CAPACITY UTILIZATION UNDER REGULATORY CONSTRAINTS

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Abstract—This paper presents a methodology for predicting the effect of quota-type regulatory constraints on capacity utilization for a multiproduct profit-maximizing firm. The approach builds on recent advances in the use of virtual prices to model the effects of rationing. This allows the effects of regulatory constraints to be examined ex ante. The methodology is illustrated through a case study of the imposition of output quotas in an open-access marine fishing industry on the Pacific Coast of the United States. The results suggest that, for certain species, output quotas can cause strong disinvestment incentives.

I. Introduction

MEASURES of capacity utilization (*CU*) have been used for many years to analyze the current status of the economy, the expansionary or contractionary forces on investment and inflation, and productivity movements. Traditional *CU* measures were based on the notion of maximum possible output. Recently, economists have developed measures derived from the economic theory of the firm and based instead on a notion of optimal output (Berndt and Fuss, 1986; Hickman, 1964; Klein, 1960; Morrison, 1985, 1988; Segerson and Squires, 1990a). These measures assume that some inputs are quasi-fixed and that capacity utilization is determined by the level of the quasi-fixed input(s) relative to the level of output.

Previous studies of theory-based *CU* measures have generally assumed that the industry under study was free from regulatory constraints. An exception is Morrison's (1988) study, which analyzed (among other things) the effect of pollution-control regulations on capacity utilization in the U.S. and Canadian steel industries. The analysis is retrospective, however, since it studied the impacts of regulations that were already in effect.

In many cases, it would be useful to be able to predict the effect of proposed regulations on capacity utilization. Such prospective or ex ante analysis would provide regulators with useful information regarding the likely effect of alternative policies on investment incentives. For example, regulatory production limits on a single product (such as quotas) may cause multiproduct firms to change the volume and mix of their production, which could in turn change investment incentives.[1] Likewise, input use restrictions could affect both output supplies and the demands for unregulated inputs, thereby altering investment incentives. Predictions of these changes would contribute to designing more effective public policies regulating capacity and investment.

If the impacts of regulations on supply are important, output choices must be endogenous in the models that predict those impacts. Previous studies of *CU* have treated output as exogenous, however, focusing on cost-minimization as the behavioral objective of the firm.[2] Thus, to be of use in predicting the effects of regulatory constraints on investment incentives, the standard *CU* measures must be modified to reflect an alternative behavioral assumption, such as profit maximization.

The purpose of this paper is to present a methodology for predicting the effect of quota-type regulatory constraints on capacity utilization for a multiproduct profit-maximizing firm. We develop the methodology in the context of a firm

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[1] In addition to a change in the mix of regulated and unregulated products, if the production limit is applied to a product class, which actually entails several variants of a product, quality upgrading could result, i.e., firms could also adjust their product mix within the category of regulated outputs. We are grateful to an anonymous referee for noting this possibility.

[2] An exception is Squires (1987). See further discussion below.

that faces possible input or output quotas. Our approach builds on recent advances in the use of virtual prices to model the effects of rationing (e.g., Neary and Roberts, 1980). We then illustrate the methodology by predicting the effect of output quotas in a multiproduct fishing industry on the Pacific Coast of the United States. In the context of our example, a special case of profit maximization, namely, revenue maximization, is assumed, since for many fisheries all inputs are effectively fixed in the short run.

Although implementation of the methodology is developed through a case study of a marine fishing industry, the approach should be widely applicable to analyses of *CU* for any industry with profit-maximizing multiproduct firms facing input or output constraints. For example, it could be applied in the context of agriculture where farms face potential water rationing or restrictions on the use of chemical fertilizers or pesticides or potential output quotas to regulate production.[3] Alternatively, in the context of international trade, it could be used to analyze the effects of export quotas or voluntary export restrictions. Other possible applications include the impacts of policies that would ban the production of a particular output or use of a particular input (for health or environmental reasons) and fiscal policies that might result in credit rationing.

II. Measures of Capacity Utilization

Capacity utilization measures have only recently been developed from the theory of firm behavior (Klein, 1960; Hickman, 1964; Morrison, 1985, 1986; Berndt and Fuss, 1986).[4] For single product firms, the primal measure of *CU* is defined as $CU^Y = Y'/Y^*$, where Y' is actual output and Y^* is the long-run equilibrium output level under cost minimization, i.e., the output level at which the short-run and long-run average cost curves are tangent. *CU* can be equivalently measured in terms of the cost gap that exists when Y' is not equal to Y^* (Morrison, 1985). This dual *CU* measure contains information on the difference between the current temporary equilibrium and the long-run equilibrium in terms of the implicit costs of divergence from long-run equilibrium. It is defined as $CU^C = C^*/C$, where C is the firm's actual cost and C^* is its shadow cost.

