Regulation Under Uncertainty: An Intuitive Survey and Application to Fisheries

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Abstract This paper surveys the issues involved in setting or improving regulatory activity in the presence of uncertainty. It is conducted in a way that will bring forth the underlying intuitions of the existing literature so that the various policy options can easily be distinguished on grounds of efficiency, as well as distributional and international considerations. This approach not only fits well into a section outlining the need for regulatory review, but also provides a basis for suggesting the issues involved in regulating fisheries. Intuition more than modeling aids in initially applying general analysis to specific areas, and the fisheries example illustrates how that application can be scientifically accomplished.

1. Introduction

An extensive literature has developed over the past decade in which the relative merits of various types of regulatory control mechanisms have been investigated under uncertainty. These studies have been fairly analytical and abstract, but they have begun to be applied to a variety of more specific problems. Environmental controls have been studied.[1] International trade restrictions have been studied.[2] Applications to tax-based incomes

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policies and legalistic fining schedules have been accomplished.[3] The list is longer, to be sure, and grows with this volume to include fisheries, as well. In contributing to this growth, though, this paper will continue in the newer vein of the literature to stress intuition rather than hard-core analytics. These analytics are no longer necessary because the previous work has revealed a robust intuitive underpinning that is more easily applied. If we are to be able to talk to the people who do the regulating, moreover, a thorough understanding of that intuition will be essential. We must be able to communicate our work to regulators without risking the glazed-eye disbelief that so often greets a technically tight modeling of a regulatory problem.

With that objective in mind, this paper begins with a description of the efficient responses to uncertainty that one might expect to observe in a perfectly functioning market. These responses are subsequently employed, in section 3, to catalog reasons why regulations might be required before we turn to discuss alternative mechanisms in sections 4 and 5. Section 4 will discuss the single-firm situation, not because it is terribly relevant to applied problems, but rather because the intuition is more easily explained when there is only one firm about which to worry. Section 5 corrects for the simplicity of the single-firm example by including an arbitrary multiple-firm market. Section 6 looks briefly at informational concerns before my perceptions of the fisheries problem are employed to reach policy conclusions about their regulation in the concluding section. My knowledge of fisheries is, at best, limited, but it is hoped that the intuition outlined in the earlier sections will enable the reader to determine how correcting for my perceptual errors might alter my conclusions.

2. Efficient Responses to Uncertainty

When they operate efficiently, costlessly, and in the absence of any externalities, competitive markets allow unrestrained reactions to all relevant sources of uncertainty by every agent. These agents respond in their own best interest, of course, but their collective response maximizes welfare in each and every state of nature. This statement is simply a generalization of the fundamental theorem of welfare economics and is thus widely known,[4] but it says nothing about the distribution of welfare across agents. Formalizing the collection of individual responses to uncertainty can, as a result, provide not only enormous insight into the distributions of agent responses as functions of random uncertainty, but also on potential rationale for regulatory intrusion into the marketplace. Postponing that for later, though, we first turn to providing the requisite formalization.

Consider a market for some good x consisting of N individuals indexed by their inverse demand schedules $d^i(x_i, \beta_1)$; $i = 1, \ldots, N$; and M firms indexed by their cost schedules $c^j(x_j, \delta_j)$; $j = 1, \ldots, M$. The vector $\boldsymbol{\beta} \equiv (\beta_1, \ldots, \beta_M)$ reflects random variables that influence the demand schedules for x registered by the various consumers, while the vector $\boldsymbol{\delta} \equiv (\delta_1, \ldots, \delta_M)$ reflects similar variables that can alter the cost of producing x at the various firms. The competitive equilibrium for an arbitrary state of nature $(\boldsymbol{\beta}, \boldsymbol{\delta})$ is now easily characterized. It requires simply that the universal marginal cost of producing x equals the price every consumer must pay *and* that the total quantity supplied at that price equal the total quantity demanded. Notationally, then, the market-clearing price $p^*(\boldsymbol{\beta}, \boldsymbol{\delta})$ produces reaction schedules $x_i^*[\beta_i, p^*(\boldsymbol{\beta}, \boldsymbol{\delta})]$ for individuals and $x_j^*[\delta_j, p^*(\boldsymbol{\beta}, \boldsymbol{\delta})]$ for firms that satisfy

$$p^*(\boldsymbol{\beta}, \boldsymbol{\delta}) = d^i\{x_i^*[\beta_i, p^*(\boldsymbol{\beta}, \boldsymbol{\delta})], \beta_i\} = c_1^j\{x_j^*[\delta_j, p^*(\boldsymbol{\beta}, \boldsymbol{\delta})], \delta_j\} \quad (1)$$

for all $i = 1, \ldots, N$ and $j = 1, \ldots, M$, and

$$\sum_{i=1}^{n} x_i^*[\beta_i, p^*(\boldsymbol{\beta}, \boldsymbol{\delta})] = \sum_{j=1}^{M} x_j^*[\delta_j, p^*(\boldsymbol{\beta}, \boldsymbol{\delta})] \quad (2)$$

Each firm, as well as the entire industry, therefore generates a distribution of quantity produced over $(\boldsymbol{\beta}, \boldsymbol{\delta})$ just as each consumer, as well as the entire market, generates a distribution of quantity demanded. The crux of the regulatory problem under uncertainty will be argued to center on these distributions and how well various regulatory mechanisms allow them to continue even in their presence. It will pay us dividends, therefore, to spend a few sentences seeing what equations 1 and 2 can tell us about efficient reaction to uncertainty.

