Regulation of two-part tariffs and quality choice under asymmetric information

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Abstract

In many instances prices and quality of utilities are regulated. We identify and analyze six distinct regulation regimes allowing for welfare maximization and extraction of monopoly rents if, first, the regulator has full information about market conditions and, second, quality is verifiable. These regimes call for two-part tariffs. We analyze a three-stage game where the regulator, in stage one, sets regulation under uncertainty about market conditions. In contrast, the firm has perfect information in stage two. In stage three customers decide on demand. We show that instruments that make use of standards on prices, in combination with bonuses for quality normally, optimize expected welfare.

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1 Introduction

It is common international practice that prices and quality of utilities are regulated due to welfare and distributional objectives. The definition of quality strongly depends on the utility in question. In the transport sector quality is often measured by congestion. For instance, air navigation service providers and airports are asked to optimize delays in air transport operations because congestion is costly for airlines and passengers. An important variable which determines quality in the postal sector is delivery speed. In the electricity, gas, and water sector, quality can be measured by, say, the number and duration of service interruptions and in the telecommunications sector by, e.g., installation speed of telephone services and the number of trouble reports [2].

The effect of monopolistic behavior on quality performance is not clear-cut. While profit maximizing monopolistic firms typically set prices too high, Spence [15] and Sheshinski [14] showed that from a social point of view monopolistic firms can under- or even overperform with regard to quality aspects. The reason is that the monopoly firm bases quality choice on the preferences of the *marginal* user while the social planner bases quality choice on the preferences of the *representative* user. Hence, if and only if the marginal user is representative, then the monopoly and the social planner will choose a similar quality level. Otherwise, if the marginal user has a higher preference for quality than the representative user, then the monopoly chooses quality too high et vice versa.

To control monopoly behavior the utilities' prices are traditionally linked to their costs. Under a rate-of-return regulation, which is common in the U.S., the return on the utilities' invested capital is constrained which determines prices. Since a rate-of-return regulation forces the capital stock up [4], the quality level depends on whether quality is capital-using or not [15]. As a consequence, a rate-of-return regulation can deteriorate quality if it is labor intensive. In comparison, under a cost-plus regulation, which is common in Europe, prices are determined by a maximum return on total costs. Since quality improvements will increase the firms costs, and these costs can be reimbursed by higher prices, this stimulates quality performance [11], [15], [14].

The price-cap approach became an international standard where price constraints are chosen ex ante for a certain period of time, normally around five or six years. Hence, the regulated firm can realize additional profits from reducing costs because the price-cap is not supposed to be adjusted during the regulation period. This enhances the incentives of the firm to actually generate efficiency gains compared to the other regulation regimes. However, under a price-cap regulation, utilities choose suboptimal low quality levels from a social point of view [15], [14], [5]. The reason is that cost reductions directly increase profits while increasing costs due to quality enhancements can not be used as a vehicle to increase prices.

Furthermore, different regulation approaches are available that directly target the quality performance of the firm including minimum quality standards, bonuses and penalties, and the publication of quality measures [12], [13]. Bonuses and penalties can be output or input oriented. In contrast to minimum quality standards, bonuses and penalties induce the regulated firm to use its privileged cost information. However, a basic condition for output oriented regulation schemes to be workable is that the quality performance of the regulated firm is verifiable, i.e. whether quality can be observed and documented for a third party, e.g., a court [13]. In contrast, the publication of quality measures only requires observability. Input oriented rewarding schemes can be applied in the cases where neither verifiability nor observability of quality is given.

In practice measures of price and quality regulation are frequently combined. For instance, the price-cap of the British air navigation service provider NATS depends on an index that is based on average delays of flights. Improvements of the average delay looses the price-cap while deteriorations tightens it. A similar approach is also applied to the price-cap regulation of water companies in the UK and energy network providers in the UK, Norway, and the Netherlands [1]. A major disadvantage of this type of regulation is that it implies a trade-off between prices on the one hand and quality performance on the other hand. A higher quality leads to higher prices and, therefore, reduces demand, or prices are low but quality is also low.

Observe that current regulation regimes focus on linear pricing systems. Moving towards two-part tariffs significantly changes the picture. For instance, under perfect price discrimination a monopoly chooses output quantity and quality in order to optimize welfare because it can use fixed fees to fully extract consumer surplus. However, redistribution of monopoly rents towards consumers is an important regulatory objective [9]. Indeed, we identify a set of regulatory regimes based on two-part tariffs that are capable of implementing a welfare optimum and allowing for arbitrary redistribution of monopoly rents towards customers. Necessary preconditions are that the regulator possesses perfect information about market conditions and that quality is verifiable. However, the relation between the regulator and the firm is normally characterized by asymmetric information. In fact, the monopoly is supposed to have better information about demand and cost conditions than the regulator. For that reason we analyze the potential of the different regulation regimes to increase expected welfare.

The regulation regimes we consider are based on standards as instruments only, which we will call pure standards regimes, or combinations of standards and bonuses as instruments. Under pure standards regimes the regulator combines standards on quality with standards on output quantity or price. Additionally, the regulator sets a cap on fixed fees in order to control monopoly rents. Regulation regimes that combine standards and bonuses as instruments are of four different types. Two include a standard on quality in combination with bonuses for increasing output or decreasing price. The way bonuses are granted is by variations of the fixed fee cap. The higher the output or the lower the price the higher the fixed fee cap. The remaining two regimes consist of standards on outputs or prices in combination with bonuses for increasing quality. Bonuses are again granted by variations of the fixed fee cap depending on the quality performance of the firm.