CU has traditionally been measured for single-product firms. Segerson and Squires (1990a) considered *CU* measurement for multiproduct firms and found that the extension of the single-product primal measure to the multiproduct case can be problematic because a scalar measure of output does not generally exist.[5] However, a dual measure of *CU* for the multiproduct firm that is directly analogous to the single-product measure can be easily defined.

Measures based on the assumption that the firm's objective is cost minimization are particularly well-suited when production strategies strive for economies of scale arising from high-volume focused production of standardized goods in anticipation of a stable market demand. These mass production firms may be concerned primarily with costs in order to meet competition from low-cost producers (Abegglen and Stalk, 1985; Dosi, 1988; Skinner, 1985). If production is not fixed, however, choice of output levels must be considered. This consideration seems particularly important for multiproduct firms, which often seek to adjust their product line in response to a shifting, more disaggregated market (Abegglen and Stalk; Dosi; Stalk, 1988).[6] In addition, it is a potentially important component of a firm's regulatory response.

If multiproduct firms choose output levels to maximize profit, then the shadow value of the

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[3] Constraints have been used in many other industries as well, including trucking, railroads, airlines, and banking.

[4] An alternative approach, based on the concept of maximum output, has been used for many years. For a discussion, see Morrison (1985).

[5] A consistent scalar measure of output in multiproduct firms exists if all outputs are homothetically separable from inputs. In this case, a direct analogue of the single-product primal measure of *CU* can be developed for the multiproduct firm. When the technology is not homothetically separable, Segerson and Squires (1990a) suggest two alternative ways of defining a primal *CU* measure. However, since both make restrictive assumptions, namely, that outputs move along a ray (giving a ray measure of *CU*) or that only one output adjusts (giving a partial measure of *CU*), we have chosen to focus here on dual measures, which do not require these assumptions.

[6] Industries where such firms are likely to be important include mini-mill steel, machine tools, metal working, medical equipment, high-end apparel, and increasingly, automotive production.

quasi-fixed input[7] (Z) will be the change in restricted profit resulting from a marginal change in Z, i.e., the derivative of the restricted profit function (H) with respect to Z (Lau, 1976). A dual CU measure can then be defined in terms of the profit gap (rather than the cost gap) that results from being out of long-run equilibrium (Squires, 1987).[8] In particular, we can define $CU^S = S/S^*$, where S is the actual profit and S^* is the shadow value of profit. Thus,

$$CU^S = \frac{H(P,W;Z) - W_Z Z}{H(P,W;Z) - W_Z^* Z}$$

$$= 1 + \frac{(W_Z^* - W_Z)Z}{H(P,W;Z) - W_Z^* Z} \qquad (1)$$

where $H(P,W;Z)$ is the restricted profit function, $S^* = H(P,W;Z) - W_Z^* Z$, P is a vector of competitive prices for M outputs, W is a vector of competitive prices for N variable inputs, W_Z is the market or rental price for Z, and $W_Z^* = H_Z$.

III. The Effects of Regulatory Constraints

Given data on variable input and output prices and the level of the quasi-fixed factor, the restricted profit function can be estimated and used to calculate either of the two alternative dual measures of CU discussed above. If the firm was not subject to any regulatory constraints during the sample period, these measures provide information on investment incentives in the absence of regulation.[9] In this section, we suggest a methodology for predicting how a regulatory constraint subsequently imposed would affect those investment incentives through changes in CU.

We consider first the case of an output quota, where the output of some product, say Y_1, is restricted to be less than or equal to some exogenous level, y_1.[10] Because the estimated restricted profit function is dependent on prices rather than output levels, it is not possible to incorporate the output constraint directly into the CU measure. However, as noted by Weitzman (1974), primal and dual production constraints are theoretically equivalent in a static, full-information, deterministic setting. Thus, through the use of "virtual prices" (Neary and Roberts, 1980), the quantity constraint can be transformed into a price constraint, which in turn can be directly incorporated into the CU measures.

More specifically, the effect of the quantity constraint on CU can be determined by calculating the new shadow price of the quasi-fixed input, i.e., the shadow price with the regulation, and using this new price to calculate a post-regulation CU measure. If the production constraint is binding and the demands for all other products are perfectly elastic,[11] then the shadow price under regulation can be calculated as follows:

(a) derive the supply function for the regulated output from the restricted profit function $H(P, W; Z)$ using Hotelling's Lemma, i.e., $Y_1^* = H_1$, where $Y_1^*(P,W;Z)$ is the profit-maximizing level of output 1;
(b) given the prices of all other outputs and the variable inputs and the level of Z, find the level of P_1 for which $Y_1^* = y_1$, which gives the virtual price p_1 corresponding to the quantity constraint; and
(c) calculate the post-regulation shadow price of Z as H_Z evaluated at the price vector $(p_1, P_2, \ldots, P_M, W, Z)$.

This new shadow price for Z can then be used to

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[7] We assume throughout that there is a single quasi-fixed factor. Although the definition of CU can be easily extended to include multiple quasi-fixed factors, its interpretation becomes unclear in this context since it is possible to have $CU = 1$ even if the actual prices of the quasi-fixed factors do not equal their shadow values (e.g., if there are offsetting effects). The implications of this for investment incentives are unclear. Finally, the model of a single, aggregate quasi-fixed input has been used elsewhere (Diewert, 1974; Kirkley and Strand, 1988) and is appropriate for our case study. For these reasons, we consider only this case in our conceptual model.

[8] This suggests that theory-based measures of CU are not unique, but instead depend on the underlying behavioral assumption.

[9] In general, when capacity utilization exceeds one, there is an incentive for the firm to invest, i.e., increase the level of its quasi-fixed factor. Likewise, capacity utilization less than one implies disinvestment incentives. This interpretation assumes, however, that output is expected to remain at its current level, i.e., that the current output level is not the result of a temporary variation.

[10] We assume that this quota is strictly binding, i.e., that in the absence of the quota the chosen level of Y_1 exceeds y_1.

[11] This assumption is appropriate in many applications, including our empirical example. If demand were not perfectly elastic, imposition of the quota on one product could change other product prices through shifts in their supply curves. Predicting these other price changes would require information about the demands for these products.

calculate the level of CU that would exist under the regulation.[12]

It should be clear that the effect of an input restriction could be found in an analogous way, i.e., by deriving the corresponding virtual price for the input constraint (the price at which the unconstrained demand for the input equals the restricted level) and evaluating H_Z at that virtual price and all other actual prices.

Note that, in calculating the effect of input or output constraints on CU, we hold the quasi-fixed factor at its actual (i.e., pre-regulation) level. This should not, however, be interpreted as suggesting that the firm could not or would not change the level of its quasi-fixed factor in response to the regulation. On the contrary, given regulatory lags, it is likely that the firm would be able to adjust its level of Z in response to the regulation, prior to deciding on the levels of its outputs and variable inputs. Nonetheless, it is appropriate to hold Z constant in the above calculations, since it is only by assessing how actual costs (or profits) compare to their shadow values at the *current* level of Z that we can determine the impact of the regulation on the firm's incentives to change that level.[13]

Finally, the above methodology allows the long-run equilibrium level of the quasi-fixed input under the regulation to be determined. Since the long-run equilibrium level is the level at which the shadow price of the input equals its actual (market) price, its level under the regulation can be determined by solving

$$H_Z(p_1, P_2, \ldots, P_M, W, Z) = W_Z \quad \text{for } Z.$$

IV. An Application

One multiproduct industry for which policymakers often consider the imposition of regulatory constraints is the fishing industry. It is well known that the open access nature of the fishing industry can lead to over-exploitation of the resource stock, excess investment and reduced harvests and incomes (Gordon, 1954). Possible policy responses include license limitations, which restrict the number of vessels with access to the resource, and harvest quotas, which limit allowable catches.[14] Since most fisheries are characterized by multiproduct production, regulations keyed to a single species will have spillover effects on other species. Efforts to enhance the stock of one species might lead to pressures on other resource stocks. These combined direct and indirect effects of the regulations could either increase or decrease investment incentives as reflected in CU. Information on how CU is affected would help regulators design policies consistent with overall objectives relating to resource use and investment (Young, 1988).

