(\gamma) p^D(\gamma) \\ &= \frac{8t^3\gamma^2\sigma^4}{(-1 + 4t + 8t^2(F(\gamma)/f(\gamma) + \gamma)\sigma^2)(-1 + 4t(1 + 2t(F(\gamma)/f(\gamma) + \gamma)\sigma^2 + t\gamma^2\sigma^4))}, \end{aligned}$$

we know that the agent gets higher utility under centralized pricing than under price delegation. The firm compares her expected profit under centralized pricing and delegated pricing when determining which pricing policy to use. By (5) and (12), we know that the firm's expected profit under centralized pricing and under delegated pricing, respectively, are

$$\begin{aligned} E[H^C(\gamma)] &= \int_{\underline{\gamma}}^{\bar{\gamma}} \left(\frac{t(1 + 2t(\sigma^2 \frac{F(\gamma)}{f(\gamma)} + \gamma\sigma^2))}{4t - 1 + 8t^2(\sigma^2 \frac{F(\gamma)}{f(\gamma)} + \gamma\sigma^2)} \right) f(\gamma) d\gamma, \\ E[H^D(\gamma)] &= \int_{\underline{\gamma}}^{\bar{\gamma}} \frac{1}{4} \left(1 + \frac{1}{-1 + 4t + 4t^2\sigma^2(2\frac{F(\gamma)}{f(\gamma)} + 2\gamma + \gamma^2\sigma^2)} \right) f(\gamma) d\gamma. \end{aligned} \quad (14)$$

Therefore, we have

$$\begin{aligned} & E[H^C(\gamma)] - E[H^D(\gamma)] \\ &= \int_{\underline{\gamma}}^{\bar{\gamma}} \frac{t^2\gamma^2\sigma^4}{(4t - 1 + 8t^2(\sigma^2 \frac{F(\gamma)}{f(\gamma)} + \gamma\sigma^2))(-1 + 4t + 4t^2\sigma^2(2\frac{F(\gamma)}{f(\gamma)} + 2\gamma + \gamma^2\sigma^2))} f(\gamma) d\gamma \\ &\geq 0, \end{aligned}$$

which shows that the firm's expected profit is higher under centralized pricing. ■

Lal (1985) shows that if the sales manager and the salesperson have identical information about the selling environment, then the profits to the firm from delegation and centralization are identical. Mishra and Prasad (2004) state that centralized pricing does no worse than price delegation for the firm when there is no information asymmetry and the firm is free to design an optimal compensation plan. Our result is different from Lal (1985) and Mishra and Prasad (2004) mainly due to the fact that we focus on the linear compensation contract and consider the presence of information asymmetry on risk aversion. Moreover, we study the pricing policy preference of both the firm and the agent in contrast to Lal (1985) and Mishra and Prasad (2004) which analyze the preference of the firm solely. Analyzing the joint effect of the risk aversion and the effort valuation, Theorem 3 states that both the firm and the agent favor centralized pricing over delegated pricing. This might be because that the agent who values his effort highly are better motivated by centralized pricing to exert more efforts which result in a higher utility.

4 Contract Design with Multiple Agents

We now examine the case with n independent agents serving different markets. An example in practice could be one firm having n sales agents each serving a single sales territory. The decision faced by the firm is, should she provide a single price used by all sales agents or let each agent determine a regional price for his sales territory? In order to determine that, the firm needs to compare her expected profit under centralized pricing and delegated pricing.

First we analyze centralized pricing. We use subscript $i, i = 1, \dots, n$, to denote agent i and $-i$ the agents other than agent i . The sales quantity of agent i , denoted by D_i , is given by

$$D_i = \mu_i(p_i) + a_i + \epsilon_i, \quad i = 1, \dots, n.$$

Note that since we consider the scenario in which each agent sells in his own region, for delegated pricing the sales for an agent only depends on his own selling price and his own sales effort. We assume that the random variables $\epsilon_1, \dots, \epsilon_n$ are independent of one another.