We show that pure standards regimes are not dominated by regulation regimes that combine standards and bonuses as instruments in terms of expected social welfare. Furthermore, we demonstrate that for a reasonable range of demand variance price standards in combination with bonuses for enhanced quality optimize expected welfare.

The next section presents the model. In section 3 we compare welfare optimal and monopolistic behavior. In section 4 we identify the set of regulation regimes to be analyzed. Pure standards regimes are considered in section 5. Regulation regimes that combine standards and bonuses as instruments are considered in section 6. Conclusions are presented in section 7.

2 The Model

We consider a monopoly firm on an upstream market that charges a two-part tariff to its customers, i.e. firms on the downstream market. The latter also charge a two-part tariff to final consumers. Furthermore, downstream firms are supposed to be under perfect competition. The monopoly firm chooses the demand x of the representative customer, the level of output quality $s \geq 0$, and a fixed fee $\tilde{p} \geq 0$ that has to be payed by each customer. Suppose that s is a quality index that gives a verifiable indication of the quality level realized. For instance, the index can show the average delay per flight owing to the air navigation service provider or the number and duration of service interruptions owing to deficient network conditions in telecommunications or energy markets.

The monopoly firm is supposed to be regulated. We model this as a regulation game with three stages. In stage one of the game the regulator chooses and sets the regulation instruments. In the second stage the monopoly maximizes profits. Finally, in stage three customers choose demand.

The relationship between the regulator and the firm is characterized by asymmetric information. The monopoly firm has perfect information about market conditions, i.e. about demand and cost conditions. In contrast, the regulator is uncertain about market conditions. However, the regulator knows that the representative customer's inverse demand $P \geq 0$ is determined by

$$P(x, s) = s\,(a - b\,x + e_p) \tag{1}$$

with $a, b > 0$.[1] The inverse demand function is linear, decreasing in output, and increasing in quality. In particular, the quality level increases the

[1]The specification of the inverse demand function follows Tirole [16]. In contrast to Tirole we add a stochastic term into the formula for the inverse demand function.

prohibitive price and the slope of the inverse demand function but not maximum demand. Uncertainty is due to the stochastic term $e_p \in \Re$ with expectation value 0 and variance $\sigma_p^2 > 0$ which is also positively affecting the prohibitive price. Note that in the case of externalities in the downstream market, e.g. due to congestion in air space, the inverse demand is net of marginal external costs.

Furthermore, the regulator knows that the monopoly's costs per capita C are determined by

$$C(s) = \frac{s^2\, d\, e_c}{2}$$

with $d > 0$. The cost function contains a stochastic term $e_c \geq 0$ with expectation value equal to 1 and a variance equal to $\sigma_c^2 > 0$. Note, the marginal costs of output are assumed to be equal to zero. In contrast, marginal costs of quality are increasing with a constant rate that depends on the realization of e^c. Cost shocks are independent from demand shocks.

From the representative customer's point of view, the welfare W depending on demand and quality is given by

$$\begin{aligned} W(x,s) &= B(x,s) - C(s) \\ &= s\,x\left(a - \frac{b\,x_i}{2} + e_p\right) - \frac{s^2\,d\,e_c}{2} - F \end{aligned}$$

with

$$B(x,s) := \int_0^x P(y,s)\,dy$$

where $B(x,s)$ determines the customer's benefits net of the variable costs of the downstream firms which is a valid indicator of final consumers' benefits given that downstream firms are in perfect competition and externalities are not existent or internalized [6]. In stage one of the game the regulator maximizes expected welfare. On the other hand, in stage two the monopoly firm knows the values e_p and e_c and, therefore, maximizes actual profits subject to the participation constraint. These profits Π in terms of the representative customer are determined by

$$\begin{aligned}\Pi(x,s) &= x\,P(x,s)+\tilde{p}-C(s)\\ &= x\,s\,(a-b\,x+e_p)+\tilde{p}-\frac{s^2\,d\,e_c}{2}.\end{aligned}$$

Furthermore, the customer surplus CS is determined by

$$CS(x,s)=B(x,s)-x\,P(x,s)-\tilde{p}=\frac{b\,s\,x^2}{2}-\tilde{p}.$$

Assume that the surplus of all customers is identical.

The game will be solved by backward induction for a specific set of regulation regimes. However, our analysis compares welfare and profit maximizing behavior to show that regulation is reasonable. Then we turn to the analysis of the regulation regimes.

3 Welfare vs. profit maximization

In this section we analyze the behavior of a profit maximizing monopoly that uses two-part tariffs. We start with welfare optimization subject to the participation constraint which we call 'regime $*$'. Suppose that under this regime the firm is owned and managed by a social planner solving

$$\max_{x,s,\tilde{p}} W(x,s) \text{ s.t. } CS(x,s)\geq 0. \tag{2}$$

The solution for (2) must satisfy conditions

$$P(x^*,s^*)=0,\;\; B_s(x^*,s^*)=C_s(s^*),\;\text{ and } \tilde{p}^*\leq CS(x^*,s^*). \tag{3}$$

The conditions depicted by (3) reproduce the familiar result that welfare optimization requires marginal cost pricing. On the other hand, they show that optimal output quality is reached if the increase in welfare due to a marginal increase of quality is equal to the marginal cost of quality. Observe that fixed fees are not well-defined. Straightforward calculations lead to

$$(x^*, s^*) = \left(\frac{(a+e_p)}{b}, \frac{(a+e_p)^2}{2\,b\,d\,e_c} \right) \tag{4}$$

and

$$\tilde{p}^* \leq \frac{(a+e_p)^4}{8\,b^2\,d\,e_c}. \tag{5}$$

Maximum welfare is determined by

$$W(x^*, s^*) = \frac{(a+e_p)^4}{8\,b^2\,d\,e_c}.$$

Since marginal costs of output are constant and zero, marginal cost pricing would normally lead to losses. However, with two-part tariffs cost recovery requires $\tilde{p}^* \geq C(s^*)$ which is consistent with welfare maximization [7].