The above methodology was used to study capacity utilization in a trawl fishing industry on the Pacific Coast of the United States. This industry is comprised of many multiproduct firms, i.e., relatively small and unspecialized vessels that are diversified in their product mix. At the beginning of each fishing trip, vessel operators key production directly to the market (without stockpiling products in anticipation of future demand), given vessel and resource abundance constraints and relative prices. In addition, inputs on the vessel are largely fixed because boats are away at sea where input levels cannot be readily altered. Thus, a special case of profit maximization, namely, revenue maximization, is the appropriate behavioral objective for a fishing trip once a resource stock area has been determined (Kirkley and Strand, 1988).[15] Furthermore, since vessel size or capital stock is fixed at the trip level and largely determines the level of other inputs over this short production period of one to four days, the

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[12] Note that, when the profit-gap measure is used to predict the impact of the regulation on CU, the restricted profit function $H(P, W, Z)$ should also be evaluated at the virtual price for the regulated output.

[13] We emphasize this point since one reviewer of an earlier version of this paper seemed to suggest that holding Z constant in the calculation of CU was inappropriate if the firm could adjust Z in response to the regulation, suggesting that our methodology is applicable only to unanticipated regulations imposed immediately, i.e., before any possible adjustment in Z. As stated in the text, however, it is not the *actual* adjustment of Z that is of interest, but rather the *incentive* for adjustment. That incentive can be determined from our methodology even if the firm anticipates the regulation and actually responds to it prior to choosing its output and variable input levels.

[14] Other policies, such as individual transferable quotas (ITQs), may be more efficient as means of maximizing social welfare (Waugh, 1984). However, the actual choice of policies is usually dominated by biologists, who may have objectives other than efficiency and tend to prefer quotas or caps on harvest rates. We thus analyze quotas here not because they are necessarily efficient but rather because they are often used in practice.

[15] See also Squires and Kirkley (1991) for a discussion of the use of revenue functions to model fisheries' production technologies.

input bundle can be specified as a single, composite input, proxied by vessel size.[16]

In the special case where all inputs are quasi-fixed (so that variable costs are zero), the cost-based measure of capacity utilization takes a particularly simple form, namely,

$$CU^C = W_Z^*/W_Z, \tag{2}$$

where W_Z^* and W_Z are the shadow and actual prices of the quasi-fixed input, respectively. In addition, it can be easily shown that the elasticity of CU with respect to P_i depends directly on the product-specific scale elasticity[17] ($e_{iZ} = d\ln(Y_i)/d\ln(Z)$), weighted by the ratio of revenue from output i, P_iY_i, to the shadow cost of Z, W_Z^*Z (see Segerson and Squires, 1990b). Thus, the larger the contribution of Y_i to total revenue and the size of this revenue relative to W_Z^*Z, the greater the sensitivity of CU^C to a change in P_i. Furthermore, a large scale elasticity implies that CU^C will be sensitive to changes in the price of product i. These relationships will be useful below in interpreting the differences in the effects of quotas on different products.

A. The Empirical Model

The revenue-maximizing vessel-level production process for each fishing trip can be modeled by a nonhomothetic generalized Leontief revenue function. With symmetry imposed, so that $a_{ij} = a_{ji}$ for i not equal to j, it is written (Kirkley and Strand):[18]

$$\begin{aligned} R(P;Z) = {} & \sum_i \sum_j a_{ij}\left[P_iP_j\right]^{1/2} Z + \sum_i a_i P_i Z^2 \\ & + \sum_i \sum_k b_{ik} D_k P_i Z \\ & + \sum_i \sum_l g_{il} E_l P_i Z, \end{aligned} \tag{3}$$

where D_k is the k^{th} of two home port dummy variables for Brookings and Crescent City and E_l is the l^{th} of three quarterly dummy variables for winter, spring, and fall. The area dummy variables account for spatial variations in access to resource stocks, species abundance, and port effects on prices. The quarterly dummy variables account for intertemporal variations in the technological constraints of weather and resource abundance. Z represents the capital stock or composite input, measured by a vessel's gross registered tonnage (GRT). Note that the presence of output cross-price interaction terms in (3) allows for the possibility of jointness-in-inputs, which gives rise to economies of scope.[19]

Input-compensated, revenue-maximizing product supply equations $Y^*(P;Z)$ are given by Hotelling's Lemma (McFadden):

$$\begin{aligned} \partial R(P;Z)/\partial P_i &= Y_i^*(P;Z) \\ &= \sum_j a_{ij}\left[P_j/P_i\right]^{1/2} Z + a_i Z^2 \\ &\quad + \sum_k b_{ik} D_k Z + \sum_l g_{il} E_l Z. \end{aligned} \tag{4}$$

Linear homogeneity in prices is automatically satisfied with this functional form.

