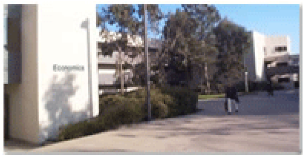

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CAPACITY AND CAPACITY UTILIZATION IN FISHING INDUSTRIES

BY

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by

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CAPACITY AND CAPACITY UTILIZATION IN FISHING INDUSTRIES

Abstract

Excess capacity of fishing fleets is one of the most pressing problems facing the world's fisheries and the sustainable harvesting of resource stocks. Considerable confusion persists over the definition and measurement of capacity and capacity utilization in fishing. Fishing capacity and capacity utilization, rather than capital (or effort) utilization, provide the appropriate framework. This paper provides both technological-economic and economic definitions of capacity and excess capacity in fishing and illustrates the technological-economic approach through a case study using Data Envelopment Analysis.

Excess capacity of fishing fleets is one of the most pressing problems facing the world's fisheries and the sustainable harvesting of resource stocks. Since 1989, both world marine fish catches and the world-wide number of vessels have leveled off, with many species fully or over-exploited and with a general excess number of vessels (FAO 1998b). The widespread adoption of the Precautionary Principle (FAO 1995), calling for resources stocks higher than those of maximum sustainable yield and sustainable catch levels correspondingly lower, exacerbates the existing problem of excess capacity.

International organizations and national governments show increasing concern over overfishing and excess capacity. In 1995, Articles 6 and 7 of the FAO Code of Conduct for Responsible Fisheries directly addressed the issue of excess capacity, calling on nations "to take measures to prevent or eliminate excess fishing capacity" and to "reduce capacity to levels commensurate with the sustainable use of fishery resources" (FAO 1995). To this end, the 23rd session of the Committee on Fisheries of the FAO (FAO/COFI) agreed in February 1999 to a global plan of action to manage world fishing capacity. In May 1998, FAO/COFI called for a drastic reduction of at least 30 percent of world fishing capacity on the main high-valued species (FAO 1998b). In the U.S., the Sustainable Fishing Act (1997) requires that resources be rebuilt to at least maximum sustainable yield (MSY) levels within a ten year period.

Excess capacity creates a number of problems. It generates intense pressure to continue harvesting past the point of sustainability in order to keep as much of the fleet working as possible. With revenues spread among many vessels operating under little or no profits, reductions in fleet size become politically and socially more difficult. Vessels are more vulnerable to changes in the resource base and regulations when they are only marginally viable because of excess capacity. Excess capacity encourages inefficient allocation and constitutes a major waste of economic resources. Overcapitalization and excessive use of variable inputs follow. Excess capacity also complicates the fishery management process, particularly in open access, frequently leading to detailed and comprehensive regulation. Excess capacity substantially reinforces the increasing tendency for management decisions to become primarily allocation decisions, i.e. decisions about the gainers and losers of wealth and profits (or losses) from alternative management choices over an overfished or even declining resource stock.

Given the widespread and deep concern over excess capacity in many of the world's most important fisheries, enormous confusion persists over the definition and measurement of capacity and capacity utilization in fishing industries (Kirkley and Squires 1998). Yet, a precise definition and widely applicable method of measurement is required for monitoring and measuring excess capacity, especially at the international level, where clearly agreed upon definitions and measures are required to develop international consensus and cooperation for global and regional plans of action to monitor and reduce excess capacity.

Fishing capacity and capacity utilization, rather than capital (or effort) utilization, provide the appropriate framework to manage fisheries. The aim is to harvest a target sustainable yield from a resource stock. Capacity output can be compared to this target, measures of excess or under capacity established, and the corresponding level of capital stock determined. The capital stock (or effort) and its utilization, important considerations in their own right, require a reference production flow from the resource stock, which in almost all fisheries of the world is a total allowable catch (TAC) or some other long-term target. Capital (or effort) and its utilization can provide the framework in lieu of capacity and capacity utilization only under very stringent conditions. The vast majority of the fisheries literature on capacity actually examines capital and its utilization.

This paper addresses the definition and measurement of capacity in fishing industries. The paper draws upon the corresponding background paper (Kirkley and Squires) and discussions from the Breakout Group on defining and measuring fishing capacity in the FAO Technical Working Group on the Management of Fishing Capacity, La Jolla, USA, 15-18 April 1998 (FAO 1998a), the U.S. NMFS National Capacity Management Team meeting, La Jolla, 25-26 January 1999, and various meetings of the U.S. Congressional Task Force on Investment.

Capacity can be defined and measured following either a technological-economic approach or explicitly predicated on economic optimization from microeconomic theory (Morrison 1985, 1993). This paper, Kirkley and Squires, and the different working groups primarily focus on the former because the general paucity of cost data in most fisheries world-wide militates against estimation of cost or profit functions to derive economic measures of capacity and capacity utilization. Similarly, the technological-economic approach is the one used by the U.S. Federal Reserve Board (Corrado and Mattey 1998) and in most other countries to monitor capacity utilization throughout the economy.

The definition and measurement of capacity in fishing and other natural resource industries face unique problems because of the stock-flow production technology, in which inputs are applied to the renewable natural resource stock to produce a flow of output. There are often multiple resource stocks, corresponding to different species, with a mobile stock of capital that can exploit one or more of these stocks (Greboval and Munro 1998, Kirkley and Squires, FAO 1998a). In turn, this leads to a number of unique issues: (1) multiple stocks of capital and the resource; (2) multiple outputs or resource flows from the multiple resource stocks; (3) aggregation or how to define the fisheries and resource stocks to consider; and (4), that of "latent capacity" or how to include stocks of capital that are currently inactive or exploit the resource stock only at low levels of activity. In addition, the current stock and flow of catch frequently differs from a sustainable target or reference stock and flow level (such as a Total Allowable Catch or TAC), so that different measures of capacity and excess capacity correspond to current and target resource conditions and intermediate states. Finally, in many fisheries, such as artisanal or in isolated regions, labor may be immobile and overemployed. The stock of labor may then form a fixed factor and the definition and measurement of capacity needs to consider this additional fixed factor (Greboval and Munro, Cunningham 1999).

The widespread use of industry output quotas corresponding to target resource flows, such as TACs, leads to a distinction between input- and output-oriented measures of capacity (Kirkley and Squires). When there is a TAC, an input-oriented measure considers how inputs may be reduced relative to a desired output level. An output-oriented measure indicates how output could be expanded to reach the maximum possible output level, given the capital stock and full variable input utilization. Both the corresponding input- and output-oriented measures of excess capacity can help design vessel decommissioning schemes such as a vessel buyback program.

This paper also provides an empirical illustration of the use of Data Envelopment Analysis (DEA) to assess capacity and capacity utilization in fisheries through a case study of the Northwest Atlantic sea scallop (*Placopecten magellanicus*) fishery. Using a panel data set on ten scallop vessels operating between 1987 and 1990, we find that the sample fleet had considerable excess capacity relative to current harvests. The vessels operated at suboptimal input levels, and for trips with high resource stock, the fixed factors rather than the resource abundance actually limited production.

The balance of the paper is organized as follows. Section 2 reviews the literature on fishing capacity and provides a definition consistent with economic theory. Section 3 discusses measurement of capacity in fishing industries. Section 4 specifies the empirical model and discusses the data. Section 5 discusses the empirical results and policy implications for managing capacity in the sea scallop fishery. Section 6 provides concluding remarks.

2. Fishing Capacity[1]

2.1. Fisheries Literature Review

The concept of fishing capacity has been used in a number of ways in the scholarly fisheries and governmental "grey" literatures and in fisheries management, but in its most widespread usage is equated with the capital stock (Kirkley and Squires). Specifically, fishing capacity is conceived as the maximum available capital stock in a fishery that is fully utilized at the maximum technical efficiency in a given time period given resource and market conditions. Capacity reduction then becomes reduction of the capital stock in a fishery or fleet. In short, the discussion of capacity and capacity utilization in the literature is often actually of capital and capital utilization, so that the primary focus of concern is the optimum utilization of capital.[2] Some of the names given to this concept include available fishing effort, effort capacity, harvest capacity, maximum effort, maximum potential effort, and potential fishing capacity.

This approach equates fishing capacity with fishing power, but not the concept of fishing power developed by Garstang in the latter part of the 19th Century (Garstang 1990) and refined by others. That is, fishing power is not conceived in terms of relative catch rates per unit of time.

Instead, fishing power is considered to measure the potential ability of a vessel to catch fish, where this potential is measured in terms of average vessel characteristics (see Taylor and Prochaska 1985, Hilborn and Waters1992). Hence, fishing capacity is equated with the heterogeneous capital stock available to the fishery. Fishing effort then denotes the product of the fishing power (capital stock) and the amount of time spent fishing, giving a flow of capital services. Capacity utilization is related to one of the variants of the neoclassical economics concept of capital utilization, discussed by Hulten (1990), as the ratio of capital services to the stock of capital. The second, and less widely adopted, specification of fishing capacity as capital stock directly accounts for fishing time, and capacity becomes a flow measure.

Equating the capital stock and capital utilization to capacity and capacity utilization implicitly assumes a linear relationship between the capital stock and capacity and the two corresponding utilization rates.[3] These measures coincide only if there is but one fixed input (a single stock of capital), all variable inputs are in fixed proportions to the fixed input, and production is characterized by constant returns to scale (Berndt and Fuss 1989, Allen 1968). Thus, given a constant optimal capital-output ratio $g = K_t/Y_t^*$, capacity output Y_t^* can be expected to vary directly with the observed capital stock K_t (Berndt).

Fishing capacity has been conceived in other ways besides the capital stock, most notably maximum potential catch (Kirkley and Squires). There are several approaches discussed in the fisheries literature to measure maximum potential catch: (1) fleet hold capacity; (2) the peak-to-peak method; (3) maximum sustainable yield; and (4) fishing mortality. In some instances, the impact of various regulations or fishery management measures are considered, and in other instances they are not.

Economic measures of capacity have received substantially less attention than engineering-technological measures (Kirkley and Squires). Economic notions of capacity define output as the economic optimum when outputs are freely varied, correspond to a target level (such as TACs), or are exogenously determined in some other manner given one or more quasi-fixed or fixed inputs. In the fisheries literature, gross proceeds, measuring total output, have been suggested. When TACs are taken as given, the focus has shifted to examining the optimal fleet size rather than the maximum potential catch level, often using linear programming. Break-even analysis has also been used, where excess capacity can be defined as the reduction in fleet size required to provide a break-even catch level to the remaining vessels. Duality-based econometric estimates of economic capacity and capacity utilization in fisheries, as initially developed by Berndt and Morrison (1981), Morrison (1985), and Nelson (1989), have been used on a limited basis, with the first by Squires (1987) and Segerson and Squires (1990).

2.2. Capacity and Capacity Utilization

Capacity is a short-run concept, where firms and industry face short-run constraints, such as the stock of capital or other fixed inputs, existing regulations, the state of technology, and other technological constraints.[4] Johansen (1968, p. 52) defined capacity for the technological-economic approach as, "...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted." Capacity output thus represents the maximum level of production the fixed inputs are capable of supporting. This concept of capacity generally conforms to that of a full-input point on a production function, with the qualification that capacity represents a realistically sustainable maximum level of output rather than some higher unsustainable short-term maximum (Klein and

Long 1973). This approach gives an endogenous output and incorporates the firm's *ex ante* short-run optimization behavior for the production technology (given full utilization of the variable inputs). This approach does not directly capture the influences of changes in economic variables and is not explicitly based on economic optimization .

The maximum potential catch in fisheries is the maximal or expected harvest that variable inputs are capable of producing given the observed capital stock, other vessel characteristics, the state of technology, and the resource stock (Kirkley and Squires). In fisheries, we actually consider the maximum potential nominal catch or maximal level of landings. Rarely is it possible to know what is actually caught and discarded at sea. The definition adopted by the TWG Break-Out Group is (FAO 1998a, para 66) is, "Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully-utilized, given the biomass and age structure of the fish stock and the present state of the technology. Fishing capacity is the ability of a vessel or fleet of vessels to catch fish." This definition was adopted by the U.S. National Marine Fisheries Service Capacity Management Team and a very closely related one was adopted by the U.S. Congressional Task Force on Subsidies and Investment in Fisheries.

A second basic approach to capacity explicitly builds upon an economic foundation (Morrison 1985). Capacity can be defined as that output pertaining to one of two economic optimums: (1) the tangency of the short- and long-run average cost curves (Chenery 1952, Klein 1960, Friedman 1963), so that the firm is in long-run equilibrium with respect to its use of capital, or (2), the tangency of the long-run average cost curve with minimum short-run average total cost curve (Cassel 1937, Hickman 1964); these measures coincide for a linear homogeneous technology. These capacity output levels are in steady state in that the firm does not have an incentive to change output levels provided that input prices, stocks of fixed inputs, and state of technology remain constant (Morrison 1985). Berndt and Morrison (1981), Berndt and Fuss (1986), Morrison (1985, 1986), and Nelson (1989) developed the dual approach with exogenous output, which measures the cost gap when actual output differs from capacity output.[5] This cost-minimizing economic approach, in which outputs are exogenous, neatly fits the widespread application of TACs in fisheries, where the output level is exogenously defined by population biologists.[6] The use of exogenous output contrasts with the endogenous output of the output-oriented technological-economic approach. The economic approach requires cost data, which hinders its applicability on a widespread and consistent basis in fisheries.

Capacity utilization (CU) represents the proportion of available capacity that is utilized, and is usually defined as the ratio of actual output to some measure of capacity output (Morrison 1985, Nelson). In the technological-economic approach that was adopted by FAO, NMFS, and the U.S. Congressional Task Force, full CU represents full capacity and CU cannot exceed one. CU less than one indicates that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers 1960).

CU can be measured in two different ways with the technological-economic approach. CU can be measured as the ratio of observed output to capacity output, which is the standard approach. When TACs are used, observed output at the industry level is the TAC. CU can also be measured as the ratio of technically efficient output to capacity (Färe *et al.* 1994). The latter definition corrects for any bias that could otherwise arise from technical inefficiency. Otherwise, the CU measure combines both deviations from full technical efficiency and full capacity.

2.3. Two Stocks: Capital and Resource

Two types of stocks are paramount in the short-run of stock-flow production processes in natural resource industries, the stock of capital and the natural resource stock, and in some instances, the stock of labor. The resource stock is often specified as another type of capital stock (in which case, capacity and capacity utilization can be indeterminate, a topic we turn to in greater detail below). When resource stocks are specified as another type of capital stock, they can be treated as either discretionary or nondiscretionary inputs.[7] The resource stock can also be specified as a technological constraint rather than as a fixed factor (in which case the above indeterminancy problem does not arise).

Capacity with either specification of the natural resource stock must contend with both of these stocks changing over time, not simply the capital stock. Capacity can be defined and evaluated with the resource stock at existing or long-run equilibrium levels or any equilibrium level.

2.4. Excess Capacity

In fisheries and other renewable resource industries, excess capacity should ideally be defined relative to some biological or bio-socio-economic reference point which accounts for sustainable resource use. To appropriately set the target capacity, it is necessary to specify a target resource stock size. The TWG recommended that the target level of output be evaluated at both the current and target stock sizes (FAO 1998a).

In practice, the long-range target, such as the long-run steady-state optimum, may be difficult to estimate, so that the most important objective is to develop a capacity management strategy that moves in the right direction.[8] It is important to determine the magnitude of the difference between current and target capacity to determine severity of problem, and the appropriate step size in the future. As the fleet moves along the adjustment path towards a preliminary target estimate, accumulation of knowledge and a better indication of changes in technology and other factors may result in continual updating of the ultimate target.[9]

Excess capacity, in an output-oriented technological-economic approach, can be defined as the difference between capacity output and desired or target level of capacity output, such as the TAC (OECD 1996, Kirkley and Squires, Greboval and Munro, FAO 1998a). The target level of output was defined by the TWG as (FAO 1998a), "Target fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized while satisfying fishery management objectives designed to ensure sustainable fisheries..." The TWG observed that current and target capacity need to be evaluated and compared relative to the same stock size (FAO 1998).

Excess capacity, in an input-oriented technological-economic approach, starts with a TAC (either current or long-term projection) and determines how many of each vessel and gear type would catch this TAC, then compares this result to current fleet size, given full utilization of the variable inputs and the resource stock. In an economic approach, and given a TAC or set of TACs, the corresponding cost-minimizing level of capital stock can be found, and excess capacity is the difference between the observed output and the TAC.

Optimal capacity, if defined, can be better defined as a range rather than a specific quantity or metric (FAO 1998a). Optimal can be specified relative to outer boundaries. According to paragraph 7 of Annex II of the Straddling Stocks Agreement, the minimum standard for a biological reference point should be the fishing mortality rate that generates maximum sustainable yield. The capacity corresponding to a resource stock beyond this mortality rate limit is an upper bound on optimal or target capacity. "The following definition for ‘limit’ capacity conforms with the direction in which international law is developing: Limit capacity is the maximum amount of fish that can be produced on a sustainable basis by a fully-utilized fleet. Thus, the limit capacity corresponds to MSY." (FAO, 1998a, para 68).

Capacity measured at the level of the individual firm, vessel, vessel size class, port, or region can be aggregated over all categories to give a measure of overall capacity. This overall capacity measure can then be compared to the target capacity or reference point.

Excess capacity differs from overcapitalization (Cunningham, Kirkley and Squires). Excess capacity occurs when a firm or industry has the potential to produce well in excess of what is actually produced. Specifically, there is an excessive use of all inputs -- including labor, heterogeneous capital, and other fixed factors -- to produce a given set of outputs; overcapitalization refers to the excessive use of only capital. Overcapacity and overcapitalization are usually equated because either inputs are aggregated to form a single composite input, fishing effort (which in turn is equated to the capital stock and capital utilization), or because of the specification of a homogeneous capital stock.

2.5. The Measurement of Capacity and the Natural Resource Stock

In fisheries and other renewable resource industries with stock-flow production processes, capacity can be *measured* conditional upon the size and composition (e.g. age structure, species, and density) of the resource stock or without the resource stock. The former gives a measure of the maximum potential output which could be produced at given resource stock levels; the resource establishes an upper limit on output in the stock-flow production technology. The latter provides a measure of the potential output which could be produced in the absence of resource constraints, such as after a resource stock has begun rebuilding beyond the current depleted level.

Including the resource stock in the assessment of capacity makes it possible to determine whether or not resource abundance rather than the fixed inputs limit the harvest. In this latter case, capacity is calculated with and without the resource abundance. If the capacity output with abundance included equals capacity output with abundance excluded from the analysis, the fixed factors and not the resource stock constrain production.

2.6. Full Utilization of Variable Inputs

Capacity output (in the technological-economic approach) is the level of output attainable by "full utilization" of the variable factors of production, given the current technology and keeping fixed factors at their current levels. This raises the question of defining the full-employment or full utilization level of variable inputs (Corrado and Mattey, