

**Simple Regulatory Policies in the Presence of  
Demand and Cost Uncertainty**

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## **ABSTRACT**

We analyze the design of regulatory policy in the presence of demand uncertainty when the regulated firm has superior knowledge of its cost structure. The presence of demand uncertainty introduces important new considerations for the regulator. We show that by limiting the regulated firm's obligation to serve and by protecting the firm against stranded investment, the regulator can enhance consumer welfare relative to the case where the regulator can only set a single price for the regulated product before demand is realized.

## **1. Introduction.**

Demand uncertainty presents critical problems in many regulated industries, including telecommunications and electricity. It is often essential to make plans to serve future demand long before the exact magnitude of demand for the regulated product is known. Doing so while ensuring adequate earnings for the regulated producer can be problematic, particularly when the regulated firm has better information than the regulator about production costs.

The purpose of this research is to examine the design of regulatory policy when the regulated producer has superior technological information and when future demand for the regulated product is uncertain at the time regulatory policy is formulated. We assume that before all demand uncertainty is resolved, the regulator must specify fully the policy that will prevail once demand is realized. This assumption reflects the reality that considerable resources are consumed in designing regulatory policy, and it is prohibitively costly to revise regulatory policy every time new information arrives. We also assume that the regulator's policy instruments are limited. The regulator can specify only: (1) a two-part tariff for the regulated product; (2) a minimum level of sales for the firm; and (3) a maximum amount of the regulated product that consumers can purchase. The minimum sales guarantee helps insure the firm against stranded investment when demand for the regulated product turns out to be unexpectedly small. The consumption ceiling serves to limit the firm's obligation to serve when demand is unexpectedly high. These restrictions on feasible regulatory policy are designed to capture the fact that, in practice, regulatory rules tend to be relatively simple. Minimum and maximum consumption levels are readily understood, as are linear prices and lump-sum fees.

Another reason for our focus on these particular simple regulatory rules is that they include as special cases two simple policies that have received considerable attention in the

literature.<sup>1</sup> Under the rules we consider, the regulator can simply set a single price for the regulated product, and instruct the firm to satisfy all demand that ultimately arises at that price. Alternatively, the regulator can specify the amount of output the firm must supply, and allow market forces to determine the price at which this output is sold. Neither of these policies is optimal, though. We show that the regulator always prefers to establish output floors and ceilings that alter market demand at the established regulatory price for some realizations of demand. Doing so enables the regulator to better approximate the consumption levels she would enforce in the absence of demand uncertainty. We find the welfare gains from limiting the firm's obligation to serve and protecting the firm against stranded investments can be sizeable, even when the firm's profits are not included in the welfare calculation.

In addition to demonstrating the welfare gains associated with limiting the firm's obligation to serve and protecting the firm against stranded investment, our analysis provides an extension of the literature on incentive regulation with asymmetric cost information to the case of uncertain demand. In most of this literature, demand is assumed to be known when regulatory policy is formulated.<sup>2</sup> Therefore, it is inconsequential whether regulatory policy specifies a price or a quantity level. In the present setting there are important differences between these two policies ... and coupling a regulated price with quantity restrictions dominates both policies.

Our analysis begins in section 2 where the key elements of our model are described. Section 3 reviews the optimal regulatory policy in the benchmark setting where there is no demand uncertainty. Our main findings are recorded in section 4, where we describe the optimal regulatory policy in the presence of asymmetric cost information and demand

uncertainty. Concluding thoughts are offered in section 5.

## 2. Elements of the Model.

There are three main actors in the model: a monopoly producer, a representative consumer, and a regulator. There are also two sources of information asymmetry: the producer has private information ( $\theta$ ) about its production costs, and the consumer has private information ( $v$ ) about how highly he values the regulated product.