The shadow price of the quasi-fixed factor is given by

$$\begin{aligned} \partial R(P;Z)/\partial Z &= W_Z^* \\ &= \sum_i \sum_j a_{ij}\left[P_iP_j\right]^{1/2} \\ &\quad + 2\sum_i a_i P_i Z \\ &\quad + \sum_i \sum_k b_{ik} D_k P_i \\ &\quad + \sum_i \sum_l g_{il} E_l P_i. \end{aligned} \tag{5}$$

This shadow value depends upon the product prices P_i, and the level of the quasi-fixed input,

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[16] More formally, we assume Leontief separability of all the inputs over the short production period. Any input variation is likely to be unplanned and not systematic. See Kirkley (1986) and Kirkley and Strand (1988) for a discussion of this assumption.

[17] See Kirkley (1986) for a discussion of product-specific scale elasticities.

[18] Diewert (1974) and Laitinen (1980) provide further development of the revenue function. Kirkley and Strand (1988) provide one of the first empirical applications.

[19] In our application of the model, we used a likelihood ratio test to test for nonjointness-in-inputs throughout the product set. The null hypothesis was rejected. For a more detailed discussion of jointness-in-inputs, see Baumol, Panzar and Willig (1982), Squires (1987), and Kirkley and Strand (1988).

Z. If the model extended beyond a single year, the impact of exogenous technical change could readily be included.

The impact of changes in product prices upon W_Z^* can be evaluated by the elasticity of W_Z^* with respect to changes in the price of P_i, i.e.,

$$\begin{aligned}\frac{d\ln(W_Z^*)}{d\ln P_i} &= R_{Zi}\cdot P_i/R_Z \\ &= \Big[a_{ii}P_i + \sum_j 0.5a_{ij}[P_iP_j]^{1/2} \\ &\quad + 2a_iP_iZ + \sum_k b_{ik}D_kP_i \\ &\quad + \sum_l g_{il}E_lP_i\Big]\Big/W_Z^*. \qquad (6)\end{aligned}$$

The above system of supply equations was estimated for a group of vessels in a deep-water fishery off Northern California and Southern Oregon using data for a year without regulation, 1984.[20] All vessels were at least 75 *GRT*. There were a total of 444 observations or fishing trips on the 14 vessels. Six categories of fish were specified as outputs: Dover sole, thornyheads, sablefish, other flatfish, other rockfish, and a residual category, all others. In the "other" categories, individual species were aggregated using Divisia indices.

The input-compensated product supply functions given in equation (4) were initially estimated by ordinary least squares. Heteroscedasticity was found of the form discussed by Parks (1971), in which the error variance is proportional to the squared input level Z. Each equation was subsequently divided by Z. The system of supply equations was then estimated by Zellner's seemingly unrelated regression procedure and iterated to convergence, with results equivalent to maximum likelihood.[21]

The estimated parameter values of the input-compensated supply equations are presented in table 1.[22,23] Table 2 reports the corresponding own-price input-compensated supply elasticities evaluated at the observed sample mean. These elasticities are nonnegative for all outputs except sablefish, which is negative but statistically insignificant. In addition, the revenue function is increasing and concave in Z at the sample mean.

The own- and cross-price supply elasticities reported in table 2 are uniformly inelastic. Both substitute and complementary relationships are exhibited, although many cross-price supply elasticities are statistically insignificant. This suggests that these firms have relatively little ability to adjust the mix and volume of production in the short run in response to exogenous changes. Some adjustment is possible through changes in fishing location and speed and depth of net tow, but in general the product mix is determined by resource abundance, and most importantly, difficulties in locating the unseen resource. The product-specific scale elasticities reported in the last row of table 2 are all positive and generally inelastic, and are largest for Dover sole, thornyheads, and other rockfish.

Finally, the effects of product price changes on the shadow price of the quasi-fixed factor are reported in table 3. These shadow price elastici-

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[20] Alternatively, we could have estimated both the revenue function (3) and the supply functions (4) jointly. While this would have increased the amount of information used in the estimation, it would have increased the computational costs. In addition, unlike with the translog and normalized quadratic forms, with the generalized Leontief joint estimation is not necessary to recover all of the parameters of the objective function. Thus, following Kirkley and Strand (1988), we estimated only the supply equations.