For centralized pricing, the central price is determined by the firm after the contracts are signed by the agents. Therefore, when there are multiple agents, the central price is a function of the

types of all agents and is denoted by

$$p(\gamma) = p(\gamma_1, \gamma_2, \dots, \gamma_n) = p(\gamma_i, \gamma_{-i}),$$

where $\gamma = (\gamma_1, \dots, \gamma_n)$. In what follows, we define the notation

$$\tilde{p}(\gamma_i) = E[p(\gamma_i, \gamma_{-i})],$$

where the expectation is with respect to the types of agents other than i , i.e., γ_{-i} , and for any other function $g(\cdot)$, let

$$\tilde{g}(\gamma_i) = E[g(p(\gamma_i, \gamma_{-i}))].$$

Since agent i only knows his private information γ_i but γ_{-i} , he estimates the central price as $\tilde{p}(\gamma_i)$. Therefore, similar analysis as that in the single agent case leads to

$$\frac{u_i(\gamma_i)}{\gamma_i} = \frac{\sigma_i^2}{2} \int_{\gamma_i}^{\bar{\gamma}_i} (\alpha_i(z) \tilde{p}(z))^2 dz = \frac{\sigma_i^2}{2} \int_{\underline{\gamma}_{-i}}^{\bar{\gamma}_{-i}} \int_{\gamma_i}^{\bar{\gamma}_i} (\alpha_i(z) p(z, \gamma_{-i}))^2 dz dF_{-i}(\gamma_{-i}). \quad (15)$$

The firm aims to maximize her expected profit from all n agents, which is

$$\begin{aligned} & E\left[\sum_{i=1}^n (pD_i(p) - \alpha_i pD_i(p) - \beta_i)\right] \\ &= \sum_{i=1}^n \int_{\underline{\gamma}_i}^{\bar{\gamma}_i} \left[(1 - \alpha_i(\gamma_i))(\tilde{r}_i(p(\gamma_i)) + \frac{1}{2t_i} \alpha_i(\gamma_i) \tilde{p}^2(\gamma_i)) - \beta_i(\gamma_i) \right] dF_i(\gamma_i) \\ &= \sum_{i=1}^n \int_{\underline{\gamma}_i}^{\bar{\gamma}_i} \left[(1 - \alpha_i(\gamma_i))(\tilde{r}_i(p(\gamma_i)) + \frac{1}{2t_i} \alpha_i(\gamma_i) \tilde{p}^2(\gamma_i)) - \frac{u_i(\gamma_i)}{\gamma_i} \right. \\ &\quad \left. + \alpha_i(\gamma_i) \tilde{r}_i(p(\gamma_i)) + \frac{\frac{1}{2t_i} - \gamma_i \sigma_i^2}{2} \alpha_i^2(\gamma_i) \tilde{p}^2(\gamma_i) \right] dF_i(\gamma_i) \\ &= \sum_{i=1}^n \int_{\underline{\gamma}_i}^{\bar{\gamma}_i} \left[\tilde{r}_i(p(\gamma_i)) + \frac{1}{2t_i} \alpha_i(\gamma_i) \tilde{p}^2(\gamma_i) - \left(\frac{1}{4t_i} + \frac{1}{2} \sigma_i^2 \frac{F_i(\gamma_i)}{f_i(\gamma_i)} + \frac{1}{2} \gamma_i \sigma_i^2 \right) \alpha_i^2(\gamma_i) \tilde{p}^2(\gamma_i) \right] f_i(\gamma_i) d\gamma_i \\ &= \sum_{i=1}^n \int_{\underline{\gamma}_{-i}}^{\bar{\gamma}_{-i}} \int_{\underline{\gamma}_i}^{\bar{\gamma}_i} \left[r_i(p(\gamma)) + \frac{1}{2t_i} \alpha_i(\gamma_i) p^2(\gamma) \right. \\ &\quad \left. - \left(\frac{1}{4t_i} + \frac{1}{2} \sigma_i^2 \frac{F_i(\gamma_i)}{f_i(\gamma_i)} + \frac{1}{2} \gamma_i \sigma_i^2 \right) \alpha_i^2(\gamma_i) p^2(\gamma) \right] f_i(\gamma_i) d\gamma_i dF_{-i}(\gamma_{-i}) \\ &= \int_{\underline{\gamma}_1}^{\bar{\gamma}_1} \cdots \int_{\underline{\gamma}_n}^{\bar{\gamma}_n} \sum_{i=1}^n \left[r_i(p(\gamma)) \right. \\ &\quad \left. + \left(\frac{1}{2t_i} \alpha_i(\gamma_i) - \left(\frac{1}{4t_i} + \frac{1}{2} \sigma_i^2 \frac{F_i(\gamma_i)}{f_i(\gamma_i)} + \frac{1}{2} \gamma_i \sigma_i^2 \right) \alpha_i^2(\gamma_i) \right) p^2(\gamma) \right] \prod_{i=1}^n f_i(\gamma_i) d\gamma_1 \cdots d\gamma_n \end{aligned} \quad (16)$$