To capture these critical information asymmetries formally, we assume the monopolist's cost of producing  $q$  units of output when its cost parameter is  $\theta$  is given by:

$$C(q, \theta) = k + c(q) + \theta q, \quad (2.1)$$

where  $k \geq 0$  is a constant which represents the firm's fixed cost of production, and  $c(\cdot)$  is a strictly increasing, strictly convex function of  $q$  which captures a component of the firm's variable production costs. The remaining component of variable costs incorporates the firm's private cost information. The firm knows the exact value of  $\theta$  from the start of its relationship with the regulator. The regulator cannot observe the realization of  $\theta$ . The regulator views  $\theta$  as a random variable with strictly positive density,  $h(\theta)$ , on the interval  $[\underline{\theta}, \bar{\theta}]$ .  $H(\theta)$  is the distribution function for  $\theta$ . As is common in the literature, we assume  $\frac{d}{d\theta} \left( \frac{H(\theta)}{h(\theta)} \right) \geq 0 \quad \forall \theta \in [\underline{\theta}, \bar{\theta}]$ .<sup>3</sup>

The benefit the representative consumer with valuation parameter  $v$  derives from consuming  $q$  units of the regulated product is given by:

$$B(q, v) = b(q) + vq. \quad (2.2)$$

$b(\cdot)$  is a strictly increasing, strictly concave function of  $q$  that represents the known, deterministic component of the consumer's preferences.<sup>4</sup> Although the consumer ultimately learns the realization of  $v$  before deciding how much of the regulated product to purchase, neither the regulator nor the monopoly producer ever observe this realization. The regulator and firm view  $v$  as a random variable with strictly positive density,  $g(v)$ , on the interval  $[\underline{v}, \bar{v}]$ , and associated distribution function  $G(v)$ .<sup>5</sup>

The regulator's objective is to maximize a weighted average of consumers' surplus and profits, with respective weights of  $\alpha \in [1/2, 1]$  and  $1 - \alpha$ .<sup>6</sup> The regulator is assumed able to specify minimum ( $q_L$ ) and maximum ( $q_H$ ) levels of production, a lump-sum payment ( $T$ ) from the consumer to the producer that is independent of how much output the consumer purchases, and a unit price ( $p$ ) that the consumer must pay for each unit of output he purchases.<sup>7</sup>

When his realized valuation is  $v$  and the unit price of the regulated product is  $p$ , the consumer's preferred consumption level,  $\tilde{q}(p, v)$ , is given by:<sup>8</sup>

$$\tilde{q}(p, v) \equiv \underset{q}{\operatorname{argmax}} \{b(q) + vq - pq\}. \quad (2.3)$$

The consumer's actual consumption level given  $p$ ,  $v$  and the minimum ( $q_L$ ) and maximum ( $q_H$ ) consumption levels established by the regulator is given by:

$$q(p, v) = \begin{cases} q_L & \text{if } v \leq v_L \\ \tilde{q}(p, v) & \text{if } v \in [v_L, v_H] \\ q_H & \text{if } v \geq v_H \end{cases}, \quad (2.4)$$

$$\text{where } q_L = \tilde{q}(p, v_L) \text{ and } q_H = \tilde{q}(p, v_H).^9 \quad (2.5)$$

The first equality in (2.5) defines  $v_L$ , the largest valuation for which the consumer will purchase only the minimum quantity dictated by the regulator. When the consumer's valuation exceeds  $v_L$ , the consumer will purchase more of the regulated product. Similarly, the second inequality in (2.5) defines  $v_H$ , the smallest valuation for which the consumer will purchase the maximum quantity,  $q_H$  (at unit price  $p$ ).

As noted above, a regulatory policy consists of a menu of contracts  $\{p(\cdot), T(\cdot), q_L(\cdot), q_H(\cdot)\}$  from which the firm can make a binding choice. The firm will select the contract that provides the greatest expected profit. We will define  $(p(\theta), T(\theta), q_L(\theta), q_H(\theta))$  to be the contract selected by the regulated producer when  $\theta$  is its realized cost parameter.  $\pi(\theta)$  will denote the firm's expected profit when its realized cost parameter is  $\theta$  and it selects contract  $(p(\theta), T(\theta), q_L(\theta), q_H(\theta))$ . The firm must earn at least its reservation profit (which is normalized to zero) in expectation if it is to be induced to operate in the regulated industry.

Before providing a formal statement of the regulator's problem [RP] in this environment, we briefly review the timing in the model. First, the firm learns its private cost information,  $\theta$ . Next, the regulator specifies the menu of contracts  $\{p(\cdot), T(\cdot), q_L(\cdot), q_H(\cdot)\}$  available to the firm. After the firm chooses the contract it prefers, the consumer learns his valuation ( $v$ ) for the regulated product.<sup>10</sup> The consumer then announces how much output  $q \in [q_L(\cdot), q_H(\cdot)]$  he will purchase. Production occurs next, and compensation is paid according to the terms of

the selected regulatory contract.