Now we turn to the behavior of a profit maximizing monopoly firm ('regime m'). Solving

$$\max_{x,s,\tilde{p}} \Pi(x,s) \text{ s.t. } CS(x,s) \geq 0 \tag{6}$$

demonstrates that the first two conditions shown in (3) also hold for (x^m, s^m) which is leading to $(x^m, s^m) = (x^*, s^*)$. However, in contrast to welfare maximization, under 'regime m' the participation constraint is binding. This shows that monopolistic behavior is fully consistent with welfare maximization [10], [9]. The only difference is, however, that profit maximization leads to a binding participation constraint while welfare maximization does not. Even if cost recovery is taken into account the participation constraint is not binding. Hence, this case allows for a positive customer surplus which, due to perfect competition in the downstream market, translates into a positive surplus for final consumers.

Actually, economic regulation of monopolistic firms follows distributional objectives [8], [3], [9]. For that reason we address the problem of minimizing welfare loss due to a policy that aims to shift surplus towards final consumers. However, note that due to asymmetric information, regulation costs are always positive even if transaction costs are supposed to be zero.

4 The set of regulation regimes

Given that the regulator has perfect information and that quality is verifiable she can choose between different regulation regimes that are capable of implementing a first best allocation and, additionally, allow extracting monopoly rents. These regimes build on two-part tariffs. They can be purely based on standards as instruments or be based on combinations of standards and bonuses. Figure 1 demonstrates.

First, pure standards regimes require a quality standard and a standard on output quantities which we call 'regime $s1$' or, respectively, a standard on prices which we will call 'regime $s2$'. Additionally, these regimes include a fixed fees cap used to extract monopoly rents.

Second, combinations of standards and bonuses as instruments allow for four different regulation regimes including regimes with standards for quality, and bonuses for increasing output quantities which we will call 'regime $b1$' or, respectively, bonuses for decreasing prices which we will call 'regime $b2$'. Moreover, regimes can combine bonuses for increasing quality with standards on outputs which we will call 'regime $b3$' or, respectively, standards on prices which we will call 'regime $b4$'. Bonuses are payed by customers via increases of the fixed fees cap. Moreover, the formula that determines the fixed fees

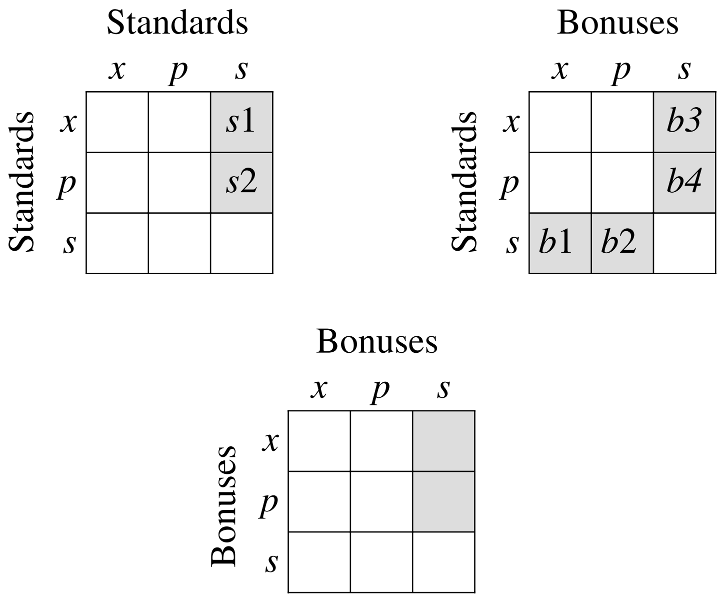

Figure 1: Regulation regimes.

cap always contains a variable which allows arbitrary extraction of monopoly rents without affecting the firms decisions on outputs or quality.

Finally, regulation regimes can be purely based on bonuses as instruments, i.e. standards are not used. Possible regulation regimes of this type include bonuses for increasing output quantity and quality or, respectively, bonuses for decreasing prices and increasing output quality. Again, the fixed fees cap could be adjusted so that monopoly rents can be extracted. However, these two regimes have been difficult to solve analytically using our approach. Therefore, we will leave them for future research and not consider them in the following.

Pure standards regimes and combinations of standards and bonuses as instruments can optimize welfare and allow for cost recovery given that the regulator has perfect information about market conditions. However, since our case describes a situation with asymmetric information, the welfare maximum is impossible to reach. For this reason we analyze the potential of these regulation regimes to maximize *expected* welfare.

5 Pure standards regimes

We start by analyzing two regulation regimes purely relying on standards as instruments beginning with 'regime $s1$'. This regime contains standards on output quantities as well as quality. As a consequence, under this regime, only the price is determined by actual market conditions. Given that the regulator maximizes expected welfare, optimal output and quality standards are given by

$$(x^{s1}, s^{s1}) := \arg\max_{x,s} E[W(x,s)] = \left(\frac{a}{b}\,,\,\frac{a^2}{2\,b\,d}\right). \tag{7}$$

Comparison of (4) with (7) shows that under perfect information, 'regime $s1$' maximizes welfare.