[21] The functional form is assumed to be exact rather than an approximation, and the errors are from optimization rather than approximation and apply only to the input-compensated supply functions. The problem of zero outputs also arose in a few instances. This creates a limited-dependent variable problem, which may cause bias and non-normality of the residuals. The procedure of Lee and Pitt (1986) can solve this problem by using virtual prices, but is not computationally feasible with the number of variables in this study. While a Box-Cox transformation could be used, we elected not to use it because it assumes a particular form of non-normal disturbances prior to transformation. All estimates instead substituted the small value of 0.1 in when necessary. Sensitivity analysis suggested that the results were relatively robust to the choice of this value. Further reductions to 0.01 and 0.001 reduced the log likelihood value by 0.0996% and 0.246%, respectively. Changes in parameter values were less than 5%.

[22] The explanatory variables in table 1 correspond to the original (uncorrected) form of the supply functions in (4). Thus, the coefficients on Effort correspond to the price effects for i not equal to j.

[23] The generalized R^2, which measures goodness of fit for the entire system of equations, was calculated for the system of equations prior to the heteroscedasticity correction. It is computed as $1 - \exp[2(L_0 - L_1)/N]$, where $L_0(L_1)$ is the sample maximum of log-likelihood when all slope coefficients equal zero (unconstrained) and N is the sample size (Baxter and Cragg, 1970). The calculated value of 0.99 indicates a very good fit. However, since this statistic is typically high, it should be interpreted with caution (White et al., 1988).

TABLE 1.—PARAMETER ESTIMATES OF INPUT-COMPENSATED SUPPLY FUNCTIONS

	Quantity Supplied of:					
Exogenous Variables	Dover Sole	Thorny- heads	Sable- fish	Other Flatfish	Other Rockfish	All Others
Price Ratio * Effort (a_{ij})						
Dover Sole	97.27	1.88	−4.55	−1.59	−2.03	0.65
	(11.78)	(1.98)	(4.82)	(0.87)	(2.69)	(1.18)
Thornyheads		19.17	7.25	−0.15	−10.45	−0.47
		(4.49)	(2.27)	(0.49)	(1.84)	(0.85)
Sablefish			37.43	0.97	−1.80	−2.07
			(7.62)	(0.88)	(1.93)	(1.06)
Other Flatfish				10.15	0.03	0.14
				(1.13)	(0.35)	(0.23)
Other Rockfish					74.86	0.54
					(17.21)	(0.34)
All others						10.45
						(1.55)
Other Exogenous Variables						
Effort Squared	−0.18	0.02	−0.13	−0.04	−0.09	−0.03
(a_i)	(0.08)	(0.03)	(0.03)	(0.01)	(0.13)	(0.01)
Brookings	−28.98	11.53	8.10	2.43	27.17	−0.04
Dummy (b_{i1})	(7.23)	(3.03)	(3.05)	(0.76)	(11.68)	(1.00)
Crescent City	−12.60	5.13	−1.03	−1.65	62.32	−2.09
Dummy (b_{i2})	(7.26)	(2.97)	(3.02)	(0.76)	(11.60)	(1.08)
Winter Dummy	15.03	1.52	3.54	1.54	−8.58	−1.78
(g_{i1})	(8.12)	(3.30)	(3.37)	(0.84)	(12.97)	(1.10)
Spring Dummy	3.63	−1.93	−0.99	0.31	3.90	−1.51
(g_{i2})	(7.92)	(3.21)	(3.28)	(0.82)	(12.67)	(1.07)
Fall Dummy	−17.88	1.63	−2.88	−1.21	−10.59	−0.69
(g_{i3})	(8.71)	(3.54)	(3.62)	(0.91)	(13.93)	(1.19)

Note: Generalized Leontief functional form. Symmetry in prices has been imposed. Linearized standard errors calculated by the delta method are given in parentheses. Apparent heteroscedasticity required estimation of supply per unit of Z, but the above exogenous variables refer to the form in (4).