Formally, the regulator's problem [RP] is the following:

$$\begin{aligned} \underset{p(\theta), T(\theta), q_L(\theta), q_H(\theta)}{\text{Maximize}} \quad & \int_{\underline{\theta}}^{\bar{\theta}} \int_{\underline{v}}^{\bar{v}} \left\{ \alpha [b(q(p(\theta), v)) + [v - p(\theta)] q(p(\theta), v) - T(\theta)] \right. \\ & \left. + [1 - \alpha] [p(\theta) q(p(\theta), v) + T(\theta) - k - c(q(\cdot)) - \theta q(\cdot)] \right\} dG(v) dH(\theta) \end{aligned} \quad (2.6)$$

subject to,  $\forall \theta, \hat{\theta} \in [\underline{\theta}, \bar{\theta}]$ :

$$\pi(\theta) \geq 0 \quad ; \quad \text{and} \quad (2.7)$$

$$\pi(\theta) \geq \pi(\hat{\theta} | \theta) \quad , \quad (2.8)$$

$$\text{where } \pi(\hat{\theta} | \theta) \equiv \int_{\underline{v}}^{\bar{v}} \left\{ p(\hat{\theta}) q(p(\hat{\theta}), v) + T(\hat{\theta}) - k - c(q(p(\hat{\theta}), v)) - \theta q(p(\hat{\theta}), v) \right\} dG(v). \quad (2.9)$$

The objective function in [RP], (2.6), reflects the regulator's goal of maximizing a weighted average of expected consumer and producer benefits. The individual rationality constraint (2.7) ensures the firm expects to earn at least its reservation profit level. The incentive compatibility constraint (2.8) ensures  $(p(\theta), T(\theta), q_L(\theta), q_H(\theta))$  is the contract most preferred by the firm when the realization of its cost parameter is  $\theta$ .

### 3. A Benchmark Solution.

Before proceeding to characterize the solution to [RP], a benchmark setting is characterized briefly. The benchmark setting is identical to the setting described above except that all parties are fully informed from the outset about the consumer's valuation of the regulated product. Thus, the only information asymmetry in this setting (as in the setting of Baron and Myerson (1982)) concerns the firm's production costs. An examination of the optimal regulatory

policy in this setting facilitates a focus on those features of the solution to [RP] that arise because of the initial uncertainty about consumers' preferences.

We will call the regulator's problem in this benchmark setting [BP]. The solution to [BP] will be denoted by  $q^*$ 's. The key properties of this solution are recorded in Lemma 1.

**Lemma 1.** (Baron and Myerson (1982)). At the solution to [BP]:

$$v + b'(q^*(\theta, v)) = \theta + c'(q^*(\theta, v)) + \frac{[2\alpha - 1]}{\alpha} \frac{H(\theta)}{h(\theta)} \quad \forall v \in [\underline{v}, \bar{v}].$$

Lemma 1 states that for each realization of consumer demand ( $v$ ) and for each realization of the firm's cost parameter ( $\theta$ ), the regulator sets the price for the regulated product to maximize adjusted welfare,  $AW(\theta, v | q)$ , where

$$AW(\theta, v | q) \equiv vq + b(q) - [\theta q + c(q)] - \left[ \frac{[2\alpha - 1]}{\alpha} \frac{H(\theta)}{h(\theta)} \right] q. \quad (3.1)$$

Adjusted welfare is the difference between total welfare (i.e., the sum of realized consumer and producer surplus) and a term proportional to the firm's information rents. Notice from (3.1) that this rent adjustment term increases with  $\alpha$ . Thus, the more highly the regulator values consumer welfare relative to profits, the more costly are the rents that the firm commands from its private cost information in the regulator's effective welfare function.

There are two immediate corollaries of Lemma 1. First, less output is induced from the firm the higher its costs (i.e.,  $q^*(\theta) < 0$ ). Second, more output is induced from the firm the more highly the consumer values the regulated product (i.e.,  $\frac{dq^*(\cdot)}{dv} > 0$ ), *ceteris paribus*. It can also be shown that adjusted welfare increases with the realized consumer valuation,  $v$ , at an

increasing rate (i.e.,  $\frac{dAW(\cdot)}{dv} > 0$  and  $\frac{d^2AW(\cdot)}{dv^2} > 0$ ).