The optimal control is obtained as follows: Define

$$G_i(\alpha_i, \gamma_i) = \frac{1}{2t_i} \alpha_i(\gamma_i) - \left(\frac{1}{4t_i} + \frac{1}{2} \sigma_i^2 \frac{F_i(\gamma_i)}{f_i(\gamma_i)} + \frac{1}{2} \gamma_i \sigma_i^2 \right) \alpha_i^2(\gamma_i).$$

Note that this is independent of p , and therefore the optimal contract is

$$\alpha_i^*(\gamma_i) = \frac{1}{1 + 2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F_i(\gamma_i)/f_i(\gamma_i))}. \quad (17)$$

Then the optimal selling price is obtained by maximizing the following concave function

$$H(p, \gamma_1, \dots, \gamma_n) = \sum_{i=1}^n \left[r_i(p) + \left(\frac{1}{2t_i} \alpha_i^*(\gamma_i) - \left(\frac{1}{4t_i} + \frac{1}{2} \sigma_i^2 \frac{F_i(\gamma_i)}{f_i(\gamma_i)} + \frac{1}{2} \gamma_i \sigma_i^2 \right) (\alpha_i^*(\gamma_i))^2 \right) p^2 \right]$$

Same as before, we assume $\mu_i = 1 - p$. Substituting $\alpha_i^*(\gamma_i)$ of (17) into $H(p, \gamma_1, \dots, \gamma_n)$ leads to

$$\begin{aligned} & H(p, \gamma_1, \dots, \gamma_n) \\ &= np(1-p) + p^2 \sum_{i=1}^n \left[\left(\frac{1}{2t_i} \alpha_i^*(\gamma_i) - \left(\frac{1}{4t_i} + \frac{1}{2} \sigma_i^2 \frac{F_i(\gamma_i)}{f_i(\gamma_i)} + \frac{1}{2} \gamma_i \sigma_i^2 \right) (\alpha_i^*(\gamma_i))^2 \right) \right] \\ &= np(1-p) + p^2 \sum_{i=1}^n \frac{1}{4t_i(1 + 2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F_i(\gamma_i)/f_i(\gamma_i)))} \end{aligned}$$

Therefore, we obtain the optimal centralized price and the expected profit of the firm:

$$\begin{aligned} p(\gamma_i, \gamma_{-i}) &= \frac{1}{2 - \frac{1}{2n} \sum_{i=1}^n \frac{1}{t_i(1 + 2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F_i(\gamma_i)/f_i(\gamma_i)))}} \\ E[H(\gamma_1, \dots, \gamma_n)] &= E \left[\frac{n}{2(2 - \frac{1}{2n} \sum_{i=1}^n \frac{1}{t_i(1 + 2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F_i(\gamma_i)/f_i(\gamma_i)))})} \right] \end{aligned} \quad (18)$$

Comparing the compensation contracts of the single agent case and the multi-agent case, we find that the commission rates are the same while the base salaries are different.

Proposition 8 *Different from the single agent case, $\beta_i(\gamma_i)$ is not guaranteed to be increasing in γ_i even when the effort valuation is large for the multi-agent case under centralized pricing.*

Proof We consider the special case when $t_i = 1/2$. By (15), we have

$$\beta_i(\gamma_i) = \frac{\sigma_i^2}{2} \int_{\gamma_i}^{\bar{\gamma}_i} \alpha_i^2(z) \tilde{p}^2(z) dz - \alpha_i(\gamma_i) \tilde{r}_i(p(\gamma_i)) - \frac{1 - \gamma_i \sigma_i^2}{2} \alpha_i^2(\gamma_i) \tilde{p}^2(\gamma_i).$$