TABLE 2.—PARTIAL EQUILIBRIUM PRODUCT SUPPLY AND SCALE ELASTICITIES

	Quantity Supplied					
Price Change	Dover Sole	Thorny- heads	Sable- fish	Other Flatfish	Other Rockfish	All Others
Dover Sole	0.037	0.046	−0.118	−0.191	−0.033	0.130
	(0.038)	(0.048)	(0.125)	(0.104)	(0.043)	(0.234)
Thornyheads	0.014[a]	0.021	0.185[a]	−0.018	−0.165[a]	−0.091
	(0.001)	(0.025)	(0.058)	(0.058)	(0.029)	(0.166)
Sablefish	−0.030[a]	0.149	−0.018	0.099	−0.024	−0.364
	(0.001)	(0.047)	(0.132)	(0.089)	(0.026)	(0.177)
Other	−0.013	−0.004	0.027	0.095	0.001	0.031
Flatfish	(0.007)	(0.013)	(0.025)	(0.076)	(0.006)	(0.050)
Other	−0.014	−0.204[a]	−0.037	0.003	0.216[a]	0.086
Rockfish	(0.017)	(0.036)	(0.040)	(0.033)	(0.035)	(0.054)
All Others	0.004	−0.008	−0.039	0.013	0.006	0.190[a]
	(0.007)	(0.015)	(0.020)	(0.020)	(0.004)	(0.053)
Quasi-Fixed	0.766[a]	1.125	0.322	0.012	0.914[a]	0.563[a]
Input	(0.158)	(0.674)	(0.191)	(0.401)	(0.448)	(0.183)

Note: Calculated at observed sample mean for Eureka in summer. Linearized standard errors calculated by delta method are given in parentheses.

[a] Statistically significant at 1%.

TABLE 3.—SHADOW PRICE ELASTICITIES

Dover sole	Thorny-heads	Sable-fish	Other Flatfish	Other Rockfish	All Others
0.4875	.2248	.0517	.0007	.2252	.0103

Note: Calculated at observed sample mean for Eureka in the summer following equation (6).

ties, calculated from (6), are all positive, indicating that CU^C will increase with increased product prices. Because the shadow price elasticities are all inelastic, the effect of changes in individual product prices on the firm's implicit marginal valuation of its quasi-fixed factor will be comparatively small. This is consistent with the small own- and cross-price elasticities discussed above. In addition, the small elasticities imply that changes in product prices would be expected to cause relatively small changes in CU. The two species with the largest expected changes are Dover sole and thornyheads, since these have the largest shadow price elasticities and two of the largest revenue shares.

B. Estimates of Current Capacity Utilization

The shadow value of the quasi-fixed factor was used to estimate actual capacity utilization for the trawl industry in 1984. Both the cost-gap and the profit-gap measures were calculated. Under 1984 resource conditions and prices, the following estimates were obtained:

$$CU^C = 1.017$$

and

$$CU^S = 1.028.$$

These measures are close to one, indicating that the industry was essentially in long-run equilibrium in 1984. Thus, the output vector and the capital stock level were sustainable, given the resource stock and market conditions, since no incentives for changes in the capital stock existed.

The hypothesis of long-run equilibrium is further supported by a comparison of the actual and optimal levels of Z. Departures between actual and optimal levels of a quasi-fixed factor can be tested by the significance of departures between its service and shadow prices (Kulatilaka, 1985). If the null hypothesis $W_Z = W_Z^*$ is not rejected, then the firm is in full equilibrium, i.e., $CU = 1$. Following Kulatilaka, we used a t-test to test the null hypothesis of full equilibrium, where the calculations are conditional on the observed sample means. The rental or market price of Z (W_Z) used was the 1984 capital services price in units of gross registered tonnage of the vessel per trip. The values were derived from vessel acquisition prices obtained from confidential financial statements.[24] The shadow price of Z (W_Z^*) was from equation (5), using the observed value of Z. The estimated t-statistic was 0.06, suggesting that effort was at its optimum, full-equilibrium level. Thus, the results of this test are consistent with the CU estimates obtained above.

C. The Effect of Output Quotas

The effects of alternative output quotas on the cost- and profit-gap measures of CU were evaluated in the following manner. The estimated supply curves at the point of means were used to calculate the virtual price that would correspond to a given quota on output Y_i at the individual vessel (firm) level for each fishing trip if all other product prices remain unchanged. Specifically, the virtual price p_i corresponding to the quota-constrained output y_i was solved from $y_i = Y_i^*(P_1, \ldots, P_{i-1}, p_i, P_{i+1}, \ldots, P_M; Z)$, where $Y_i^*(\cdot)$ is the estimated equation (4) for product i. The virtual price was then used to calculate W_Z^* using equation (5). The new CU^C and CU^S measures were then calculated.