It is, more specifically, critical to notice that the reactions captured by the $x_i^*[—]$ and $x_j^*[—]$ do not benefit every agent in the market; their costs and benefits are simply balanced against each other as well as possible. To see this, consider responses in $x_i^*[—]$ to random fluctuation in β_i. These responses must improve consumer welfare, or they would not be undertaken; they increase the quantity demanded at any price when the schedule is high, and vice versa. They are not, however, beneficial to the producer side of the market if they translate into fluctuation in the *total* quantity demanded. That type of demand-inspired fluctuation increases expected production costs at each firm to the degree that it absorbs the variation.[5] By the same token, output fluctuations that reflect efficient reactions to cost uncertainties in the $x_j^*[—]$ reduce the expected benefits derived from consuming x if they, too, translate in fluctuation in the total quantity supplied. The theorem quoted above does not fail because of these trade-offs, though; it states, instead, that a competitive market balances these trade-offs as well as possible.

3. The Need for Regulation

One of the more common rationales for regulatory intervention traces its roots to a breakdown in the competitive structure of the market. Monopolists produce too little, for example, charge an excessive price, and, because they operate along a negatively sloped marginal revenue schedule that is steeper than the demand (i.e., marginal-benefit) schedule, allow too little response to cost uncertainties. Such a firm could be confronted with a variety of controls in the output market, of course, but they are most usually regulated through the return that they earn on their capital.[6] While it may appear, at first, that the model just described in section 2 would not then apply, this is not the case. It is necessary only to translate variation in the input market into variation in the output market to bring our model to bear. It has been shown, in fact, that variation in a regulated input translates into the maximum amount of variations in a regulated output for the Cobb-Douglas case, and that this translation declines to zero (some constant) as the production function displays perfect substitution (Leontief technologies).[7] Even the control alternatives have analogues. Specifying a rate of return to capital can be viewed quite accurately as a price control on the capital market, and thus it fits nicely into our model. A regulator could, alternatively, specify capital investment directly by, in a sense, nationalizing the firm into a publicly owned enterprise. That is not likely in the United States, of course, but the point is made that regulatory options available in product markets are not necessarily ruled out just because we might be talking about an input market.

Another rationale for regulation can be drawn from the uncertainties themselves. There may, for example, be reason to protect some individuals from the conditions that a competitive market would force upon them in a bad state of nature. The example that springs to mind to illustrate this case involves the rationing of an important commodity (like gasoline or home heating oil) in the event of a sudden shortfall in supply. The market would respond to such a shortfall by increasing the price of the good in question, and the resulting welfare loss would be felt most heavily by lower-income consumers. These consumers would, in particular, feel the effect of a relatively large income effect, and the government might want to protect them from such a disproportionate loss. Quantity rationing across all individuals, with or without a white market for rationing coupons, might thus be proposed.[8]

Still other situations combine the two rationales, so that both production-level concerns and variability concerns must be weighed. Consider, as an illustration, a standard pollution-control problem. Emissions without controls might be too high, and some type of mechanism designed to lower emissions would then be required. In addition, variation around a desired level of average emissions might dramatically increase their expected social cost, if high-emissions states of nature produce widespread health damage. An environmental regulator would, in that case, be forced to design a control that would not only reduce total emissions, but also lower their variability. Compounding the problem, though, would be the efficiency gains that each emitter would garner if his emissions could respond to demand and cost uncertainty. A trade-off of the sort outlined above would have to be weighed in the ultimate design even after total emissions had been reduced.

4. Regulatory Alternatives in Single-Firm Markets[9]

Consider, first of all, a single, profit-maximizing firm facing a randomly fluctuating demand environment with a stochastic production cost schedule. Part of management's role in running such a firm would be to adjust its output in response to these uncertainties. Properly administered, these adjustments would improve the firm's profitability and make it a more attractive property. If the firm's private production costs did not cover the social costs of its output, though, the firm would nonetheless always produce socially excessive output levels. Some type of regulation would be required, therefore, to correct for these excesses, but regulation designed to lower output would necessarily have some effect on management's ability to react to uncertainty. The classic trade-off between social need and private profitability would thus come squarely into play. As reported in the introduction, a widening literature has explored the comparative advantages and weaknesses of a variety of regulatory mechanisms within that trade-off. Providing the intuition behind that literature is the goal of this section.

The simplest way to develop that intuition is to consider the two single-valued alternative control mechanisms first. A control authority could, for example, issue an output order for the firm specifying precisely how much it must produce regardless of the state of nature. Since such an order would usually be issued well before actual cost and demand conditions were known, its specification would have to be based on the regulator's expectations of what should happen. The control agency could, in particular, do no better than prescribe an output target that would maximize ex ante expected welfare (expected benefits minus expected *so-*

cial cost). The target could therefore be wrong. It would equate expected marginal costs and benefits, to be sure, but imposing it would allow no flexibility in response to the ultimate economic environment. If, for example, costs were lower than anticipated or demand were higher, then the firm would strain against an output constraint; it would be forced to limit its output to the prescribed target even though ex post welfare would be improved if it were allowed to produce more. It is precisely this lack of flexibility that has led many economists to shun production quotas as an acceptable means of regulation. This widespread disdain will turn out to be ill-founded, of course, but their reasoning does isolate the source of the problems that selling-quantity restrictions might involve.

On the other extreme one finds a single-valued price control that is frequently accused of allowing too much flexibility. An optimal price could, of course, be approximated by computing the level of expected marginal production cost (or net social benefit) of the optimal quota, but the possible errors in that computation are not the critical concern. Far more to the point is the variability in output that prescribing a single price would allow. While that variability would make the firm more profitable than it would be under the quota (otherwise, it would not be forthcoming), it could easily lower total expected welfare. Output variation based on cost fluctuation would, in particular, both *increase* the expected social cost of that production and decrease the expected benefits that it would generate.[10] If these fluctuation effects were large enough, they could easily dominate the profitability improvement felt by the firm and could lower the level of welfare.

The best sliding control can now be viewed as an economic and political compromise between these two extremes. Suppose that the control authority were to issue a price schedule that corresponded precisely to its view of expected net marginal social benefits.[11] The profit-maximizing firm would then respond by producing an output characterized by the equality of actual marginal cost and expected net benefit. Since net social benefits reflect the extra social costs of production as well as the benefits of consumption, such a schedule would best represent what a control agency could do in the face of uncertainty; it would allow the appropriate amount of output response to cost variability for the expected conditions of the benefit side.

To see the source of this superiority more clearly, consider Figure 1. On that graph, $\tilde{p}$ represents the best price control; $\hat{x}$, the best quota; Emc, the expected marginal cost of production; and Emsb_1 and Emsb_2, two different schedules of expected *net social benefits*. Note that these last schedules are drawn to intersect Emc at $(\hat{x}, \tilde{p})$; their only difference lies in their slopes, but that difference reflects a critical contrast between the benefit side conditions that they represent. Schedule Emsb_2 is, in particular, steeper so that it incorporates a steep demand schedule for product x, a steep marginal social cost schedule for x, or both. The former means that cost-induced output variation could dramatically lower the expected benefits of consumption from the level achieved by $\hat{x}$, and the latter means that such variation would similarly increase the expected social cost of production. In either case, an optimal sliding control would seriously dampen the amount of output variation allowed even though it might help the firm to become more profitable. Figure 1 shows that issuing a sliding schedule that duplicates the Emsb_i would do just that. For a low-cost state of nature like the one drawn there, for example, $\hat{x}$ would still be produced under the quota, but $\tilde{x} >> \hat{x}$ would be produced under $\tilde{p}$. A sliding schedule corresponding to Emsb_1 would elicit x_1^*, meanwhile, and the expense of the variations allowed by $\tilde{p}$ might thereby be reduced. For the steep schedule Emsb_2, though, $x_2^* << \tilde{x}$ would be produced. Precisely when output variation would be expensive, therefore, a sliding price set to mimic expected set marginal social benefits would dampen that variation.

5. Regulatory Mechanisms in Multiple-Firm Markets

With this intuition in mind, it is now time to introduce a serious caveat. Economists who have attempted to apply the control mechanisms that optimally regulate a single firm to situations involving more than one firm have frequently run into trouble. Their problem has been to devise a way of dividing the schedule