Notice that with no uncertainty about consumer demand, the regulator knows exactly how much output the consumer will purchase at any specified price,  $p$ . Thus, no gains arise from stipulating minimum and maximum consumption levels in this benchmark setting. In contrast, the regulated minimum and maximum consumption levels can play a key role in the presence of uncertainty about consumer preferences.

#### 4. Optimal Regulatory Policy.

Returning to the setting of primary interest, we now characterize the optimal regulatory policy when the regulator and firm are initially uncertain about consumer demand for the regulated product. The key elements of the solution to [RP] are recorded in Proposition 1.

**Proposition 1.** At the solution to [RP]:

$$(i) \quad q_L(\theta) = \tilde{q}(p(\theta), v_L(\theta)) \in (q^*(\theta, \underline{v}), q^*(\theta, v_L(\theta)));$$

$$(ii) \quad q_H(\theta) = \tilde{q}(p(\theta), v_H(\theta)) \in (q^*(\theta, v_H(\theta)), q^*(\theta, \bar{v}));$$

$$(iii) \quad \int_{\underline{v}}^{v_L(\theta)} \frac{\partial}{\partial q_L(\theta)} [AW(\theta, v | q_L(\theta))] dG(v) = 0;$$

$$(iv) \quad \int_{v_L(\theta)}^{v_H(\theta)} \frac{\partial}{\partial p(\theta)} [AW(\theta, v | q(p(\theta), v))] dG(v) = 0; \text{ and}$$

$$(v) \quad \int_{v_H(\theta)}^{\bar{v}} \frac{\partial}{\partial q_H(\theta)} [AW(\theta, v | q_H(\theta))] dG(v) = 0.$$

The conclusions recorded in Proposition 1 are best explained by considering the hypothetical setting where the regulator is unable to specify minimum and maximum consumption levels in the industry. When consumer preferences are initially uncertain in this setting, the best the regulator can do is establish a single price that maximizes expected adjusted welfare. Although adjusted welfare may be maximized on average under this policy, it will not be maximized for each realization of the consumer's valuation,  $v$ . When  $v$  is smaller than expected, the established price will exceed its ideal level, and consumption will be restricted unduly. Similarly, when  $v$  is larger than expected, the established price will fall short of the level that maximizes adjusted welfare, leading to excessive consumption.

The minimum and maximum consumption levels imposed by the regulator help limit the losses that arise when the regulated price that is best on average provides inappropriate incentives for consumption when demand for the regulated product turns out to be especially low or especially high. In particular, when the best average price stifles consumption for low demand realizations, a minimum consumption requirement helps return consumption toward its ideal level. Similarly, a limit on demand helps reduce consumption towards its ideal level when the best average price encourages excessive consumption for the higher demand realizations.

Proposition 1 explains how the production floor and ceiling are optimally determined. Notice that the regulator could set the production floor at the level of output the consumer with the smallest valuation ( $\underline{v}$ ) would purchase in the benchmark setting, given the established regulated price. Doing so would ensure a welfare gain when  $v = \underline{v}$  without incurring any loss in welfare for the higher demand realizations. But greater expected welfare gains are available when  $q_L(\theta)$  is raised above  $q^*(\theta, \underline{v})$  (as reported in property (i) of Proposition 1), because the

higher floor raises consumption towards its ideal level for higher demand realizations. The floor is optimally raised to the point where the expected gains in (adjusted) welfare from raising consumption toward its ideal level (for a range of intermediate  $v$  realizations) are exactly offset by the expected losses in (adjusted) welfare from raising consumption above its ideal level (for the smallest  $v$  realizations). This fact is reported in property (iii) of Proposition 1. Analogous calculations determine the optimal production ceiling, as summarized in properties (ii) and (v) of Proposition 1.

Property (iv) in Proposition 1 states that for those intermediate demand realizations where neither the production floor nor the production ceiling constrain the consumer's consumption (i.e., for  $(v \in (v_L(\theta), v_H(\theta)))$ ), the regulated price is set to balance the losses in expected (adjusted) welfare from inducing too much versus too little consumption relative to the benchmark setting. When she can only set a single price that will prevail for all demand realizations, the regulator will necessarily set a price that is too high when the consumer's valuation turns out to be small, and too low when the realized consumer valuation is large. The best single price balances the resulting losses in expected adjusted welfare.