The effects of an output quota upon the cost- and profit-gap measures of CU are reported in table 4. All measures were evaluated at the observed sample mean, and quotas for each output were progressively set as 10%, 20%, and 30% reductions of the unconstrained sample mean production levels.[25] While the effects on the cost- and profit-gap measures are qualitatively similar, they are more pronounced for the profit-gap

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[24] The use of confidential financial data raises questions about replicability of the reported results by other researchers. While these data are not (and cannot be made) public, the authors could make arrangements for replicability if necessary.

TABLE 4.—ECONOMIC CAPACITY UTILIZATION MEASURES WITH OUTPUT QUOTAS

Output Quota		Dover Sole	Thorny-heads	Other Flatfish	Other Rockfish	All Others
10%	Cost:	0.5805	0.8091	1.0123	0.8814	1.0042
	Profit:	0.5331	0.7150	1.0264	0.8015	1.0088
20%	Cost:	0.5688	0.7975	1.0123	0.8703	1.0040
	Profit:	0.5263	0.7028	1.0263	0.7869	1.0084
30%	Cost:	0.5648	0.7946	1.0123	0.8641	1.0038
	Profit:	0.5239	0.6999	1.0262	0.7790	1.0081

Note: Calculated at observed sample mean for Eureka in the summer. Output quota corresponds to percentage reduction from mean production.

measure. This should not be surprising since CU^S reflects the effect of the quota not only on shadow costs but also on revenue. This additional revenue effect reinforces the effect of the quotas on shadow costs, thereby increasing the investment incentives or disincentives beyond the levels implied by CU^C. This suggests that using the cost-gap measure of *CU* for firms whose output levels are endogenous may understate the actual expansionary or contractionary forces of the regulation.

In terms of product-specific effects, as anticipated, the products with the highest shadow price elasticities, Dover sole and thornyheads, had the largest reductions in *CU* in response to the quotas. Since the own-price product supply elasticities were highly inelastic, a comparatively large implicit price decrease was required to support each quota, contributing to the large reductions in *CU* for Dover sole and thornyheads.

Output quotas in this industry are counted on to smooth production of overexploited resource stocks over the entire year, thereby maintaining year-round production, while not limiting the number of firms in the industry. Our results suggest that for most species quotas impose only minor implicit costs to firms in the form of implicit taxes and reductions in the firm's implicit marginal valuation of its quasi-fixed factor. For these outputs, quotas should not create disruptive capacity imbalances and disinvestment incentives. However, quotas on Dover sole and thornyheads are likely inadvertently to reduce rates of capacity utilization enough to induce disinvestment and ultimately exit of some firms from the industry. Since those firms exiting the industry may be among the more efficient, another form of regulation to reduce their production rate may be preferred.

V. Summary

This paper has developed a methodology for using *CU* measures to predict the expansionary or contractionary investment tendencies that would result from the imposition of input or output constraints such as quotas. The methodology uses the concept of virtual prices to translate a primal constraint into the corresponding dual constraint. This allows the effects of regulatory or other constraints to be examined ex ante, i.e., before they are imposed, so that concerns about these effects can be incorporated into policy design.

The results are presented using two alternative measures of capacity utilization for multiproduct, profit-maximizing firms. The two are based, respectively, on the cost and the profit gaps that result from being out of long-run equilibrium. Although the two measures provide equivalent qualitative information about the existence of investment incentives or disincentives, they differ in magnitude. To the extent that output adjustments are an important component of regulatory response, the profit-based measure, which incorporates endogenous output choices, seems to capture more accurately the magnitude of the incentives that would exist as a result of the regulatory constraint.

The methodology for predicting the effects of constraints on investment incentives or disincentives is illustrated through a case study of an open-access marine fishing industry on the Pacific Coast of the United States. The results indicate that output quotas may help allocate production over the entire year for most species when they face excessive exploitation, but that for two of the

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[25] The effects of an output quota were not evaluated for sablefish, because its own-price supply elasticity was negative (but statistically insignificant).

outputs, Dover sole and thornyheads, even seemingly generous quotas can create disinvestment pressures severe enough for firms to exit the industry. In this case, should reductions in industry capacity through disinvestment be desired, other forms of regulation and disinvestment incentives allowing efficient resource reallocation may be preferred.[26]

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[26] Individual transferable quotas are one possibility, since the most efficient firms can purchase the transferable production quotas while less efficient firms exit the industry. This approach maximizes social surplus and directly addresses the issue of property rights. License limitation is another alternative. The application of *CU* measures to this latter case is discussed by Segerson and Squires (1990a). For a discussion of the welfare effects of alternative policies used in fisheries management, see Waugh (1984).