Assume that the regulator can find a fixed fee cap which allows for cost recovery with certainty. The expected welfare under 'regime $s1$' is then given by

$$E[W(x^{s1}, s^{s1})] = \frac{a^4}{8\,b^2\,d}. \tag{8}$$

The second variant of a regulation regime that only uses standards as instruments, 'regime $s2$', combines standards on prices and quality. Under this regime only output quantities are determined by actual market conditions. Optimal standards are determined by

$$(p^{s2}, s^{s2}) := \arg\max_{p,s} E[W(D(p,s),s)] = \left(0, \frac{a^2+\sigma_p^2}{2\,b\,d}\right).$$

where expression $D(p,s)$ directly follows from equation (1). Under perfect information this system will also lead to welfare maximization. Furthermore, observe that $s^{s2} > s^{s1}$ holds. Assume that the regulator can find a fixed fee cap that leads to cost recovery for all realizations of e_p and e_c. The expected welfare under 'regime $s2$' is now given by

$$E[W(D(0,s^{s2}),s^{s2}] = \frac{\left(a^2+\sigma_p^2\right)^2}{8\,b^2\,d} > 0. \tag{9}$$

Which one of the two regimes leads to a higher expected welfare and should be preferred by the regulator?

Proposition 1 *Moving from 'regime $s1$' to 'regime $s2$' increases expected welfare.*

Proof Comparing the expected welfare under 'regime $s1$' with expected welfare under 'regime $s2$' leads to

$$E[W(D(0,s^{s2}),s^{s2}] - E[W(x^{s1},s^{s1})] = \frac{\sigma_p^2\,(2\,a^2+\sigma_p^2)}{8\,b^2\,d}. \tag{10}$$

■

An apparent advantage of 'regime $s2$' is that for a given level of output quality, and in our specific case even for *each* level of output quality, the welfare optimal output quantity is reached because prices are always equal to zero. The reason that optimal output quantities are reached for each level of quality is that quality does not affect maximum demand. Furthermore, the higher quality standard contributes to an increase of expected welfare

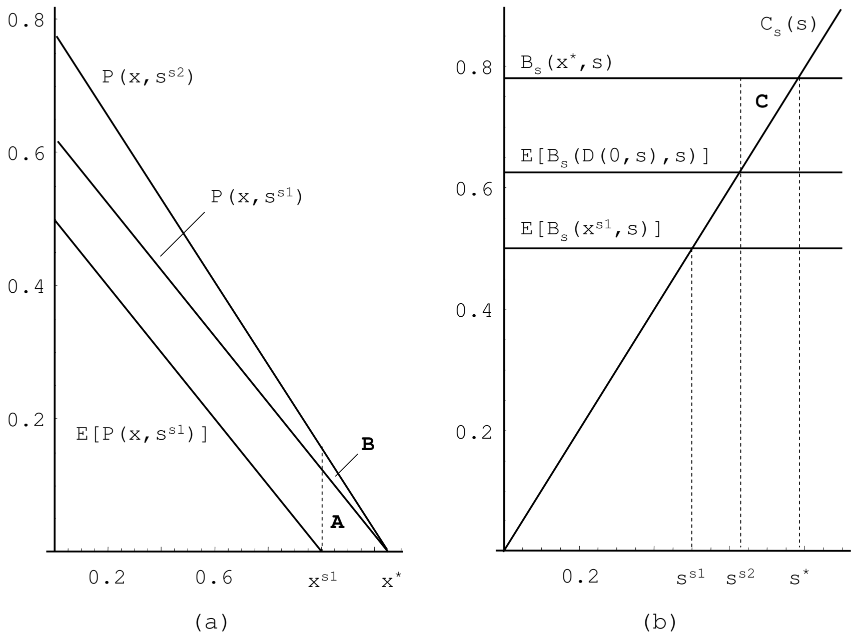

Figure 2: Output versus price standards. Parameter specifications: $a = b = d = e_c = 1$ and $e_p = \sigma_p^2 = 1/4$.

compared to ‘regime $s1$’. The following example in Figure 2 illustrates this. Suppose that $a = b = 1$ holds implying $x^{s1} = 1$. Figure 2a demonstrates that $E[P(1, s^{s1})] = 0$ is satisfied. Additionally, suppose that $d = 1$ and $\sigma_p^2 = 1/4$ holds implying $s^{s1} = 1/2$ and $s^{s2} = 5/8$. Moreover, assume that $e_c = 1$ realizes leading to $E[C_s(s)] = C_s(s) = s$. Figure 2b shows that $E[B_s(1, 1/2)] = E[C_s(1/2)]$ and $E[B_s(D(0, 5/8), 5/8)] = E[C_s(5/8)]$ is satisfied. Finally, assume that $e_p = 1/4$ holds.

Under ‘regime $s1$’ in this situation the price is equal to 1/8 leading to a welfare loss given by area A for a given quality s^{s1} as shown in Figure 2a. Due to zero prices ‘regime $s2$’ avoids this welfare loss and, because the quality standard is higher compared to ‘regime $s1$’, generates a further welfare increase given by area B. However, although output is optimal under ‘regime $s2$’ the overall welfare optimum is not reached because quality is still too low. An increase of quality from s^{s2} up to $s^* = 25/32$ would lead to a further welfare increase of size C.

However, a regulation regime that fully determines the firms’ behavior prevents the firm from making use of its superior information and flexibly responses to actual market conditions. Therefore, we now turn to regulation regimes that combine standards with bonuses as instruments which are less restrictive regarding the firm’s behavior.

