1. Introduction

Nonlinear pricing refers to any kind of price structure wherein a nonlinear relationship between price and quantity of a good prevails. The most common nonlinear price schedules are quantity discounts and multipart tariffs. The literature on nonlinear pricing under asymmetric information was initiated by Mussa and Rosen (1978) and Maskin and Riley (1984). In a canonical nonlinear pricing model, a monopoly sells a good to a continuum of heterogeneous buyers who possess private information over a scalar taste parameter. The monopolist devises a price-quantity menu to elicit the private information from the continuum of buyers. The equilibrium price-quantity menu offers the highest valuation buyer the efficient quantity of the good, while all other buyers self-select into downward-distorted quantities. The prices that induce this allocation often include quantity discounts that are unrelated to costs.[1]

In reality, firms may have desires to avoid consequences wherein ex-post suboptimal decisions appear to have been made even though these decisions are de facto ex-ante optimal based on the information available at that time. To account for this consideration, Bell (1982, 1983) and Loomes and Sugden (1982) propose regret theory that defines regret as the disutility arising from not having chosen the ex-post optimal alternatives. Quiggin (1994) and Sugden (1993) provide an axiomatic foundation of regret theory, which is supported by extensive experimental studies that document regret-averse preferences among individuals (see, e.g., Loomes, 1988; Loomes et al., 1992; Loomes and Sugden, 1987; Starmer and Sugden, 1993).[2]

The purpose of this paper is to incorporate regret theory into the canonical principal-agent model of nonlinear pricing *à la* Maskin and Riley (1984) wherein there are two types of

[1] Extensions to oligopolistic competition or several products include Armstrong (1996), Armstrong and Vickers (2001), Oren et al. (1983), Rochet and Chone (1998), and Stole (1995), to name just a few.

[2] Steil (1993) conducts a survey of 26 multinational firms in the U.S. regarding their foreign exchange risk management. Most respondents in his survey strongly object to the hedging strategies as suggested by expected utility maximization because they regard those strategies as ex-post suboptimal ones, which is consistent with regret theory.

buyers, namely, high and low valuation buyers. To this end, we follow the regret-theoretical approach of Braun and Muermann (2004) and Wong (2014, 2015) to characterize the monopolist's preferences by a modified utility function that includes disutility from having chosen ex-post suboptimal alternatives. The magnitude of regret is measured by the difference between the actual profit and the maximum profit that could have been earned should the monopolist have observed each buyer's true taste parameter. Regret aversion is modeled by a convex function defined over the magnitude of regret.[3] We are particularly interested in examining how the prevalence and intensity of regret aversion affect the optimal nonlinear pricing contracts.[4]

We show that high valuation buyers purchase the first-best quantity of the good and receive positive information rents, whereas low valuation buyers purchase the second-best quantity of the good that is below the first-best level and receive zero information rents in equilibrium. This captures the usual tradeoff between efficiency and rent extraction that arises under asymmetric information (Laffont and Martimort, 2002) with one caveat. The regret-averse monopolist encounters regret from two sources: (i) the efficiency loss from selling downward-distorted quantities to low valuation buyers, and (ii) the information rent conceded to high valuation buyers in order to induce truth-telling. When buyers are more likely to have high (low) valuation in the standard model, the rent extraction-efficiency tradeoff leads to a greater (smaller) magnitude of the efficiency loss as compared to that of the information rent. The regret-averse monopolist as such finds more (less) regret due to the efficiency loss than that due to the information rent. To minimize regret, the monopolist reduces (enlarges) the downward distortion on the second-best quantity offered to low valuation buyers, thereby making the magnitude of the efficiency loss closer to that of the information rent. This results in lower (higher) unit prices paid by all buyers. While low valuation buyers are indifferent when regret aversion prevails, high valuation buyers are made better (worse) off and the monopolist always earns a lower expected profit.

[3]Bleichrodt et al. (2010) provide empirical evidence that regret functions are indeed convex.

[4]Buyers have no concern for regret aversion as they are perfectly informed about their taste parameters, thereby facing no uncertainty.

Using the same canonical principal-agent model under asymmetric information, Wang et al. (2019) introduce risk aversion to the monopolist and show that the downward distortion on the second-best quantity offered to low valuation buyers must be reduced in equilibrium. Wang et al. (2019) show further that all the qualitative results hold when risk aversion is replaced by ambiguity aversion (see also Zheng et al., 2015). Regret aversion, however, can have the same or opposite implications, depending on whether buyers are more likely to have high or low valuation, respectively. This suggests that regret aversion plays a distinct role in optimal nonlinear pricing under asymmetric information.

The rest of this paper is organized as follows. The next section delineates the canonical principal-agent model of nonlinear pricing wherein the monopolist is regret averse. Section 3 characterizes the optimal solution to the model. Section 4 examines the global and marginal effects of regret aversion on the optimal nonlinear pricing contracts. The final section concludes.