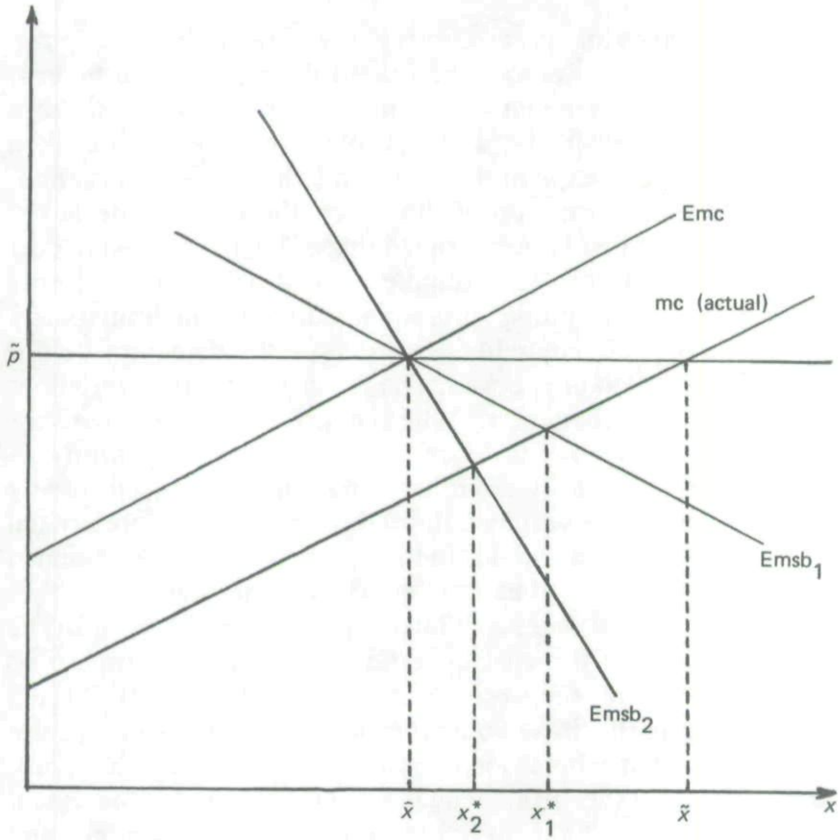

FIGURE 1. Comparison of control mechanisms.

that best regulates their collection of offending firms into its optimal component parts—the schedules that best regulate the individual firms that constitute their collection. Compounding the problem, there are frequently physical and legal barriers that make it next to impossible for one firm in the collection to know very much about what is happening elsewhere. Any proposed control mechanism must, nonetheless, be applicable to the multiple-firm case if it is to be considered seriously. It is thus fortunate that the intuitive groundwork for extending the schedule developed in the previous section to situations involving more than one regulatee has already been completed.

Earlier studies of direct control mechanisms have reported that the covariances across the output distribution can be critically important when many firms are to be regulated.[12] Because these covariances will play a similar role here, care must be taken at this juncture to explain the intuition behind this observation. Even without a formal proof, however, the explanation is not difficult. It has already been argued that efficient reaction to cost uncertainty by a firm, for example, should be encouraged only up to a point; the resulting variation in output could dramatically reduce the expected benefits generated on the demand side if it were allowed to go unchecked. The greater the output variation, the greater the reduction. When many firms are involved, though, expected benefits depend upon the variation in *total* output, and not necessarily upon the variation in the output of any particular firm. The variance in total output is therefore crucial in the multifirm case, and it is in the computation of that variance that the covariance can assume enormous importance.

To see why, it is necessary to consider only two cases. In the first, suppose that the cost uncertainties facing the firms to be regulated were, on the average, negatively correlated. The desired outputs of the firms would then tend to move in the opposite direction so that where some firms were increasing their production levels, other firms would be lowering theirs. Individual output variation would therefore cancel, to some degree, and more flexibility could be allowed at the firm level for any given variation in total output. If, on the other hand, the cost uncertainties were positively correlated, individual production levels would tend to move in the same direction and the opposite conclusion would be drawn; less flexibility could be allowed at the firm level for a given variance in their total output. A more precise demonstration can be provided, but this intuitive description of the role of correlations across firms is sufficient to trace the impact on the shape of the best flexible control.

It is possible, in particular, to argue that the adjustments just prescribed can be accomplished by simply changing the slope of the optimal sliding control schedule in a straightforward way. Recall Figure 1. It was observed there that steeper control schedules dampen the output response of any firm to random cost fluctuation; flatter schedules conversely encourage larger output responses to the same fluctuation. If the positive correlations mandate smaller responses at the individual firms, therefore, one need only make the sliding control schedule facing the firm a little steeper. The appropriate adjustment in output variation would automatically follow. Negative correlations have been shown to afford the opportunity for large responses, on the other hand, and flatter schedules would be appropriate. The size of these adjustments would, of course, depend not only on the strength of the correlations, but also on demand cost parameters; the direction, however, has been shown dependent only on the sign of the correlations.

If it now strikes the reader that it would be enormously difficult to compute sliding schedules that would incorporate all of these correlation effects as well as the price elasticity of demand, I must admit that I agree. It would, in most cases, border on the impossible. There is, however, one alternative that simplifies the computation while, at the same time, allowing the maximum amount of intrafirm flexibility subject to a constant level of *total* output. This alternative is a market solution, but only in an artificial sense. If, in particular, transferable production licenses were issued in a quantity that matched the desired *total* output of the industry, then that quantity would be produced with maximum efficiency. Firms confronting a bad state of nature would respond to an excess in licenses by selling their surplus to firms wishing to exceed their allotment. The result would be an equalization of net marginal production costs across all firms even as the prescribed level of total output appeared in the market.[13] Welfare losses would accrue only on the demand side as the optimal quantity demanded fluctuated, and therein would lie the trade-off. In cases in which variation in total output would be harmful, then, this type of "white market" in licenses should be strongly considered.

6. Informational Requirements

Quantity standards are frequently rejected out of hand because, to be set properly, they would require that the regulatory agency digest marginal cost data from every single firm. It is clear from equation 1, however, that computing the appropriate price alternative would require the same information. The "white market" solution suggested in section 5 avoids that problem, though, because the efficient distribution of output across firms would be forthcoming *regardless of how the licenses were initially allocated.*[14] This is a strong statement, but it speaks to the power of markets—the power of the license market, in this case. Moreover, the market-clearing price for licenses reveals an enormous amount of information. It can be argued, in fact, that the price a production license would bear would reflect the price control defined in equation 1. If one were interested in setting a price control on output, therefore, one could choose to run a license market for a short period of time *in lieu of computing the plethora of marginal cost schedules that equation 1 prescribes.*

To see why all of these points are valid, it is simpler to put uncertainty concerns aside for the moment and consider a model of how one might attempt to manage a supply shortfall. Let $d_j(p)$ represent the demand for good x registered at any price p by the jth agent ($j = 1, \ldots, n$). Since an agent can be either a private consumer or an industrial producer, $d_j(p)$ can reflect either an individual's consumptive demand for a product on a firm's derived demand for a factor.[15] Suppose now that a total demand could be restricted to some $\bar{x}$ by a set of taxes that could be different for each agent. The best set of these taxes, $\{t^*d_j\}_{j=1}^{n}$, minimizes the deadweight loss; that is, under the appropriate conditions on the marginal utility of income, the $\{t^*d_j\}_{j=1}^{n}$ minimize

$$\sum_{j=1}^{n} \int_{p_o}^{p+t_j} d_j(s)\, ds - t_j d_j(p_o + t_j) \qquad (3)$$

with respect to each t_j subject to

$$\sum_{j=1}^{n} d_j(p_o + t_j) \leq \bar{x}$$

In equation 3, p_o is the initial price that clears the market before the shortfall. Setting up the appropriate Lagrangian, the first-order conditions that

$$d_j(p_o + t_j^*) - d_j(p_o + t_j^*) - t_j^* d_j'(p_o + t_j^*) + \lambda d_j'(p_o + t_j^*) = 0, \qquad j = 1, \ldots, n$$

dictate that

$$t_j^* = \lambda \equiv t^*, \qquad j = 1, \ldots, n \tag{4}$$

The price increase faced by *each* individual must reflect precisely the social shadow price of the rationing constraint so that *all* of the optimal individual tax rates are equal.

There are a number of reasons why this tax mechanism might not be employed, especially for a short-term shortage. First of all, there are what might be termed equity concerns. The tax would amount to a sudden increase in the price of x which would, to some extent, be unanticipated. A large number of intertemporal and locational (long-term) decisions may have been made on the expectation of a stable (relative) price for x. If the shortfall is to be of limited duration, distortions in those decisions should be avoided. Even if the shortfall is permanent, a policy that increased the price more gradually over a longer period of time would be preferable. Finally, there is an informational concern. Correctly computing the social shadow price of $\overline{x}$ requires demand information from every agent that purchases x. Collecting and digesting that information would be extraordinarily expensive.

The equity concern could be alleviated by adopting an equivalent set of quotas:[16]

$$\{x_j^* \equiv d_j(p_o + t^*)\} \sum_{j=1}^{n} \tag{5}$$

For a short-term shortage, coupons entitling the holder to one unit of x could be given away in accordance with equation 5. For the duration of the shortfall, the purchase of x could then require both the payment of p_o in cash and the forfeiture of one coupon. For a long-term shortage whose sudden appearance is unsettling, the same allocation of coupons could be sold at a price that gradually increased from zero to t^* at whatever rate seems appropriate. The same informational problems arise here, though, since equation 5 also requires demand parameters from each agent. In addition, an allocation mechanism that quickly delivers exactly x_j^* to agent j would be an administrative task of incredible difficulty. The cost of collecting, digesting, and acting upon the demand information necessary to construct either the optimal tax or its equivalent quotas therefore seems to preclude the imposition of either.

Alternatives abound, though. A variety of arbitrary coupon allocations can be proposed that might be less involved. Each agent could, for example, be sold coupons at p_o up to an amount that will reduce his demand by the same proportion (or absolute amount) as everyone else. Both of these schemes have an air of equity, but they both require that the rationing authority know how much each agent ordinarily demanded at p_o—another informational nightmare. Suppose, instead, that the available supplies were shared equally among the agents. Only supply information would be required, in that case, but serious distributional effects might then be felt. Agents whose initial demands were high would bear more of the burden than someone who actually used less than his share before the shortage, for example. An intermediate policy that could strike a compromise between these extreme administrative and allocative difficulties would be best.

Fortunately, there is a way of making that compromise. Suppose that each agent were sold a fixed number of coupons ($\bar{x}_j$) at p_o, where $\bar{x}_j$ emerges from some arbitrary mechanism and

$$\sum_{j=1}^{n} \bar{x}_j = \bar{x} \tag{6}$$

Each coupon would entitle the bearer to one unit of x, so equation 6 is the supply constraint. It can be argued that from $\{\bar{x}_j\}_{j=1}^n$, a final distribution of goods that reproduces $\{x_j^*\}_{j=1}^n$ can be achieved, at least in approximation, by simply allowing the purchase and sale of the coupons at whatever price the market will bear. It will also be shown that the equilibrium price for coupons will be $(p_o + t^*)$. Despite these results, though, there is a distributional cost caused by a transfer to consumer surplus from the buyers of coupons to the sellers. This loss is smaller the closer $\{\bar{x}_j\}_{j=1}^n$ is to $\{x_j^*\}_{j=1}^n$, but it is *always* smaller than the loss that would be felt under either a laissez-faire policy on a tax of t^*; both would allow suppliers to charge $p_o + t^*$ for *each unit*, not just for those units for which coupons changed hands. If the shortage were permanent, furthermore, the coupon price could be slowly raised in an anticipated pattern that would allow consumers some time to prepare for the higher price while always restricting total consumption to $\bar{x}$. Unless it is very expensive for the rationing agency to come reasonably close to $\{x_j^*\}_{j=1}^n$, therefore, a "white market" mechanism seems extremely worthwhile.

It remains only to support these claims by analyzing the residual market in coupons that would emerge after an arbitrary rationing allocation. For simplicity, assume that each agent's demand for x is linear in p; that is, represent the demand schedule for agent j by[17]

$$p = a_j - b_j x_j, \qquad j = 1, \ldots, n$$

Let $\hat{x}_j$ represent preshortage consumption by agent j at p_o and χ_j represent the number of coupons agent j buys ($\chi_j > 0$) or sells ($\chi_j < 0$). For a rationing allotment designated $\bar{x}_j$,

$$\begin{aligned} p &= p_o + b_j\hat{x}_j - b_j x_j \\ &= p_o + b_j\hat{x}_j - b_j\bar{x}_j - b_j\chi_j \end{aligned}$$

because $x_j = \bar{x}_j + \chi_j$. As a result, the excess demand for coupons by agent j is

$$\chi_j = \frac{(p_o - p) + b_j(\hat{x}_j - \bar{x}_j)}{b_j}, \qquad j = 1, \ldots, n \tag{7}$$

In equilibrium, total excess demand for coupons must be zero, so from equation 7

$$(p_o - p') \sum_{j=1}^{n} (1/b_j) + (\hat{x} - \bar{x}) = 0$$

where $\hat{x} \equiv \sum_{j=1}^{n} \hat{x}_j$. Clearly, then, the price of coupons exceeds p_o by

$$(p' - p_o) = \frac{\hat{x} - \bar{x}}{\sum_{j=1}^{n} (1/b_j)} \tag{8}$$

and

$$\chi_j' = (\hat{x}_j - \bar{x}_j) - (\hat{x} - \bar{x})/\left[b_j \sum_{j=1}^{n} (1/b_k)\right] \tag{9}$$

is the equilibrium transaction made by agent j. Under the white market, the rationing causes agent j to adjust total consumption by

$$(\Delta x_j)' \equiv \bar{x}_j - \hat{x}_j + \chi_j - \frac{\hat{x} - \bar{x}}{b_j \sum_{k=1}^{n} (1/b_k)} \tag{10}$$

It is important to note that equation 9 is independent of the initial rationing $\{\bar{x}_j\}_{j=1}^{n}$; only the total shortfall $(\hat{x} - \bar{x})$ appears in this summary of the overall change in the coupon price. Finally, it will be useful to observe from equation 10

$$\frac{(\Delta x_j)'}{(\Delta x_i)'} = \frac{b_i}{b_j}, \qquad i \neq j = 1, \ldots, n \tag{11}$$

and

$$\sum_{j=1}^{n} (\Delta x_j)' = \hat{x} - \bar{x}$$

These equations can be viewed as a linear system in $\{\Delta x_j\}_{j=1}^{n}$ whose solution defines the consumption equilibrium for $\{\bar{x}_j\}_{j=1}^{n}$.[18]

The best allocation $\{x_j^*\}_{j=1}^{n}$ meanwhile minimizes the sum of the deadweight losses felt by every agent. In terms of the linear demand schedules postulated above, the x_j^* minimize

$$\frac{1}{2}\sum_{j=1}^{n} b_j(\hat{x}_j - x_j)^2$$

subject to

$$\sum_{j=1}^{n} x_j = \bar{x}$$

The appropriate first-order conditions,

$$-b_j(\hat{x}_j - x_j^*) = -\lambda, \qquad j = 1, \ldots, n$$

can be written

$$\frac{(\Delta x_j)^*}{(\Delta x_i)^*} = \frac{b_i}{b_j}, \qquad i \neq j = 1, \ldots, n \tag{12}$$

where $(\Delta x_j)^* \equiv \hat{x}_j - x_j^*$. Since

$$\sum_{j=1}^{n} (\Delta x_j)^* = \hat{x} - \bar{x}$$

as well, it must be true (looking at equations 11 and 12) that

$$(\Delta x_j)' = (\Delta x_j)^*, \qquad j = 1, \ldots, n$$

The equivalent t^* can also be computed. Market demand for x can be derived from horizontal addition of individual demand schedules, so

$$x = \sum_{j=1}^{n} x_j = -p \sum_{j=1}^{n} (1/b_j) + \sum_{j=1}^{n} (a_j/b_j)$$

When total consumption falls from $\hat{x}$ to $\bar{x}$, then

$$\bar{x} - \hat{x} = p_o \sum_{j=1}^{n} (1/b_j) - (p_o + t^*) \sum_{j=1}^{n} (1/b_j)$$

and

$$t^* = \frac{\hat{x} - \bar{x}}{\sum_{j=1}^{n} (1/b_j)}$$

Comparing t^* with $(p' - p_o)$ on equation 8, it is clear that the residual coupon market for any rationing allocation achieves the best distribution of x at a market-clearing price precisely equal to the coupon allocation price plus the equivalent tax.

My claims have thus been verified in the simplest of models. They do extend, however. They are true for every state of nature when demand is uncertain. The analysis easily applies to supply-side regulation, so that the full generality of equation 1 can be achieved. And the results hold in close approximation when demand is not linear. Finally, it should be observed that the power of the license market depends in no way upon optimality properties, either the chosen aggregate constraint $\bar{x}$ or the initial allocation $\bar{x}_j$. These allocations could be arbitrarily set and their total could be biologically determined, for example, and still the market would function to produce the optimal distribution.

7. Concluding Remarks: An Application to Fisheries

Though certainly naive, my perception of the fisheries problem is framed by two conjectures:

1. There exists a need to allow the maximum flexibility in the quantity of fish caught by each fishermen.

2. But, at the same time, there exists a need to strictly regulate the total number of fish caught during any one particular season.

The rough parallels between the fisheries problem and a pollution control problem are, at least to me, therefore quite striking. While flexibility is desirable, wide swings in total production could be extremely harmful to the efforts to maintain a steady-state stock of fish and extremely expensive in terms of fishing activity in bad states of nature. It would seem, therefore, that the existing literature should apply.

In light of that literature, in fact, it should be no surprise that my naive perception would lead me to strongly urge the institution of a program of transferable, quantity-specific licenses. Total output could thus be closely regulated in an environment that would allow fishermen as much flexibility as possible. At the same time, administrative costs could be held to a minimum because regulators could rest assured that if their initial allotments were incorrect, the license market would automatically correct their errors. Finally, a license market would guarantee that even a fisherman whose luck had deserted him during one or two periods could generate at least some income by selling some of the allotment he was granted for those periods to others. Solvency worries might thereby be reduced.

Notes

1. See Spence and Roberts (1976) and Yohe (1976; 1980) for environmental application of basic work in Ireland (1973), Karp and Yohe (1979), Laffont (1977), Weitzman (1974), and Yohe (1979a).
2. Fishelson and Flatters (1976), Pelcovits (1976), and Stiglitz and Dasgupta (1977).
3. See Becker (1968), Polinsky and Shavell (1979), and Yohe (in press).
4. See Atkinson and Stiglitz (1980), chapters 1 and 2.
5. This point is argued later in the text, but it depends only upon convex cost schedules. Any variable output inspired for noncost reasons then increases expected costs over the cost of producing their certainty equivalent. Thus the need for inventories.

6. See Averch and Johnson (1962), Baumol and Klevorick (1970), and Roberts, Madalla, and Enholm (1978).

7. See Yohe (1977a; 1979a).

8. See Yohe (1979b) and references.

9. The single-firm examples that appear in this section operate under the assumption that the firm is *not* exercising its monopoly power. The various control options are presented in the context of a socially minded firm that acts as if it were a competitive market so that the options may be initially studied without the complications that many firms create. Multifirm examples will subsequently be examined in section 5. It should also be noted that the stochastic demand schedule developed here can, under appropriate assumptions about the marginal utility of income, be considered to represent marginal benefits. These widely known assumptions are made implicitly throughout the paper.