6 Combinations of standards and bonuses

Combining standards and bonuses as instruments allows for four different regulation regimes which we called ‘regime $b1$’ to ‘regime $b4$’. In the following we consider the potential of these regimes to optimize expected welfare.

Quality standards and output bonuses 'regime $b1$***'***

'Regime $b1$' is a combination of quality standards with a cap on fixed fees that depends on output quantities. In contrast to the pure standards regimes, under 'regime $b1$' the firm can choose outputs freely without any restrictions.

Assume that the regulator sets a quality standard $s^{b1} \geq 0$ the firm has to satisfy and a cap on fixed fees determined by

$$\tilde{p} \leq \alpha\,(x - \bar{x}). \tag{11}$$

with $\alpha \geq 0$ determining the change of the fixed fees cap due to marginal changes of output quantities. Formula (11) contains a critical level for output quantities $\bar{x} \in \mathbb{R}$. If the chosen quantity is higher than $\bar{x}$, then the fee cap is positive. Otherwise, the fee cap is equal to zero or negative. Hence, the fee cap constitutes a reward scheme where higher quantity levels lead to bonus payments to the firm via higher fixed fees for the customers. On the other hand, low output levels can lead to penalty payments to customers via a negative fixed fee. The latter case is similar to customer compensation schemes. Observe that we allow for $\bar{x}$ to be negative. This means that the regulator can choose $\bar{x}$ so that the firm can charge a positive fixed fee to customers even though output quantities are equal to zero.

Solving backwards, we obtain the firm's optimal strategy, or reaction function

$$x_r^{b1}(\alpha, s) := \arg\max_x \; \Pi(x, s) \text{ s.t. } \tilde{p} \leq \alpha(x - \bar{x})$$

leading to

$$x_r^{b1}(\alpha, s) = \frac{(a + e_p)\; s + \alpha}{2\,b\,s}.$$

Observe that with positive demand shocks, the firm extends quantities et vice versa. Assume that the regulator can find a value of $\bar{x}$ that leads to cost recovery of the firm for each realization of e_p and e_c. The values α^{b1} and s^{b1} that maximize expected welfare are then given by

$$(\alpha^{b1}, s^{b1}) := \arg\max_{\alpha,s} E[W(x_r^{b1}(\alpha, s), s)] = \left(\frac{4\,a^3 + 3\,a\,\sigma_p^2}{8\,b\,d}, \frac{4\,a^2 + 3\,\sigma_p^2}{8\,b\,d}\right)$$

leading to

$$x_r^{b1}(\alpha^{b1}, s^{b1}) = \frac{2\,a + e_p}{2\,b} \tag{12}$$

which shows that 'regime $b1$' maximizes welfare under perfect information. Note, $s^{b1} > s^{s2}$ holds for $\sigma_p^2 > 0$. Calculating expected welfare under 'regime $b1$' leads to

$$E[W(x_r^{b1}(\alpha^{b1}, s^{b1}), s^{b1}] = \frac{16\,a^4 + \sigma_p^2\,(24\,a^2 + 9\,\sigma_p^2)}{128\,b^2\,d}. \tag{13}$$

Can bonuses on outputs contribute to enhanced expected welfare?

Proposition 2 *Moving from 'regime $s1$' to 'regime $b1$' increases expected welfare. In contrast, moving from 'regime $s2$' to 'regime $b1$' reduces expected welfare.*

Proof Comparing the expected welfare under 'regime $s1$', 'regime $s2$', and 'regime $b1$' leads to

$$\frac{\sigma_p^2\,(2\,a^2 + \sigma_p^2)}{8\,b^2\,d} > E[W(x_r^{b1}(\alpha^{b1}, s^{b1}), s^{b1}] - E[W(x^{s1}, s^{s1})] = \tag{14}$$

$$\frac{3\,\sigma_p^2\left(8\,a^2 + 3\,\sigma_p^2\right)}{128\,b^2\,d} > 0.$$

with the ratio of the left hand side of (14) stemming from equation (10). ■

This demonstrates that pure standards regimes are not dominated by regimes that combine standards and bonuses as instruments.

Quality standards and price bonuses 'regime $b2$***'***

We now turn to 'regime $b2$' which uses quality standards and a cap on fixed fees that depends on prices. Similar to 'regime $b1$', this regime allows the firm to choose output quantities without restrictions.

The regulator sets a quality standard $s^{b2} \geq 0$ the firm has to satisfy and a cap on fixed fees determined by

$$\tilde{p} \leq \beta\,(\bar{p} - P(x,s)). \tag{15}$$

with $\beta \geq 0$ determining the change of the fee cap due to marginal changes of the price. Formula (15) also includes a critical price level $\bar{p} \in \mathbb{R}$ affecting the level of bonus payments for given prices.

The firm's optimal strategy, or reaction function

$$x_r^{b2}(\beta,s) := \arg\max_x\ \Pi(x,s) \text{ s.t. } \tilde{p} \leq \alpha(x - \bar{x})$$

leading to

$$x_r^{b2}(\beta,s) = \frac{a + e_p + b\,\beta}{2\,b}.$$

Assume that the regulator can find a value of $\bar{p}$ so that the firm recovers costs for all realizations of e_p and e_c. The values β^{b2} and s^{b2} that maximize expected welfare are then given by

$$(\beta^{b2}, s^{b2}) := \arg\max_{\beta,s} E[W(x_r^{b2}(\beta,s),s)] = \left(\frac{a}{b}, \frac{4\,a^2 + 3\,\sigma_p^2}{8\,b\,d}\right).$$

Note that $s^{b1} = s^{b2}$ holds and β^{b2} is equal to the expected maximum demand. Moreover, welfare effects of 'regime $b1$' to 'regime $b2$' are equal as we will show now.