We here present a counterexample to show that $\beta_i(\gamma_i)$ is not increasing in γ_i . When $n = 2$, we have

$$\begin{aligned} & (\beta_1(\gamma_1))'_{\gamma_1} \\ &= \int_{\underline{\gamma}_2}^{\bar{\gamma}_2} \frac{2\sigma_1^2(1 + (\frac{F(\gamma_1)}{f(\gamma_1)})'_{\gamma_1})(1 + \frac{F(\gamma_2)}{f(\gamma_2)}\sigma_2^2 + \gamma_2\sigma_2^2)(A - \gamma_1\sigma_1^2(3 + 4\frac{F(\gamma_2)}{f(\gamma_2)}\sigma_2^2 + 4\gamma_2\sigma_2^2))}{(2 + 3\frac{F(\gamma_2)}{f(\gamma_2)}\sigma_2^2 + 3\gamma_2\sigma_2^2 + \frac{F(\gamma_1)}{f(\gamma_1)}\sigma_1^2(3 + 4\frac{F(\gamma_2)}{f(\gamma_2)}\sigma_2^2 + 4\gamma_2\sigma_2^2) + \gamma_1\sigma_1^2(3 + 4\frac{F(\gamma_2)}{f(\gamma_2)}\sigma_2^2 + 4\gamma_2\sigma_2^2))^3} d\gamma_2 \end{aligned}$$

where

$$\begin{aligned}
A = & 4 + 13 \frac{F(\gamma_2)}{f(\gamma_2)} \sigma_2^2 + 13 \gamma_2 \sigma_2^2 + 10 \left(\frac{F(\gamma_2)}{f(\gamma_2)} \right)^2 \sigma_2^4 + 20 \frac{F(\gamma_2)}{f(\gamma_2)} \gamma_2 \sigma_2^4 + 10 \gamma_2^2 \sigma_2^4 \\
& + \frac{F(\gamma_1)}{f(\gamma_1)} \sigma_1^2 (3 + 10 \gamma_2 \sigma_2^2) + 8 \frac{F(\gamma_2)}{f(\gamma_2)} \sigma_2^4 + 8 \gamma_2^2 \sigma_2^4 + 2 \frac{F(\gamma_2)}{f(\gamma_2)} \sigma_2^2 (5 + 8 \gamma_2 \sigma_2^2).
\end{aligned}$$

Therefore, we know that when γ_1 is sufficiently large, $\beta_1(\gamma_1)$ is decreasing in γ_1 ; and when γ_1 is small, $\beta_1(\gamma_1)$ is increasing in γ_1 . ■

We next study the case of price delegation when they are multiple agents and each of which sets his own price according to his risk aversion coefficient. Following the same logic as in Section 3.2, we find that the results are the same as in the single agent case. That is, the menu of contracts for agent i ($i = 1, \dots, n$) is the same as that in Section 3.2 except that it depends on the distribution of his risk aversion coefficient $F_i(\cdot)$.

Now we compare the results of centralized pricing and price delegation. As before, we assume $t_i \geq 1/4$ to make both policies valid and use superscripts C and D to differentiate the results of these pricing policies. For example, $p^C(\gamma_i, \gamma_{-i})$ and $p_i^D(\gamma_i)$ stand for agent i 's price under centralized and delegated pricing, respectively. Recall that the centralized price is the same for all agents while the delegated price is different from agent to agent. It is worthwhile to notify that increasing the number of agents does not change commission rate $\alpha_i(\gamma_i)$ for both centralized and delegated pricing. Therefore, the comparison of the commission rate for the single agent case in Proposition 6 still holds.

Proposition 9 *When there are multiple agents, for agent i with $\gamma_i \sigma_i^2 \geq \frac{1}{2t_i}$, centralized pricing will execute a higher price than delegated pricing, i.e., $p^C(\gamma_i, \gamma_{-i}) \geq p_i^D(\gamma_i)$.*

Proof For the centralized price and the delegated price, we have

$$\begin{aligned}
& p^C(\gamma_i, \gamma_{-i}) - p_i^D(\gamma_i) \\
= & \frac{1}{2 - \frac{1}{n} \sum_{i=1}^n \frac{1}{2t_i(1+2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F(\gamma_i)/f(\gamma_i)))}} - \frac{1}{2 - \frac{\frac{1}{2t_i} - \gamma_i \sigma_i^2}{1 + (2t_i - \frac{1}{2})\gamma_i \sigma_i^2 + t_i \gamma_i^2 \sigma_i^4 + 2t_i \sigma_i^2 F(\gamma_i)/f(\gamma_i)}}.
\end{aligned}$$