2. The model

Consider a monopolist who produces a single good at a constant marginal cost, $c > 0$. The monopolist sells the good to a continuum of heterogeneous buyers with unit mass using nonlinear pricing contracts of the form, (t, q), where q is the number of units sold at the lump-sum payment, t. A buyer who accepts a contract, (t, q), derives a net benefit in monetary terms of $u(q, \theta) - t$, where θ is a taste parameter privately known to the buyer. The taste parameter, θ, is drawn independently from the same binary distribution such that $\theta = \underline{\theta}$ with probability p and $\theta = \overline{\theta}$ with probability $1 - p$, where $0 < p < 1$. We refer to buyers with $\theta = \underline{\theta}$ as high valuation buyers and those with $\theta = \overline{\theta}$ as low valuation buyers. We assume that $u(0, \theta) = 0$, $\lim_{q \to 0} u(q, \theta) = \infty$, and $u_q(q, \theta) > 0$, $u_{qq}(q, \theta) < 0$, $u(q, \underline{\theta}) > u(q, \overline{\theta})$, $u_q(q, \underline{\theta}) > u_q(q, \overline{\theta})$, and $u_{qq}(q, \underline{\theta}) > u_{qq}(q, \overline{\theta})$ for all $q > 0$, where the subscripts signify partial derivatives with respect to q.

We assume that the monopolist's preferences are represented by the following "modified" utility function that includes some compensation for regret:

$$\phi(\pi, \delta) = \pi - \beta g(\delta), \tag{1}$$

where $\beta > 0$ is a constant, and $g(\delta)$ is a regret function defined over the magnitude of regret, δ, such that $g(0) = 0$, and $g'(\delta) > 0$ and $g''(\delta) > 0$ for all $\delta > 0$. The magnitude of regret, $\delta = \pi^{\max} - \pi$, is measured by the difference between the actual profit, π, and the maximum profit, $\pi^{\max}$, that could have been earned should the monopolist have observed each buyer's true taste parameter. Since π cannot exceed $\pi^{\max}$, the monopolist experiences disutility from forgoing the possibility of undertaking the ex-post optimal decision. The parameter, β, is a constant regret coefficient that reflects the increasing importance of regret aversion on representing the monopolist's preferences as β increases. In the extreme case that $\beta = 0$, we are back to the standard model wherein the monopolist is no longer regret averse.

Under symmetric information in that the monopolist can observe each buyer's taste parameter, the first-best nonlinear pricing contracts, $(\underline{t}^{\mathrm{FB}}, \underline{q}^{\mathrm{FB}})$ and $(\overline{t}^{\mathrm{FB}}, \overline{q}^{\mathrm{FB}})$, which are offered to high and low valuation buyers, respectively, are such that $\underline{t}^{\mathrm{FB}} = u(\underline{q}^{\mathrm{FB}}, \underline{\theta})$, $\overline{t}^{\mathrm{FB}} = u(\overline{q}^{\mathrm{FB}}, \overline{\theta})$, and $\underline{q}^{\mathrm{FB}}$ and $\overline{q}^{\mathrm{FB}}$ are the solutions to the following first-order conditions:

$$u_q(\underline{q}^{\mathrm{FB}}, \underline{\theta}) = c, \tag{2}$$

and

$$u_q(\overline{q}^{\mathrm{FB}}, \overline{\theta}) = c, \tag{3}$$

respectively. Eqs. (2) and (3) are the usual optimality condition that the marginal benefit of a type-θ buyer is equated to the marginal cost of the monopolist at the optimum. Since $u_q(q, \underline{\theta}) > u_q(q, \overline{\theta})$ and $u_{qq}(q, \theta) < 0$, Eqs. (2) and (3) imply that $\underline{q}^{\mathrm{FB}} > \overline{q}^{\mathrm{FB}}$. Since $\underline{q}^{\mathrm{FB}}$ maximizes $u(q, \underline{\theta}) - cq$, we have $u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - c\underline{q}^{\mathrm{FB}} > u(\overline{q}^{\mathrm{FB}}, \underline{\theta}) - c\overline{q}^{\mathrm{FB}} > u(\overline{q}^{\mathrm{FB}}, \overline{\theta}) - c\overline{q}^{\mathrm{FB}}$, where the second inequality follows from $u(q, \underline{\theta}) > u(q, \overline{\theta})$. Hence, we conclude that the gain from trade with a high valuation buyer exceeds that with a low valuation buyer in the first-best scenario under symmetric information.