The regulator's calculus is illustrated in Figure 1. The regulator would like to induce the benchmark output level  $q^*(\theta, v)$  for each demand realization,  $v$ . When she is forced to set a single price for all demand realizations, though, the regulator can only approximate this production schedule imperfectly. The best approximation  $(q(p(\theta), v))$  is achieved through judicious use of the unit price and the production floor  $(q_L(\theta))$  and ceiling  $(q_H(\theta))$ , as shown in the lower panel of Figure 1. The welfare losses that arise from the imperfect approximation of the benchmark production schedule are depicted in the upper panel of Figure 1.<sup>11</sup> Property

(iii) of Proposition 1 implies that (probability-weighted) areas A1 and A2 in Figure 1 are equal in size, because the production floor is set to equate the expected losses in adjusted welfare from inducing too much versus too little consumption in the region where  $q_L(\cdot)$  is consumed. Similarly, the regulated price is chosen to equalize expected losses in adjusted welfare from too little (area A3) and too much (area A4) consumption in the region where the production ceiling and floor do not affect the consumer's consumption choice (i.e., for  $v \in (v_L(\theta), v_H(\theta))$ ). The production ceiling is chosen in analogous fashion, ensuring the expected losses in adjusted welfare given by areas A5 and A6 are of equal magnitude.

Having characterized the optimal use of a production floor and ceiling, it remains to examine the welfare gains that arise from their use. To do so, consider the following example.

EXAMPLE.  $b(q) = 7.5q - \frac{1}{2}q^2$ ;  $c(q) = 5q + \frac{1}{2}q^2$ ;

$$\alpha = 1; \quad g(v) = \frac{1}{v} \quad \forall v \in [0, \bar{v}]; \quad \text{and} \quad h(\theta) = \frac{1}{\theta} \quad \forall \theta \in [0, \bar{\theta}].$$

The example captures a simple setting where both random variables have uniform distributions and the deterministic portions of demand and cost are quadratic. These functional forms facilitate complete solutions to [RP], once values are chosen for the remaining parameters.

If, for instance,  $\bar{\theta} = \bar{v} = 1$ , then the solution to [RP] for the case where  $\theta = .5$  is:

$$q(p(\theta), v) = \begin{cases} q_L = \frac{5}{6} & \text{for } 0 \leq v \leq \frac{1}{3} \\ \frac{1}{2} + v & \text{for } \frac{1}{3} < v < \frac{2}{3} \\ q_H = \frac{7}{6} & \text{for } \frac{2}{3} < v < 1 \end{cases} .$$

Thus, the minimum and maximum consumption constraints each bind for one third of the possible demand realizations. The induced consumption level increases linearly with  $v$  over the intermediate third of the possible realizations of  $v$ . It can be shown that if the regulator were only permitted to set a price for the regulated product, the optimal price would induce  $q(\cdot) = .5 + v \quad \forall v \in [0,1]$ . Similarly, if the regulator could only prescribe a single output level, he would require  $q(\cdot) = 1$ . Both of these policies would generate a level of expected welfare of 1.5.<sup>12</sup> The solution to [RP], in contrast, generates an expected welfare of 1.518. In the benchmark setting where the realization of  $v$  is known to the regulator, he could achieve an expected welfare level of 1.521. Thus, in this setting, the regulator who can bound consumption levels and set a single price for the regulated product achieves over 98% of the level of expected welfare a regulator could achieve who was able to formulate regulatory policy after all demand uncertainty was resolved. Of course, the relative welfare losses when operating under demand uncertainty will increase (respectively, decrease) as the uncertainty becomes more (respectively, less) pronounced (i.e., as  $\bar{v}$  increases (respectively, decreases)).

The gains that arise from the authority to dictate minimum and maximum consumption levels are limited in this example. More pronounced gains arise when the assumption of uniform demand uncertainty is relaxed.<sup>13</sup> To illustrate, consider a setting identical to that in the example described above, except that  $v$  has a discrete, trinary distribution. In particular, suppose  $v = 0$  with probability .945,  $v = 5$  with probability .01, and  $v = 10$  with probability .045. Although the expected value of  $v$  is the same in this setting as in the example above, this discrete formulation of demand admits a significant likelihood that demand will be low. The

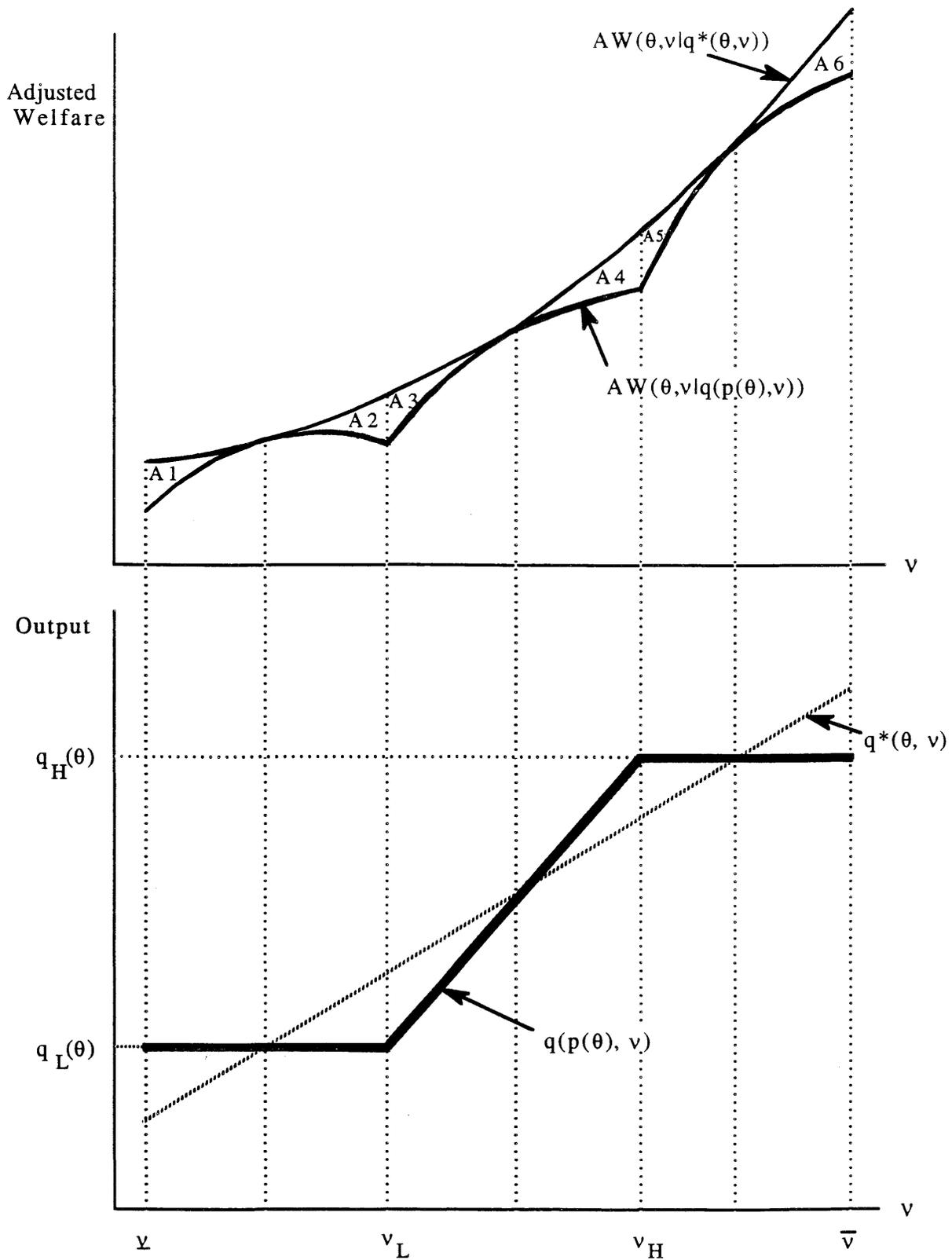
ability to enforce a minimum consumption level when demand is low in this setting enables the regulator to secure sizable welfare gains. In particular, it can be shown that the regulator can increase expected welfare (benefits less costs) by 75 percent when he can specify minimum and maximum consumption levels relative to the case where he can only set a single price or a single quantity.

#### **4. Conclusions.**

The purpose of this note was to examine how simple regulatory tools are optimally employed in the presence of demand and cost uncertainty. Our analysis incorporated the realistic assumption that regulators are often forced to formulate policy before all relevant information about the relevant costs and benefits of different actions is known. Our focus was on the ways in which demand uncertainty alters the standard incentive regulation policy of Baron and Myerson (1982). We also extended the literature initiated by Weitzman (1974) on the relative merits of price and quantity controls by allowing the regulated firm to have private information about production costs when regulatory policy is formulated. We found that, depending on the nature of the demand uncertainty, the imposition of minimum sales levels and maximum consumption levels can provide significant welfare gains relative to the case where the regulator can dictate only a single price for or a single quantity of the regulated product.