For agent i with $\gamma_i \sigma_i^2 \geq \frac{1}{2t_i}$, we know that $p^C(\gamma_i, \gamma_{-i}) > 1/2$, $p_i^D(\gamma_i) < 1/2$, and therefore, $p^C(\gamma_i, \gamma_{-i}) \geq p_i^D(\gamma_i)$. ■

Comparing to Proposition 7 in the single agent case, we find that the agent with high risk aversion coefficient tends to determine a price lower than the centralized price in both the single agent case and the multiple agent case. And this is partially caused by the risk aversion of the agents and the risk neutrality of the firm. Proposition 9 also implies that the agent with strong risk aversion or high effort valuation tends to set a price lower than the centralized price and the substitutable impact between the risk aversion and the effort valuation will be discussed further in the results below.

We have the following relationships:

$$\begin{aligned}
& (2 - 1/p_i^D(\gamma_i)) - (2 - 1/p^C(\gamma_i, \gamma_{-i})) \\
= & \frac{\frac{1}{2t_i} - \gamma_i \sigma_i^2}{1 + (2t_i - \frac{1}{2})\gamma_i \sigma_i^2 + t_i \gamma_i^2 \sigma_i^4 + 2t_i \sigma_i^2 F(\gamma_i)/f(\gamma_i)} - \frac{1}{n} \sum_{i=1}^n \frac{1}{2t_i(1 + 2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F(\gamma_i)/f(\gamma_i)))} \\
= & \frac{\frac{1}{2t_i} - \gamma_i \sigma_i^2}{1 + (2t_i - \frac{1}{2})\gamma_i \sigma_i^2 + t_i \gamma_i^2 \sigma_i^4 + 2t_i \sigma_i^2 F(\gamma_i)/f(\gamma_i)} - \frac{1}{n} \frac{1}{2t_i(1 + 2t_i(\gamma_i \sigma_i^2 + \sigma_i^2 F(\gamma_i)/f(\gamma_i)))} \\
& - \frac{1}{n} \sum_{j=1, j \neq i}^n \frac{1}{2t_j(1 + 2t_j(\gamma_j \sigma_j^2 + \sigma_j^2 F(\gamma_j)/f(\gamma_j)))} \\
= & \frac{-[2 + 4F(\gamma_i)/f(\gamma_i)t_i \sigma_i^2 - \gamma_i \sigma_i^2 + 4t_i \gamma_i \sigma_i^2 + 2t_i \gamma_i^2 \sigma_i^4 + 2n(-1 + 2t_i \gamma_i \sigma_i^2)(1 + 2F(\gamma_i)/f(\gamma_i)t_i \sigma_i^2 + 2t_i \gamma_i \sigma_i^2)]}{2nt_i(1 + 2F(\gamma_i)/f(\gamma_i)t_i \sigma_i^2 + 2t_i \gamma_i \sigma_i^2)(2 + 4F(\gamma_i)/f(\gamma_i)t_i \sigma_i^2 + (-1 + 4t_i)\gamma_i \sigma_i^2 + 2t_i \gamma_i^2 \sigma_i^4)} \\
& - \frac{1}{n} \sum_{j=1, j \neq i}^n \frac{1}{2t_j(1 + 2t_j(\gamma_j \sigma_j^2 + \sigma_j^2 F(\gamma_j)/f(\gamma_j)))}
\end{aligned}$$

Note that the denominator of the first term in the above equation is increasing in γ_i , but the numerator is not guaranteed to be decreasing in γ_i when $\gamma_i \sigma_i^2 < \frac{1}{2t_i}$. Therefore, $p^C(\gamma_i, \gamma_{-i}) - p_i^D(\gamma_i)$ is decreasing in γ_{-i} but it is not guaranteed to be increasing in γ_i . Hence, more risk-averse rivals will drive the agent to set a price higher than the centralized price, while it might not hold if the agent himself is less risk-averse. We hereafter loosely use the term “more risk-taking” to mean less risk-averse.