Information, however, is asymmetric in that the monopolist only knows the binary distribution of θ but not any buyer's true taste parameter. To induce truth-telling by the continuum of privately informed buyers, the monopolist offers a menu of nonlinear pricing contracts, $\{(\underline{t},\underline{q}),(\overline{t},\overline{q})\}$, such that $(\underline{t},\underline{q})$ is chosen by all high valuation buyers and $(\overline{t},\overline{q})$ is chosen by all low valuation buyers in equilibrium. We can state the monopolist's ex-ante decision problem as follows:

$$\max_{\{(\underline{t},\underline{q}),(\overline{t},\overline{q})\}} \quad p\Big[\underline{t}-c\underline{q}-\beta g\Big(u(\underline{q}^{\mathrm{FB}},\underline{\theta})-c\underline{q}^{\mathrm{FB}}-\underline{t}+c\underline{q}\Big)\Big]$$

$$+(1-p)\Big[\overline{t}-c\overline{q}-\beta g\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-\overline{t}+c\overline{q}\Big)\Big], \tag{4}$$

$$\text{s. t.} \quad u(\underline{q},\underline{\theta})-\underline{t}\geq u(\overline{q},\underline{\theta})-\overline{t}, \tag{5}$$

$$u(\overline{q},\overline{\theta})-\overline{t}\geq u(\underline{q},\overline{\theta})-\underline{t}, \tag{6}$$

$$u(\underline{q},\underline{\theta})-\underline{t}\geq 0, \tag{7}$$

$$u(\overline{q},\overline{\theta})-\overline{t}\geq 0, \tag{8}$$

where inequalities (5) and (6) are the incentive compatibility constraints for high and low valuation buyers, respectively, and inequalities (7) and (8) are the participation constraints for high and low valuation buyers, respectively.

3. Solution to the model

In this section, we solve program (4). Incentive compatibility constraint (5) for high valuation buyers implies that $u(\underline{q},\underline{\theta})-\underline{t}\geq u(\overline{q},\underline{\theta})-\overline{t}>u(\overline{q},\overline{\theta})-\overline{t}\geq 0$, where the second inequality follows from $u(q,\underline{\theta}) > u(q,\overline{\theta})$, and the third inequality follows from participation constraint (8) for low valuation buyers. Hence, we conclude that participation constraint (7) for high valuation buyers does not bind and can be ignored. This is rather intuitive in that high valuation buyers have stronger incentives to mimic low valuation buyers, resulting in the necessity of giving positive information rents to high valuation buyers so as to induce truth-telling in equilibrium.

Using the method of Kuhn-Tucker, we form the Lagrangian:

$$L = p\Big[\underline{t} - c\underline{q} - \beta g\Big(u(\underline{q}^{\mathrm{FB}},\underline{\theta}) - c\underline{q}^{\mathrm{FB}} - \underline{t} + c\underline{q}\Big)\Big]$$

$$+(1-p)\Big[\overline{t} - c\overline{q} - \beta g\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta}) - c\overline{q}^{\mathrm{FB}} - \overline{t} + c\overline{q}\Big)\Big]$$

$$+\lambda_1[u(\underline{q},\underline{\theta}) - \underline{t} - u(\overline{q},\underline{\theta}) + \overline{t}] + \lambda_2[u(\overline{q},\overline{\theta}) - \overline{t} - u(\underline{q},\overline{\theta}) + \underline{t}] + \lambda_3[u(\overline{q},\overline{\theta}) - \overline{t}],$$

with the corresponding complementary slackness conditions for the three constraints, where $\lambda_1 \geq 0$, $\lambda_2 \geq 0$, and $\lambda_3 \geq 0$ are the Lagrange multipliers of constraints (5), (6), and (8), respectively. The first-order conditions are given by

$$\frac{\partial L}{\partial \underline{t}} = p\Big[1 + \beta g'\Big(u(\underline{q}^{\mathrm{FB}},\underline{\theta}) - c\underline{q}^{\mathrm{FB}} - \underline{t}^{\mathrm{SB}} + c\underline{q}^{\mathrm{SB}}\Big)\Big] - \lambda_1 + \lambda_2 = 0, \tag{9}$$

$$\frac{\partial L}{\partial \overline{t}} = (1-p)\Big[1 + \beta g'\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta}) - c\overline{q}^{\mathrm{FB}} - \overline{t}^{\mathrm{SB}} + c\overline{q}^{\mathrm{SB}}\Big)\Big] + \lambda_1 - \lambda_2 - \lambda_3 = 0, \tag{10}$$

$$\frac{\partial L}{\partial \underline{q}} = -p\Big[1 + \beta g'\Big(u(\underline{q}^{\mathrm{FB}},\underline{\theta}) - c\underline{q}^{\mathrm{FB}} - \underline{t}^{\mathrm{SB}} + c\underline{q}^{\mathrm{SB}}\Big)\Big]c$$

$$+\lambda_1 u_q(\underline{q}^{\mathrm{SB}},\underline{\theta}) - \lambda_2 u_q(\underline{q}^{\mathrm{SB}},\overline{\theta}) = 0, \tag{11}$$

and

$$\frac{\partial L}{\partial \overline{q}} = -(1-p)\Big[1 + \beta g'\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta}) - c\overline{q}^{\mathrm{FB}} - \overline{t}^{\mathrm{SB}} + c\overline{q}^{\mathrm{SB}}\Big)\Big]c$$

$$-\lambda_1 u_q(\overline{q}^{\mathrm{SB}},\underline{\theta}) + (\lambda_2 + \lambda_3) u_q(\overline{q}^{\mathrm{SB}},\overline{\theta}) = 0. \tag{12}$$