Proposition 3 *Moving from 'regime $b1$' to 'regime $b2$' has no effect on welfare.*

Proof Observe that

$$x_r^{b2}(\beta^{b2}, s^{b2}) = x_r^{b1}(\alpha^{b1}, s^{b1}) = \frac{2\,a + e_p}{2\,b}$$

holds. Hence, output quantities and quality are equal under 'regime $b1$' and 'regime $b2$'. It follows that welfare effects must also be equal. ■

Therefore, the results derived for 'regime $b1$' also hold for 'regime $b2$'. In particular, under certainty 'regime $b2$' will lead to welfare maximization, too.

Output standards and quality bonuses 'regime $b3$'

'Regime $b3$' is a combination of output standards and bonuses for improvements of the firm's quality performance. In contrast to 'regime $b1$' and 'regime $b2$', under 'regime $b3$' the firm can freely choose the quality level of outputs.

Suppose that the regulator sets an output standard $x^{b3} \geq 0$ and a cap on fixed fees given by

$$\tilde{p} \leq \gamma\,(s - \bar{s}) \tag{16}$$

with $\gamma \geq 0$ determining the change of the fee cap due to marginal variations of quality. Condition (16) includes a critical level of quality $\bar{s} \in \mathfrak{R}$ determining the fixed fee cap for a given quality.

The firms reaction function s_r^{b3} is given by

$$s_r^{b3}(x, \gamma) = \arg\max_s \Pi(x, s) \text{ s.t. } \tilde{p} \leq \gamma\,(s - \bar{s})$$

leading to

$$s_r^{b3}(x, \gamma) = \max\left\{ 0, \frac{x\ (a + e_p - b\,x) + \gamma}{d\,e_c} \right\}. \tag{17}$$

Observe that the quality level is decreasing in e_c and increasing in e_p as long as $s_r^{b3} > 0$ is satisfied.

Assume that the regulator sets a value $\bar{s}$ that allows full cost recovery of the firm for all realizations of e_p and e_c. The optimal standards and bonuses (x^{b3}, γ^{b3}) are then determined by

$$(x^{b3}, \gamma^{b3}) := \arg\max_{x,\gamma} E[W(x, s_r^{b3}(x, \gamma))] \text{ s.t. } s_r^{b3}(x, \gamma) \geq 0. \tag{18}$$

However, ignoring the non-negativity constraint for quality leads to

$$(x^{b3}, \gamma^{b3}) \approx \left(\frac{5\,a^2 - 4\,\sigma_p^2 - 3\,a\,\sqrt{a^2 - 8\,\sigma_p^2}}{4\,b}, \frac{3\,a - \sqrt{a^2 - 8\,\sigma_p^2}}{2\,b} \right) \tag{19}$$

which gives

$$s_r^{b3}(x^{b3}, \gamma^{b3}) \approx \frac{a^2 + 6\,a\,e_p + 4\,\sigma_p^2 + (a - 2\,e_p)\,\sqrt{a^2 - 8\,\sigma_p^2}}{4\,b\,d\,e_c}. \tag{20}$$

Using (18) and (20) it is straightforward to check that 'regime $b3$' maximization under perfect information.

Due to equation (17) the non-negativity constraint is binding if condition

$$e_p < -a + b\,x - \frac{\gamma}{x} \tag{21}$$

is satisfied. Using condition (21), the approximation values given by (19), and applying Chebyshev's Theorem shows that

$$\text{Prob}\left\{ e_p < -a + b\,x^{b3} - \frac{\gamma^{b3}}{x^{b3}} \right\} =$$
$$\text{Prob}\left\{ e_p < \frac{1}{4}\left(-a - \sqrt{a^2 - 8\,\sigma_p^2} \right) \right\} \lessapprox 0.95 \tag{22}$$

holds for $\sigma_p^2 \leq a^2/81$. For that reason we consider the values given by (19) as valid approximations for an optimal regulation under 'regime $b3$' as long as $\sigma_p^2 \leq a^2/81$ is satisfied. Approximating the expected welfare under 'regime $b3$' we obtain

$$E[W(x^{b3}, s_r^{b3}(x^{b3}, \gamma^{b3})] \lessapprox \frac{\left(a^4 + a\left(a^2 - 8\,\sigma_p^2\right)^{\frac{3}{2}} + \sigma_p^2\,\left(20\,a^2 - 8\,\sigma_p^2\right)\right)\,\phi}{16\,b^2\,d} \tag{23}$$

with $\phi := E[1/e_c] > 1$ for $\sigma_p^2 > 0$. Observe that (23) depicts an upper limit for the expected welfare that can be obtained under 'regime $b3$'.

Proposition 4 *The approximation given by (23) indicates that moving from 'regimes1', 'regime s2', 'regime b1' or 'regime b2' to 'regime b3' would increase expected welfare.*

Proof Comparing expected welfare under 'regime $b1$' with the expected welfare under 'regime $b3$' leads to

$$E[W(x^{b3}, s_r^{b3}(x^{b3}, \gamma^{b3})] - E[W(x_r^{b1}(\alpha^{b1}, s^{b1}), s^{b1}] \lessapprox$$
$$\frac{(a\,(a^2 - 8\,\sigma_p^2)^{\frac{3}{2}} + (a^4 + \sigma_p^2\,(20\,a^2 - 8\,\sigma_p^2)))\,\phi - 2\,(a^2 + \sigma_p^2)^2}{16\,b^2\,d} > 0.$$

■

However, for exact results we need to specify the distribution of demand shocks and recalculate expected welfare under 'regime $b3$'. For that reason, in appendix A we apply a uniform distribution of demand shocks and show that the indications named in proposition 4 are valid for this case.