Theorem 4 *Agent i is better off under centralized pricing than under delegated pricing if $\gamma_i \sigma_i^2 \geq \frac{1}{2t_i}$.*

Proof We compare agent i 's utility under centralized pricing, denoted as $u_i^C(\gamma_i, \gamma_{-i})$, and his utility under delegated pricing, denoted as $u_i^D(\gamma_i)$. Note that $u_i^C(\gamma_i, \gamma_{-i})$ is also a function of γ_{-i} since

the price is centrally determined. By (15), we have

$$\begin{aligned}
& \frac{u_i^C(\gamma_i, \gamma_{-i})}{\gamma_i} - \frac{u_i^D(\gamma_i)}{\gamma_i} \\
&= \frac{\sigma_i^2}{2} \int_{\underline{\gamma}_{-i}}^{\bar{\gamma}_{-i}} \int_{\gamma_i}^{\bar{\gamma}_i} (\alpha_i^C(z) p^C(z, \gamma_{-i}))^2 dz dF_{-i}(\gamma_{-i}) - \frac{\sigma_i^2}{2} \int_{\gamma_i}^{\bar{\gamma}_i} (\alpha_i^D(z) p_i^D(z))^2 dz \\
&= \frac{\sigma_i^2}{2} \int_{\gamma_i}^{\bar{\gamma}_i} [(\alpha_i^C(z))^2 \int_{\underline{\gamma}_{-i}}^{\bar{\gamma}_{-i}} (p^C(z, \gamma_{-i}))^2 dF_{-i}(\gamma_{-i}) - (\alpha_i^D(z) p_i^D(z))^2] dz.
\end{aligned} \tag{19}$$

Comparing $\alpha_i^C(\gamma_i, \gamma_{-i})$ and $\alpha_i^D(\gamma_i)$, by Proposition 6, we know that, when $\gamma_i \sigma_i^2 \geq \frac{1}{2t_i}$, $\alpha_i^C(\gamma_i, \gamma_{-i}) \geq \alpha_i^D(\gamma_i)$. And by Proposition 9, the result follows. ■

Theorem 4 states that an agent with strong risk aversion and high effort valuation tends to benefit more from the centralized pricing than the delegated pricing. It implies that strong risk aversion and high effort valuation hinder the agents from making right pricing and effort decisions to maximize their profit, while these factors are alleviated when the price is determined centrally by the firm. Meanwhile, the risk-averse coefficient and the effort valuation could be interpreted as two substitutable factors for the agent's pricing preference. Both strong risk aversion and high effort valuation drive the agents to benefit more in centralized pricing than in delegated pricing, and we use numerical analysis to further explore this in Section 5.

Remark 1 *Theorem 4 states that, when the agents are very risk-averse, i.e., $\gamma_i \sigma_i^2 > \frac{1}{2t_i}$, centralized pricing can better motivated them to exert more effort and be paid off with higher utility. When the conditions do not hold, recall that $p^C(\gamma_i, \gamma_{-i}) - p_i^D(\gamma_i)$ is decreasing in γ_{-i} while $\alpha_i^C(\gamma_i) - \alpha_i^D(\gamma_i)$ is not related to γ_{-i} . Therefore, one agent tends to favor delegated pricing when his rivals, other agents, are more risk-averse. However, it might not hold if the agent himself becomes more risk-taking.*

We return to the question that, should pricing decisions be made by herself or delegated to the salesforce? To answer this question, the firm needs to compare the expected profit under these two pricing policies. By (14) and (18), we obtain the expected profit of the firm under centralized

pricing and delegated pricing, respectively,

$$E[H^C(\gamma_1, \dots, \gamma_n)] = E \left[\frac{n}{2(2 - \frac{1}{2n} \sum_{i=1}^n \frac{1}{t_i(1+2t_i(\gamma_i\sigma_i^2 + \sigma_i^2 F(\gamma_i)/f(\gamma_i)))})} \right],$$

$$E[H^D(\gamma_1, \dots, \gamma_n)] = E \left[\sum_{i=1}^n \frac{1}{4} \left(1 + \frac{1}{-1 + 4t_i + 4t_i^2\sigma_i^2(2\frac{F(\gamma_i)}{f(\gamma_i)} + 2\gamma_i + \gamma_i^2\sigma_i^2)} \right) \right].$$

It is worth noting that the expected profits of the firm under both centralized pricing and delegated pricing tend to decrease when the agents become more risk-averse.