Adding Eq. (9) to Eq. (10) yields

$$\lambda_3 = 1 + \beta\Big[pg'\Big(u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - c\underline{q}^{\mathrm{FB}} - \underline{t}^{\mathrm{SB}} + c\underline{q}^{\mathrm{SB}}\Big)$$

$$+(1-p)g'\Big(u(\overline{q}^{\mathrm{FB}}, \overline{\theta}) - c\overline{q}^{\mathrm{FB}} - \overline{t}^{\mathrm{SB}} + c\overline{q}^{\mathrm{SB}}\Big)\Big] > 0. \tag{13}$$

Hence, the complementary slackness condition, $\lambda_3[u(\overline{q}^{\mathrm{SB}}, \overline{\theta}) - \overline{t}^{\mathrm{SB}}] = 0$, implies that $\overline{t}^{\mathrm{SB}} = u(\overline{q}^{\mathrm{SB}}, \overline{\theta})$. The intuition is straightforward. Giving low valuation buyers any positive rents results in greater rents for high valuation buyers to meet the latter's incentive compatibility constraint. To minimize the rents subject to the participation and incentive compatibility constraints, the monopolist gives zero rents to low valuation buyers in equilibrium.

If $u(\underline{q}^{\mathrm{SB}}, \overline{\theta}) > \underline{t}^{\mathrm{SB}}$, low valuation buyers would never accept $(\overline{t}^{\mathrm{SB}}, \overline{q}^{\mathrm{SB}})$ that gives them zero rents. Hence, it must be true that $u(\underline{q}^{\mathrm{SB}}, \overline{\theta}) \le \underline{t}^{\mathrm{SB}}$. Incentive compatibility constraint (6) for low valuation buyers, $0 = u(\overline{q}^{\mathrm{SB}}, \overline{\theta}) - \overline{t}^{\mathrm{SB}} \ge u(\underline{q}^{\mathrm{SB}}, \overline{\theta}) - \underline{t}^{\mathrm{SB}}$, as such does not bind and can be ignored. It then follows from the complementary slackness condition, $\lambda_2[u(\overline{q}^{\mathrm{SB}}, \overline{\theta}) - \overline{t}^{\mathrm{SB}} - u(\underline{q}^{\mathrm{SB}}, \overline{\theta}) + \underline{t}^{\mathrm{SB}}] = 0$, that $\lambda_2 = 0$.

From Eq. (9) and $\lambda_2 = 0$, we have

$$\lambda_1 = p\Big[1 + \beta g'\Big(u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - c\underline{q}^{\mathrm{FB}} - \underline{t}^{\mathrm{SB}} + c\underline{q}^{\mathrm{SB}}\Big)\Big] > 0. \tag{14}$$

The complementary slackness condition, $\lambda_1[u(\underline{q}^{\mathrm{SB}}, \underline{\theta}) - \underline{t}^{\mathrm{SB}} - u(\overline{q}^{\mathrm{SB}}, \underline{\theta}) + \overline{t}^{\mathrm{SB}}]$, then implies that $\underline{t}^{\mathrm{SB}} = u(\underline{q}^{\mathrm{SB}}, \underline{\theta}) + u(\overline{q}^{\mathrm{SB}}, \overline{\theta}) - u(\overline{q}^{\mathrm{SB}}, \underline{\theta})$ since $\overline{t}^{\mathrm{SB}} = u(\overline{q}^{\mathrm{SB}}, \overline{\theta})$. Since $u(q, \underline{\theta}) > u(q, \overline{\theta})$, high valuation buyers receive positive information rents equal to $r(\overline{q}^{\mathrm{SB}}) = u(\overline{q}^{\mathrm{SB}}, \underline{\theta}) - u(\overline{q}^{\mathrm{SB}}, \overline{\theta}) > 0$ in equilibrium.

Substituting Eq. (14) and $\lambda_2 = 0$ into Eq. (11) yields

$$u_q(\underline{q}^{\mathrm{SB}}, \underline{\theta}) = c. \tag{15}$$

It follows from Eqs. (2) and (15) that $\underline{q}^{\mathrm{SB}} = \underline{q}^{\mathrm{FB}}$. Substituting Eqs. (13) and (14) and

$\lambda_2 = 0$ into Eq. (12) yields

$$u_q(\overline{q}^{\text{SB}}, \overline{\theta}) = c + \left(\frac{p}{1-p}\right)\left[\frac{1 + \beta g'\Big(r(\overline{q}^{\text{SB}})\Big)}{1 + \beta g'\Big(u(\overline{q}^{\text{FB}}, \overline{\theta}) - c\overline{q}^{\text{FB}} - u(\overline{q}^{\text{SB}}, \overline{\theta}) + c\overline{q}^{\text{SB}}\Big)}\right] r'(\overline{q}^{\text{SB}}). \quad (16)$$

Since $u_q(q, \underline{\theta}) > u_q(q, \overline{\theta})$, we have $r'(q) > 0$. It then follows from Eq. (16) that $u_q(\overline{q}^{\text{SB}}, \overline{\theta}) > c$ so that from Eq. (3) and $u_{qq}(q, \theta) < 0$ we have $\overline{q}^{\text{SB}} < \overline{q}^{\text{FB}}$.