Price standards and quality bonuses 'regime $b4$'

'Regime $b4$' contains price standards and bonuses for increasing quality performance. Suppose that the regulator sets a price standard $p^{b4} = 0$ and a cap on fixed fees similar to (16). The firm's reaction function is then given by

$$s_r^{b4}(\gamma) = \arg\max_s \Pi(D(0, s), s) \text{ s.t. } \tilde{p} \leq \gamma\,(s - \bar{s})$$

which is equal to

$$s_r^{b4}(\gamma) = \frac{\gamma}{d\,e_c}.$$

Observe that s_r^{b4} is decreasing in e_c and, in contrast to s_r^{b3}, fully independent from e_p. Moreover, $s_r^{b3} > s_r^{b4}$ if and only if $a - b\,x + e_p > 0$ holds. Hence, if prices turn out to be positive under 'regime $b3$', then for a given value of γ

the firm provides a higher quality than under 'regime $b4$' et vice versa. The intuition is that an increasing quality level leads to further price increases under 'regime $b3$' and can, therefore, increase profit. On the other hand, if prices are negative, then decreasing quality reduces demand and, therefore, increases profits. In comparison, under 'regime $b4$' prices are always equal to zero.

The optimal value γ^{b4} maximizing expected welfare is given by

$$\gamma^{b4} := \arg\max_{\gamma} E[W(D(0, s_r^{b4}(\gamma)), s_r^{b4}(\gamma))] = \frac{a^2 + \sigma_p^2}{2\, b}$$

Assume that the regulator can find a value for $\bar{s}$ so that the firm can cover its costs for all realizations of e_p and e_c. Under 'regime $b4$' the expected welfare is then given by

$$E[W(D(0, s_r^{b4}(\gamma^{b4})), s_r^{b4}(\gamma^{b4}))] = \frac{\left(a^2 + \sigma_p^2\right)^2 \phi}{8\, b^2\, d}.$$

with $\phi := E[1/e_c] > 1$ for σ_p^2. Comparing the welfare effects of 'regime $b4$' with the other regimes considered leads to:

Proposition 5 *Moving from 'regime $s1$', 'regime $s2$', 'regime $b1$', or 'regime $b2$' to 'regime $b4$' increases expected welfare. Furthermore, moving from 'regime $b3$' to 'regime $b4$' always increases expected welfare if $\sigma_p^2 < 2\, a^2/25$ is satisfied.*

Proof Comparing expected welfare under 'regime $b4$' and 'regime $s2$' gives

$$E[W(D(0, s_r^{b4}(\gamma^{b4})), s_r^{b4}(\gamma^{b4}))] - E[W(D(0, s^{s2}), s^{s2}] = \frac{\left(a^2 + \sigma_p^2\right)^2 (\phi - 1)}{8\, b^2\, d} > 0$$

since $\phi > 1$ holds. Furthermore, it holds

$$E[W(D(0, s_r^{b4}(\gamma^{b4})), s_r^{b4}(\gamma^{b4}))] - E[W(x^{b3}, s_r^{b3}(x^{b3}, \gamma^{b3})] \gtrapprox$$

$$\frac{\left(a^4 - 16\,a^2\,\sigma_p^2 + 10\,\sigma_p^4 - a\left(a^2 - 8\,\sigma_p^2\right)^{\frac{3}{2}}\right)\,\phi}{16\,b^2\,d} \geq 0$$

for $\sigma_p^2 \leq 2\,a^2/25$. ■

Observe that for $\phi = 1$, i.e. there is no uncertainty about costs, 'regime $s2$' and 'regime $b4$' perform equally well. However, if costs are uncertain, then the flexibility provided to the firm by using bonuses as instruments and not fixing quality via standards actually increases expected welfare. Furthermore, this shows that 'regime $b4$' leads to welfare maximization under perfect information.

Moreover, as shown in appendix A, if demand shocks are uniformly distributed the approximations used in proposition 5 produce valid results as long as σ_p^2 is of reasonable size. However, if σ_p^2 is very high then 'regime $b3$' generates a higher expected welfare than 'regime $b4$'. Note that we set a price standard equal to zero without proving its optimality. Therefore, it might be possible to further improve welfare results by adjusting the price standard according to σ_p^2.