Theorem 5 *The firm is better off under centralized pricing than under delegated pricing if $\gamma_i\sigma_i^2 \geq \frac{1}{2t_i}$, for all i .*

Proof Comparing the firm's expected profit under centralized pricing and delegated pricing, we have

$$E[H^C(\gamma_1, \dots, \gamma_n)] - E[H^D(\gamma_1, \dots, \gamma_n)] = \int_{\underline{\gamma}_1}^{\bar{\gamma}_1} \dots \int_{\underline{\gamma}_n}^{\bar{\gamma}_n} \frac{\sum_{i=1}^n \frac{A}{4BC} + \frac{1}{4n} \sum_{i=1}^n \frac{1}{B} \sum_{i=1}^n \frac{1}{C}}{4 - \frac{1}{n} \sum_{i=1}^n \frac{1}{B}} \prod_{i=1}^n f_i(\gamma_i) d\gamma_1 \dots d\gamma_n$$

where

$$\begin{aligned} A &= 4t_i^2\gamma_i^2\sigma_i^4 - 1, \\ B &= t_i(1 + 2t_i(\gamma_i\sigma_i^2 + \sigma_i^2 F(\gamma_i)/f(\gamma_i))), \\ C &= -1 + 4t_i + 4t_i^2\sigma_i^2(2\frac{F(\gamma_i)}{f(\gamma_i)} + 2\gamma_i + \gamma_i^2\sigma_i^2). \end{aligned}$$

Hence, $\gamma_i\sigma_i^2 \geq \frac{1}{2t_i}$ is a sufficient condition for $E[H^C(\gamma_1, \dots, \gamma_n)] - E[H^D(\gamma_1, \dots, \gamma_n)]$ to be positive.

■

Theorem 5 in the multi-agent case gives sufficient conditions for the firm to prefer centralized pricing over price delegation. Analogous to the findings in Theorem 4, Theorem 5 implies that when the agents have strong risk aversion and high effort valuation, the firm tends to be better off under centralized pricing. We will use numerical analysis to further explore how the agents' risk-averse coefficients impact the firm's preference of pricing policies in Section 5.

Theorem 6 *It is mutually beneficial for the firm and all the agents to apply centralized pricing if $\gamma_i\sigma_i^2 \geq \frac{1}{2t_i}$ for all i .*

Different from the single agent case in which centralized pricing is always mutually beneficial for the firm and the agent, Theorem 6 in the multi-agent case states that when the agents are strongly risk-averse or value their efforts highly, it is mutually beneficial for the firm and the agents to apply centralized pricing. Meanwhile, Theorem 6 implies that the risk-averse coefficient and the effort valuation have substitutable impacts on the pricing policy preference of the firm and the agents.

Remark 2 *In this section we assume that the centralized pricing decision of the firm has to be equal for all sales agents. This clearly restricts the firm's ability in working out contracts with different sales agents that favor the firm, since the sales agents have different risk aversion coefficients and the equal pricing does not allow the firm to take advantage of that. This explains why the centralized pricing may not outperform the case of price delegation. If, however, in a practical setting, e.g., the sales agents are distributed in different selling regions and the firm can negotiate contract with each and every sales agent independently, such that the centralized selling price of the product can be different from agent to agent, then all the results obtained in the previous section would hold true even when there are multiple sales agents, and centralized pricing will always be better than price delegation. Indeed, in that case, we can analyze the contract design problem with each sales agent separately and independently, and the problem is reduced to the one studied in the previous sections.*

5 Numerical Study

Our theoretical analysis shows that the risk-averse coefficient and the effort valuation have substitutable effects on the agents' and the firm's preference of pricing policies. In this section, we perform a numerical study to analyze the impact of the risk aversion coefficient and the effort valuation and investigate which pricing policy performs better from the perspectives of both the firm and the agents. For brevity, we conduct the numerical study for a two-agent case, i.e., $n = 2$.

Substitutable effects. We first analyze the substitutable effects of the risk aversion coefficient and the effort valuation. Theorem 4 states the risk aversion coefficient and the effort valuation have substitutable effects on the agent's pricing preference. To illustrate the theoretical results, we analyze how risk aversion coefficient γ affects the agents' utility when the effort valuation is different. Setting $\sigma_i = 1, i = 1, 2$, $t_2 = 0.35$ and letting γ_2 be normally distributed with mean

Figure 1: Agent 1's preference between centralized pricing and delegated pricing

2 and variance 1 and γ_1 normally distributed with variance 1, we alternate the value of mean of γ_1 from 1 to 5 with step size 0.5 for different values of t_1 and report the results in Figure 1. It illustrates that both strong risk aversion and high effort valuation drive the agent to prefer centralized pricing over delegated pricing. This supports our theoretical results. Normal, uniform, and Gamma distributions are tested, and similar results are obtained.