The following proposition summarizes the results derived above.

Proposition 1. *The regret-averse monopolist offers the optimal menu of nonlinear pricing contracts,* $\{(\underline{t}^{\text{SB}}, \underline{q}^{\text{SB}}), (\overline{t}^{\text{SB}}, \overline{q}^{\text{SB}})\}$, *to the continuum of privately informed buyers such that* $\underline{q}^{\text{SB}} = \underline{q}^{\text{FB}}$, $\underline{t}^{\text{SB}} = u(\underline{q}^{\text{FB}}, \underline{\theta}) - r(\overline{q}^{\text{SB}})$, $\overline{t}^{\text{SB}} = u(\overline{q}^{\text{SB}}, \overline{\theta})$, *and* $\overline{q}^{\text{SB}} \in (0, \overline{q}^{\text{FB}})$ *solves Eq. (16), where* $r(q) = u(q, \underline{\theta}) - u(q, \overline{\theta})$.

Proposition 1 shows that high valuation buyers purchase the first-best quantity of the good, $\underline{q}^{\text{FB}}$, and receive positive information rents, $r(\overline{q}^{\text{SB}})$, whereas low valuation buyers purchase the second-best quantity of the good, $\overline{q}^{\text{SB}}$, that is below the first-best level, $\overline{q}^{\text{FB}}$, and receive zero information rents in equilibrium. The incentive compatibility constraint for high valuation buyers binds but that for low valuation buyers does not bind:

$$0 = u(\overline{q}^{\text{SB}}, \overline{\theta}) - \overline{t}^{\text{SB}} > u(\underline{q}^{\text{SB}}, \overline{\theta}) - \underline{t}^{\text{SB}}$$

$$= u(\overline{q}^{\text{SB}}, \underline{\theta}) - u(\overline{q}^{\text{SB}}, \overline{\theta}) - [u(\underline{q}^{\text{FB}}, \underline{\theta}) - u(\underline{q}^{\text{FB}}, \overline{\theta})],$$

since $u(q, \underline{\theta}) > u(q, \overline{\theta})$, $u_q(q, \underline{\theta}) > u_q(q, \overline{\theta})$, and $\overline{q}^{\text{SB}} < \overline{q}^{\text{FB}} < \underline{q}^{\text{FB}}$.

Since $\underline{q}^{\text{FB}}$ maximizes $u(q, \underline{\theta}) - cq$, we have $u(\underline{q}^{\text{FB}}, \underline{\theta}) - c\underline{q}^{\text{FB}} > u(\overline{q}^{\text{SB}}, \underline{\theta}) - c\overline{q}^{\text{SB}}$, which is equivalent to

$$u(\underline{q}^{\text{FB}}, \underline{\theta}) - c\underline{q}^{\text{FB}} - r(\overline{q}^{\text{SB}}) > u(\overline{q}^{\text{SB}}, \overline{\theta}) - c\overline{q}^{\text{SB}}. \quad (17)$$

The left-hand side of inequality (17) is the monopolist's equilibrium profit when the buyer has high valuation, and the right-hand side is the one when the buyer has low valuation.

Hence, the monopolist earns more from a buyer who has high valuation than from a buyer who has low valuation.

4. Regret aversion and optimal nonlinear pricing

In this section, we examine the effect of regret aversion on the optimal nonlinear pricing contracts. To this end, we consider the standard model wherein $\beta = 0$ as a benchmark. It then follows from Proposition 1 and $\beta = 0$ that the optimal menu of nonlinear pricing contracts in the standard model, $\{(\underline{t}_\circ^{\mathrm{SB}}, \underline{q}_\circ^{\mathrm{SB}}), (\overline{t}_\circ^{\mathrm{SB}}, \overline{q}_\circ^{\mathrm{SB}})\}$, must satisfy that $\underline{q}_\circ^{\mathrm{SB}} = \underline{q}^{\mathrm{FB}}$, $\underline{t}_\circ^{\mathrm{SB}} = u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - r(\overline{q}_\circ^{\mathrm{SB}})$, $\overline{t}_\circ^{\mathrm{SB}} = u(\overline{q}_\circ^{\mathrm{SB}}, \overline{\theta})$, and $\overline{q}_\circ^{\mathrm{SB}} \in (0, \overline{q}^{\mathrm{FB}})$ solves

$$u_q(\overline{q}_\circ^{\mathrm{SB}}, \overline{\theta}) = c + \left(\frac{p}{1-p}\right) r'(\overline{q}_\circ^{\mathrm{SB}}). \tag{18}$$