Several extensions of our analysis warrant investigation. For instance, capacity choices by the regulated firm might be considered explicitly. To induce the firm to install capacity, it will generally have to be promised a reasonable return on its investment even when realized demand is small. It would be interesting to derive the optimal manner in which to deliver this reasonable return to the firm.

It would also be interesting to endow the regulated firm with additional private information. For example, the firm might know more about likely consumer demand than the regulator. In addition, the firm might be able to undertake some investment (e.g., promoting conservation or enhancing product quality) that affects the demand for its product. These extensions await further study.



**FIGURE 1.** Output and Adjusted Welfare.

## FOOTNOTES

1. This literature dates back to Weitzman (1974), who explains how the optimal choice between price and quantity controls in the presence of asymmetric information and uncertainty is governed by the relative curvatures of the relevant benefit and cost functions. Laffont (1977) extends Weitzman's model by distinguishing between producer and consumer prices. Ireland (1977) introduces contingent prices to the analysis, and Frexias (1980) allows for subsidies. Chen (1990) constructs a dominating regulatory mechanism that admits a choice between price-dependent and quantity-dependent subsidies.
2. This is the case, for example, in the seminal work of Baron and Myerson (1982). For surveys and overviews of the literature, see Baron (1988), Besanko and Sappington (1987), and Caillaud et al. (1988).
3. Recall that this assumption helps avoid "pooling" or "bunching" in the optimal regulatory policy, and thus avoids uninteresting technical complications. See Bagnoli and Bergstrom (1989) for examples of distributions which satisfy this assumption.
4. More general cost and demand functions could be considered without altering our main qualitative conclusions. Our focus on relatively simple functional forms facilitates a

direct comparison of our findings with those in the aforementioned literature that contrasts the performance of prices and quantities as regulatory instruments.

5.  $\theta$  and  $v$  are assumed to be independent random variables.
6. The higher weight on consumers' surplus reflects both the common regulatory mandate of protecting consumers and the political pressures that consumer groups regularly impose on regulators.
7. Notice that  $(p, T)$  can be viewed as a two-part tariff for the regulated product.
8. For expositional simplicity, we assume the parameters of the model are such that even when the consumer's valuation takes on its smallest value,  $\underline{v}$ , the consumer always wishes to consume a strictly positive amount of the regulated product.
9. Notice that  $q(\cdot)$  is a function of  $p, v, q_L$  and  $q_H$ . Similarly,  $v_i(\cdot)$  is a function of  $p$  and  $q_i$ , for  $i = L, H$ . We suppress the dependence of  $q(\cdot)$  and  $v_i(\cdot)$  on  $q_L$  and  $q_H$  for expositional ease.
10. Given the regulatory policies under consideration, it is inconsequential whether the firm and/or the regulator also observe the realized consumer valuation.

11. The fact that the welfare losses stem from a limited ability to approximate the benchmark production schedule is illustrated by the following observation. Suppose  $b(\cdot)$  and  $c(\cdot)$  are both quadratic functions of  $q$ . Also suppose  $h(\cdot)$  and  $g(\cdot)$  are both uniform densities. Then it can be shown that  $AW(\theta, \nu | q^*(\theta, \nu)) - AW(\theta, \nu | q(p(\theta), \nu))$  is proportional to  $[q^*(\theta, \nu) - q(p(\theta), \nu)]^2$ .
  
12. Both policies generate the same level of expected welfare because the cost and benefit functions have the same curvature (i.e.,  $|b''(q)| = c''(q) = 1$ ). Recall from Weitzman (1974) that greater (respectively, less) expected welfare is generated under a price control policy than under a quantity control policy when the benefit function is more (respectively, less) steeply sloped than the cost function, i.e., when  $|b''(q)| >$  (respectively,  $<$ )  $c''(q)$ .
  
13. Blair (1993) shows that when  $\nu$  and  $\theta$  are uniformly distributed on the same support, and when the benefit and cost functions have the same curvature, 7.69 is the maximum percentage gain in expected welfare that can be achieved by specifying minimum and maximum consumption levels rather than setting the optimal price or the optimal quantity.

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