10. Without an associated efficiency, output variation decreases expected benefits to a degree dictated by the curvature of the benefit schedule. The more the benefit schedule is curved (i.e., the steeper the marginal benefit schedule), the more expected benefits fall for a given amount of output variation. Expected social costs are similarly affected.

11. Expected *net* social benefits indicate simply the difference between the benefits derived from the consumption and the external social costs of production.

12. See Karp and Yohe (1979) and Yohe (1977b; 1979a).

13. See Yohe (1979b).

14. See Yohe (1979b).

15. Each schedule is assumed dependent upon only the price of x for simplicity. Several of the results that will emerge are also true without this assumption, but making it is probably not too severe an approximation of the partial equilibrium type of information with which regulatory authorities are equipped. I should also note that the price control alternative will be computed as a tax to be added to the precontrol price to facilitate comparisons with the price of a license in a coupon market.

16. Here, and throughout, equivalence between two policies implies only that the same quantity is consumed under both by every agent. A tax and a set of quotas are not equivalent in terms of welfare unless the tickets are auctioned by the ration authority. Their price would be t^* in equilibrium. There will be circumstances where it will be good to move that price around, though, so equivalence will only concern quantity.

17. A few remarks on the generality of this argument when demand is not linear are contained in a concluding paragraph of this section.

18. A more rigorous proof can be easily constructed. From equations 12, 4, and 3

$$(\hat{x}_j - x_j^*) = \lambda/b_j = t^*/b_j = (\hat{x} - \overline{x})/b_j \sum_{k=1}^{n} (1/b_k)$$

From equation 9, therefore,

$$\chi_j = 0$$

if and only if $\overline{x}_j = x_j^*$.

References

Atkinson, A. B., and J. E. Stiglitz. 1980. *Lectures in public finance.* New York: McGraw-Hill.

Averch, H., and L. Johnson. 1962. Behavior of the firm under regulatory constraint. *Am. Econ. Rev.* 51: 1052–1069.

Baumol, W. J., and A. K. Klevorick. 1970. Input choices and rate-of-return regulation. *Bell J. Econ.* 1:162–190.

Becker, G. 1968. Crime and punishment: An economic approach. *J. Polit. Econ.* 76: 169–181.

Fishelson, G., and F. Flatters. 1976. The (non) equivalence of optimal tariffs and quotas under uncertainty. *J. Int. Econ.* 5:385–397.

Ireland, N. J. 1973. Ideal prices vs. prices vs. quantities. *Rev. Econ. Stud.* 44: 183–189.

Karp, G., and G. Yohe. 1979. The optimal linear alternative to price and quantity controls in the multifirm case. *J. Comp. Econ.* 3: 56–68.

Laffont, J. 1977. More prices vs. quantities. *Rev. Econ. Stud.* 44: 177–182.

Pelcovits, M. 1976. Quotes vs. tariffs. *J. Int. Econ.* 6: 363–375.

Polinsky, S., and S. Shavell. 1979. The optimal tradeoff between the probability and magnitude of fines. *Am. Econ. Rev.* 69: 880–897.

Roberts, R. B., C. S. Madalla, and G. Enholm. 1978. Determinants of the requested rate of return. *Bell J. Econ.* 9: 611–621.

Smith, V. 1968. Economics of production from natural resources. *Am. Econ. Rev.* 58: 409–431.

———. 1974. General equilibrium with a replenishable resource. *Rev. Econ. Stud.* (Symposium) 41: 105–116.

Spence, M., and M. Roberts. 1976. Effluent charges and licenses under uncertainty. *J. Pub. Econ.* 5: 193–207.

Stiglitz, J. E., and P. Dasgupta. 1977. Tariffs vs. quotas as revenue raising devices under uncertainty. *Am. Econ. Rev.* 67: 975–981.

Weitzman, M. 1974. Prices vs. quantities. *Rev. Econ. Stud.* 41: 50–61.

Yohe, G. 1976. Substitution and the control of pollution. *Environ. Econ. Manage.* 3: 312–329.

———. 1977a. Single-valued control of an intermediate good under uncertainty. *Int. Econ. Rev.* 18: 117–133.

———. 1977b. Single-valued control of a cartel under uncertainty. *Bell J. Econ.* 8: 97–111.

———. 1979a. *A comparison of price controls and quantity controls under uncertainty*. New York: Garland.

———. 1979b. Managing the demand side of a sudden supply shortage. *Res. Energy* 2: 221–241.

———. 1980. Comparative results in pollution control. Paper presented at second annual conference of Association of Public Policy Analysis and Management, Boston.

———. 1981. Should sliding controls be the next generation of pollution controls? *J. Pub. Econ.* 15: 251–256.

———. 1982. Fines as economic incentives. *Int. Rev. Law Econ.* 2: 95–109.