To compare $\overline{q}_\circ^{\mathrm{SB}}$ with $\overline{q}^{\mathrm{SB}}$, we reformulate program (4) as follows. Binding participation constraint (8) for low valuation buyers implies that $\overline{t} = u(\overline{q}, \overline{\theta})$. On the other hand, binding incentive constraint (5) for high valuation buyers implies that $u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - \underline{t} = u(\overline{q}, \underline{\theta}) - u(\overline{q}, \overline{\theta}) = r(\overline{q})$ since $\underline{q} = \underline{q}^{\mathrm{FB}}$. Hence, the monopolist's ex-ante decision problem reduces to

$$\begin{aligned} \max_q \ & p\Big[u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - r(q) - c\underline{q}^{\mathrm{FB}} - \beta g\Big(r(q)\Big)\Big] \\ & + (1-p)\Big[u(q, \overline{\theta}) - cq - \beta g\Big(u(\overline{q}^{\mathrm{FB}}, \overline{\theta}) - c\overline{q}^{\mathrm{FB}} - u(q, \overline{\theta}) + cq\Big)\Big]. \end{aligned} \tag{19}$$

Differentiating the objective function of program (19) with respect to q yields

$$\begin{aligned} f(q) = {} & (1-p)\Big[1 + \beta g'\Big(u(\overline{q}^{\mathrm{FB}}, \overline{\theta}) - c\overline{q}^{\mathrm{FB}} - u(q, \overline{\theta}) + cq\Big)\Big][u_q(q, \overline{\theta}) - c] \\ & - p\Big[1 + \beta g'\Big(r(q)\Big)\Big] r'(q). \end{aligned} \tag{20}$$

It follows from Eq. (20) that Eq. (16) is identical to $f(\overline{q}^{\mathrm{SB}}) = 0$. Differentiating Eq. (20) with respect to q yields

$$f'(q) = -(1-p)\beta g''\Big(u(\overline{q}^{\mathrm{FB}}, \overline{\theta}) - c\overline{q}^{\mathrm{FB}} - u(q, \overline{\theta}) + cq\Big)[u_q(q, \overline{\theta}) - c]^2$$

$$+(1-p)\Big[1+\beta g'\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-u(q,\overline{\theta})+cq\Big)\Big]u_{qq}(q,\overline{\theta})$$

$$-p\beta g''\Big(r(q)\Big)r'(q)^2-p\Big[1+\beta g'\Big(r(q)\Big)\Big]r''(q)<0, \tag{21}$$

where the inequality follows from the assumed properties of $g(\delta)$ and $u(q,\theta)$.

Evaluating Eq. (20) at $q=\overline{q}_\circ^{\mathrm{SB}}$ yields

$$f(\overline{q}_\circ^{\mathrm{SB}})=(1-p)\Big[1+\beta g'\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-u(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})+c\overline{q}_\circ^{\mathrm{SB}}\Big)\Big][u_q(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})-c]$$

$$-p\Big[1+\beta g'\Big(r(\overline{q}_\circ^{\mathrm{SB}})\Big)\Big]r'(\overline{q}_\circ^{\mathrm{SB}})$$

$$=(1-p)\beta[u_q(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})-c]$$

$$\times\Big[g'\Big(u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-u(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})+c\overline{q}_\circ^{\mathrm{SB}}\Big)-g'\Big(r(\overline{q}_\circ^{\mathrm{SB}})\Big)\Big], \tag{22}$$

where the second equality follows from Eq. (18). Since $u_q(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})>c$, $g''(\delta)>0$, $f'(q)<0$, and $f(\overline{q}^{\mathrm{SB}})=0$, it follows from Eq. (22) that $\overline{q}^{\mathrm{SB}}>(<)\ \overline{q}_\circ^{\mathrm{SB}}$ if, and only if, $u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-u(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})+c\overline{q}_\circ^{\mathrm{SB}}>(<)\ r(\overline{q}_\circ^{\mathrm{SB}})$, where the former is the efficiency loss from selling to low valuation buyers and the latter is the information rent given to high valuation buyers. Since $r(q)=u(q,\underline{\theta})-u(q,\overline{\theta})$, we have

$$u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-u(\overline{q}_\circ^{\mathrm{SB}},\overline{\theta})+c\overline{q}_\circ^{\mathrm{SB}}-r(\overline{q}_\circ^{\mathrm{SB}})$$

$$=u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}-u(\overline{q}_\circ^{\mathrm{SB}},\underline{\theta})+c\overline{q}_\circ^{\mathrm{SB}}, \tag{23}$$

which is positive (negative) if, and only if, $u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}>(<)\ u(\overline{q}_\circ^{\mathrm{SB}},\underline{\theta})-c\overline{q}_\circ^{\mathrm{SB}}$.