Impact of risk aversion on the firm. Recall that Theorem 5 implies that the firm tends to favor centralized pricing over price delegation when the agents are very risk-averse and have high effort valuation. We first analyze the impact of γ_i on the firm's profit given effort valuation. We set $t_i = 0.5$, $\sigma_i = 1$ and let γ_i be normally distributed with variance 0.3, $i = 1, 2$. For the cases when the mean of γ_1 equals 0.1 and 0.9 respectively, we alternate the value of mean of γ_2 from 0.1 to 1.9 with step size 0.2 and report the firm's profit in Figure 2. It shows that the expected profit of the firm under both centralized pricing and delegated pricing tend to decrease when the agents become more risk-averse. Meanwhile, it illustrates that when the agents are very risk-averse, the firm is

Figure 2: Firm's expected profit under centralized pricing and delegated pricing

better off by centrally determining the price; otherwise, the firm tends to delegate the price to the agents. Normal, uniform, and Gamma distributions are tested, and similar results are obtained.

Impact of effort valuation on the firm. We now analyze the impact of effort valuation on the firm's profit given agents' risk aversion coefficients. We set $\sigma_i = 1$ and let $\gamma_i, i = 1, 2$ be normally distributed with mean 0.1 and variance 0.3. Considering the feasible domain of the effort valuation, we alternate the value of t_1 from 0.25 to 0.75 with step size 0.05 and report the firm's profit in Figure 3. Figure 3 illustrates that, given risk aversion coefficients, the firm prefers centralized pricing over delegated pricing when the effort valuation of agents are high and vice versa.

Variance of risk aversion coefficient. We now analyze the impact of the variance of risk aversion coefficient γ_i on the firm's profit. Let γ_1 be normally distributed with mean 2 and variance 0.5, γ_2 normally distributed with mean 2, and $t_1 = t_2 = 0.5$. We alternate the value of variance of γ_2 from 0.1 to 2.5 with step size 0.5 and depict the results in Figure 4. It illustrates that the variation of risk aversion coefficient significantly reduces the profit of the firm when centralized pricing is applied, while this kind of profit reduction generally does not occur when price delegation is applied. This might due to that the risk aversion coefficient is the private information of the agents, and so the agents can better manage the pricing when the variation is large from the firm's perspective.

Figure 3: Firm's expected profit under centralized pricing and delegated pricing

Figure 4: Firm's expected profit under centralized pricing and delegated pricing

6 Conclusions

This paper aims to examine how the asymmetric information on salesperson's risk aversion coefficient affects the firm's pricing decision and analyze the impact of delegation on prices and incentives with the presence of information asymmetry. We have studied a model composed of multiple risk-averse agents with private risk aversion coefficients and analyzed both centralized pricing and price delegation under the framework of salesforce contract design. For both pricing policies, the compensation and pricing contracts are designed and the sensitivity analyses are conducted. An interesting finding in the paper is that the risk aversion coefficient and the effort valuation have substitutable effects on the pricing policy preference of the firm and the agents. When the agents are strongly risk-averse or have high effort valuation, it is mutually beneficial for the firm and the agents to utilize centralized pricing; otherwise, the firm and the agents tend to prefer delegated pricing.

The work is by necessity limited in scope, and its coverage could be fruitfully extended in a number of interesting directions in future studies. In our study, we have assumed that these n agents are independent and each of those serves a single sales territory. It is straightforward to extend the results to the case when the demand are correlated, e.g., $(\epsilon_1, \dots, \epsilon_n)$ are multi-variate normally distributed. An interesting potential avenue of future research would be to study the case in which the agents compete on customers with price. In this case, the agents face competition from each other horizontally and the principal-agent paradigm with the firm vertically. We could examine the role of information asymmetry, pricing and contract design in competitive settings. It would also be interesting to analyze the information sharing and updating between the agents and the firm as in Li (2002).

For ease of analysis in this paper we ignored the production cost in our study on the effect of asymmetry of risk attitude on incentive design. When production cost is explicitly included, the analysis will be much more involved, and it will be interesting to investigate the impact of production cost in mechanism design (we thank an anonymous reviewer for this insightful comment). We will leave this interesting issue as a future research.

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