The existing results lead to:

Proposition 6 *In equilibrium the regulator chooses 'regime $b4$' given that $\sigma_p^2 \leq 2\,a^2/25$ is satisfied. Otherwise the regulator chooses between 'regime $b3$' and 'regime $b4$'.*

Proof The first part of the proposition directly follows from proposition 5. Furthermore, appendix A demonstrates that for high values of σ_p^2 'regime $b3$' can lead to a higher expected welfare than 'regime $b4$'. ■

Because of asymmetric information the involvement of a regulator in the economic process leads to welfare losses which determine a part of the regulation costs beside transaction costs. Given that the monopoly maximizes profits it also maximizes welfare. However, regulation prevents pure profit maximization and, therefore, distorts allocation. The upper limit for expected welfare is given by

$$E[W(x^m, s^m)] = \frac{\left(a^4 + 6\,a^2\,\sigma_p^2 + 4\,a\,\sigma_p^3 + \sigma_p^4\right)\,\phi}{8\,b^2\,d}. \tag{24}$$

leading to a loss of expected welfare under 'regime $b4$' that is equal to

$$E[W(x^m, s^m)] - E[W(D(0, s_r^{b4}(\gamma^{b4})), s_r^{b4}(\gamma^{b4}))] = \frac{a\,\sigma_p^2\,(a + \sigma_p)\,\phi}{2\,b^2\,d} > 0.$$

7 Conclusions

In order to enhance social welfare and shift rents towards final consumers, monopolistic utilities, e.g. air traffic management providers and network providers in telecommunication or energy markets, are normally regulated. In most of these industries besides prices, the quality of monopolistic supply is also of importance. Against this background, we considered six distinct regulation regimes allowing for welfare optimal control of prices, quality and monopoly rents in the case of perfect information and verifiable quality. These regimes are based on standards as instruments or combinations of standards and bonuses as instruments. Furthermore, they require the use of two-part tariffs in the upstream market.

Our analysis comprises a three-stage game with asymmetric information in which, first, the regulator chooses regulation under uncertainty about market conditions, second, the monopoly chooses prices, quality, and fixed fees, and, third, consumers choose demand. We demonstrate that regimes including bonuses as instruments do not dominate regimes combining standards and bonuses as instruments. The reason is that price standards in combination with quality standards can generate a higher level of expected welfare than quality standards in combination with bonuses depending on prices or output quantities.

Moreover we showed that regulation regimes that make use of bonuses depending on quality performance in combination with quantity or price standards lead to a higher expected welfare than all other regimes considered. In particular, we proved that in equilibrium the regulator chooses a regulation regime which makes use of bonuses for quality improvements in combination with price standards for reasonably values of demand variance. In contrast to this, simulations applying a uniform distribution to demand shocks demonstrate that for high values of demand variance a regulation regime combining quality bonuses with output standards can outperform the former regime with regard to expected welfare.

A Uniform distribution of demand shocks

Suppose that e_p is uniformly distributed with support $\left[-\sqrt{3\,z}, \sqrt{3\,z}\,\right]$. Then, $\sigma_p^2 = z$ holds. Using (22) it is easy to check that for $z \leq 3\,a^2/49$ the approximations shown by (19) and (23) are exact. Therefore, the indications provided by proposition 4 are correct for $z \leq 3\,a^2/49$ in this case. For $z > 3\,a^2/49$ we obtain

$$(x^{b3}, \gamma^{b3}) = \left(\frac{8\,\left(a^2 + 2\,a\,\sqrt{3\,z} + 3\,z\right)}{25\,b}, \frac{4\,\left(a + \sqrt{3\,z}\,\right)}{5\,b} \right)$$

leading to

$$E[W(x^{b3}, s_r^{b3}(x^{b3}, \gamma^{b3})] =$$
$$\frac{12\,\left(18\,a\,\sqrt{z}\,\left(a^2 + z\right)\,\left(a^2 + 9\,z\right) + \sqrt{3}\,\left(a^2 + 3\,z\right)\,\left(a^4 + 42\,a^2\,z + 9\,z^2\right)\right)\,\phi}{3125\,b^2\,d\,\left(a + \sqrt{3\,z}\,\right)\,\sqrt{z}}.$$

Furthermore, assume that $a = b = d = 1$, and $\phi = 6/5$ holds. Figure 3 demonstrates that expected welfare under 'regime $b3$' denoted by $E[W^{b3}]$

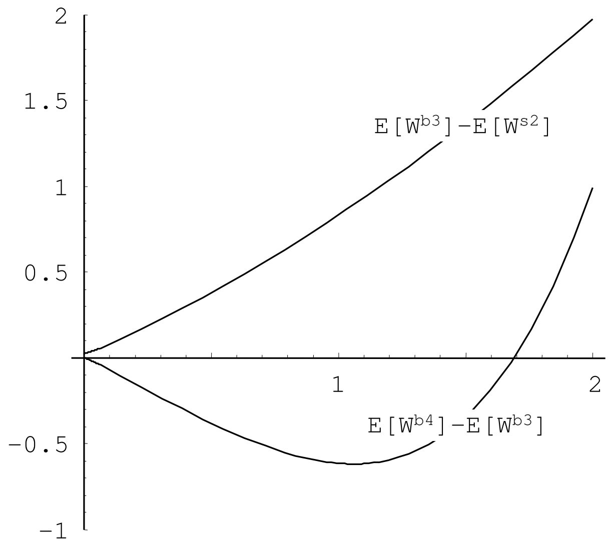

Figure 3: 'Regime $b3$' versus 'regime $s2$' and 'regime $b4$'. Parameter specifications: $a = b = d = 1$, and $\phi = 6/5$.

is strictly higher than under 'regime $s2$' denoted by $E[W^{s2}]$ since $E[W^{b3}] - E[W^{s2}] > 0$ holds for all $z \geq 0$ in this case. Observe that this includes situations without demand uncertainty, i.e. $z = 0$. The reason is that $\phi > 1$ holds and bonus systems better adjust quality levels according to actual market conditions.

On the other hand, expected welfare under 'regime $b3$' is lower than expected welfare under 'regime $b4$' denoted by $E[W^{b4}]$ for $z < 1.69$ and higher or equal otherwise. This demonstrates that 'regime $b3$' can outperform 'regime $b4$' if demand variance is high enough.

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