Define $q^*\in(0,\overline{q}^{\mathrm{FB}})$ as the solution to $u(q^*,\underline{\theta})-cq^*=u(\overline{q}^{\mathrm{FB}},\overline{\theta})-c\overline{q}^{\mathrm{FB}}$, and $q(x)$ as the solution to the following equation:

$$u_q\Big(q(x),\overline{\theta}\Big)=c+\Big(\frac{x}{1-x}\Big)r'\Big(q(x)\Big), \tag{24}$$

for all $x \in [0,1]$. Differentiating Eq. (24) with respect to x and rearranging terms yields

$$q'(x) = \frac{r'\Big(q(x)\Big)}{(1-p)^2 u_{qq}\Big(q(x), \overline{\theta}\Big) - x(1-x) r''\Big(q(x)\Big)} < 0, \tag{25}$$

where the inequality follows from the properties of $u(q,\theta)$. When $x = 0$, it follows from Eqs. (3) and (24) that $q(0) = \overline{q}^{\rm FB}$. When $x = p$, it follows from Eqs. (18) and (24) that $q(p) = \overline{q}_\circ^{\rm SB}$. When x approaches 1, it follows from $\lim_{q\to 0} u(q,\theta) = \infty$ and Eq. (24) that $\lim_{x\to 1} q(x) = 0$. Eq. (25) implies that there exists a unique point, $p^* \in (0,1)$, at which $q(p^*) = q^*$. Hence, we conclude from Eq. (25) that $q^* > (<)\ \overline{q}_\circ^{\rm SB}$ so that $u(q^*, \underline{\theta}) - cq^* = u(\overline{q}^{\rm FB}, \overline{\theta}) - c\overline{q}^{\rm FB} > (<)\ u(\overline{q}_\circ^{\rm SB}, \underline{\theta}) - c\overline{q}_\circ^{\rm SB}$ if, and only if, $p > (<)\ p^*$.

When $\overline{q}^{\rm SB} > (<)\ \overline{q}_\circ^{\rm SB}$, the unit price paid by high valuation buyers is smaller (greater) in the presence than in the absence of regret aversion since

$$\frac{\underline{t}^{\rm SB}}{\underline{q}^{\rm FB}} - \frac{\underline{t}_\circ^{\rm SB}}{\underline{q}^{\rm FB}} = \frac{r(\overline{q}_\circ^{\rm SB}) - r(\overline{q}^{\rm SB})}{\underline{q}^{\rm FB}} < (>)\ 0,$$

where the inequality follows from $r'(q) > 0$. Likewise, the unit price paid by low valuation buyers is also smaller (greater) in the presence than in the absence of regret aversion since

$$\frac{\overline{t}^{\rm SB}}{\overline{q}^{\rm SB}} - \frac{\overline{t}_\circ^{\rm SB}}{\overline{q}_\circ^{\rm SB}} = \frac{u(\overline{q}^{\rm SB}, \overline{\theta})}{\overline{q}^{\rm SB}} - \frac{u(\overline{q}_\circ^{\rm SB}, \overline{\theta})}{\overline{q}_\circ^{\rm SB}} < (>)\ 0,$$

where the inequality follows from $u(0,\theta) = 0$ and $u_{qq}(q,\theta) < 0$. We as such establish the following proposition.

Proposition 2. *Introducing regret aversion to the monopolist makes the monopolist reduce (enlarge) the downward distortion on the second-best quantity offered to low valuation buyers, and reduce (raise) the unit prices paid by all buyers if, and only if, the probability that* $\theta = \underline{\theta}$ *is greater (smaller) than the critical value,* p^**, that solves* $q(p^*) = q^*$.

The intuition for Proposition 2 is as follows. When $\underline{\theta}$ is sufficiently likely to be seen in that $p > p^*$, the tradeoff between allocative efficiency and information rent leads to greater efficiency losses from selling to low valuation buyers in exchange for lower information rents given to high valuation buyers in equilibrium of the standard model. Introducing regret aversion to the monopolist makes the monopolist take into account the difference between the disutility from the larger regret due to efficiency loss and that from the smaller regret due to information rent. To minimize regret, the monopolist reduces the downward distortion on the second-best quantity offered to low valuation buyers, thereby improving the allocative efficiency. This in turn raises the positive information rents left to high valuation buyers since $r'(q) > 0$. As such, high valuation buyers are made better off while low valuation buyers are indifferent when regret aversion prevails. The opposite is true when $\underline{\theta}$ is sufficiently unlikely to be seen in that $p < p^*$.

Finally, we examine the effect of greater regret aversion on the optimal nonlinear pricing contracts. To this end, we totally differentiate $f(\overline{q}^{\mathrm{SB}}) = 0$ with respect to β to yield

$$\frac{\partial \overline{q}^{\mathrm{SB}}}{\partial \beta} = \frac{(1-p)r'(\overline{q}^{\mathrm{SB}})}{\beta f'(\overline{q}^{\mathrm{SB}})}\left[\frac{u_q(\overline{q}^{\mathrm{SB}},\overline{\theta})-c}{r'(\overline{q}^{\mathrm{SB}})} - \frac{u_q(\overline{q}_{\circ}^{\mathrm{SB}},\overline{\theta})-c}{r'(\overline{q}_{\circ}^{\mathrm{SB}})}\right], \tag{26}$$

where we have used Eqs. (18) and (20) and $f(\overline{q}^{\mathrm{SB}}) = 0$. Since $[u_q(q,\overline{\theta})-c]/r'(q)$ is decreasing in q for all $q \in [0, \overline{q}^{\mathrm{FB}}]$, It follows from Eqs. (21) and (26) that $\partial \overline{q}^{\mathrm{SB}}/\partial \beta > (<)\ 0$ if, and only if, $\overline{q}^{\mathrm{SB}} > (<)\ \overline{q}_{\circ}^{\mathrm{SB}}$, i.e., $p > (<)\ p^*$. The unit prices paid by high and low valuation buyers, $[u(\underline{q}^{\mathrm{FB}},\underline{\theta}) - r(\overline{q}^{\mathrm{SB}})]/\underline{q}^{\mathrm{FB}}$ and $u(\overline{q}^{\mathrm{SB}},\overline{\theta})/\overline{q}^{\mathrm{SB}}$, as such decrease (increase) when β increases if, and only if, $p > (<)\ p^*$. The marginal effect of greater regret aversion on the optimal nonlinear pricing contracts as such inherits the global effect stated in Proposition 2, thereby invoking the following proposition.

Proposition 3. *Making the monopolist more regret averse induces the monopolist to reduce (enlarge) the downward distortion on the second-best quantity offered to low valuation buyers, and reduce (raise) the unit prices paid by all buyers if, and only if, the probability that $\theta = \underline{\theta}$ is greater (smaller) than the critical value, p^*, that solves $q(p^*) = q^*$.*

Since $r'(q) > 0$, high valuation buyers are made better (worse) off when the monopolist becomes more regret averse if, and only if, $\underline{\theta}$ is sufficiently likely (unlikely) to be seen in that $p > (<)\ p^*$. The monopolist's expected profit in equilibrium is given by

$$\pi^{\mathrm{SB}} = p[u(\underline{q}^{\mathrm{FB}}, \underline{\theta}) - r(\overline{q}^{\mathrm{SB}}) - c\underline{q}^{\mathrm{FB}}] + (1-p)[u(\overline{q}^{\mathrm{SB}}, \overline{\theta}) - c\overline{q}^{\mathrm{SB}}]. \tag{27}$$

Differentiating Eq. (27) with respect to β yields

$$\frac{\partial \pi^{\mathrm{SB}}}{\partial \beta} = \frac{(1-p)^2 r'(\overline{q}^{\mathrm{SB}})^2}{\beta f'(\overline{q}^{\mathrm{SB}})} \left[\frac{u_q(\overline{q}^{\mathrm{SB}}, \overline{\theta}) - c}{r'(\overline{q}^{\mathrm{SB}})} - \frac{u_q(\overline{q}^{\mathrm{SB}}_{\circ}, \overline{\theta}) - c}{r'(\overline{q}^{\mathrm{SB}}_{\circ})} \right]^2, \tag{28}$$

where we have used Eqs. (18) and (26). Hence, it follows from Eqs. (21) and (28) that $\partial \pi^{\mathrm{SB}}/\partial \beta < 0$ for all $p \neq p^*$ and $\partial \pi^{\mathrm{SB}}/\partial \beta = 0$ when $p = p^*$. Regret aversion as such always contributes to negative global and marginal effects on the monopolist's equilibrium expected profit except in the knife-edged case that $p = p^*$, wherein the monopolist's equilibrium expected profit is invariant to the prevalence and intensity of regret aversion.

5. Conclusion

In this paper, we incorporate regret theory into the canonical principal-agent model of nonlinear pricing *à la* Maskin and Riley (1984). A regret-averse monopolist sells a single good to a continuum of heterogeneous buyers who can be either high or low valuation buyers. The monopolist's preferences are characterized by a modified utility function that includes disutility from having chosen ex-post suboptimal alternatives. The magnitude of regret is measured by the difference between the actual profit and the maximum profit that could have been earned should the monopolist have observed each buyer's true taste parameter.

Taking the monopolist's regret aversion into account, we characterize the usual rent extraction-efficiency tradeoff under asymmetric information (Laffont and Martimort, 2002). When buyers are more likely to have high (low) valuation,the monopolist reduces (enlarges) the downward distortion on the second-best quantity offered to low valuation buyers so as to minimize the difference between the regret due to the efficiency loss and that due to the information rent. This results in lower (higher) unit prices paid by all buyers. While low valuation buyers are indifferent when regret aversion prevails, high valuation buyers are made better (worse) off and the monopolist always earns a lower expected profit. Our results as such shed light on how regret aversion plays a distinct role in optimal nonlinear pricing under asymmetric information.

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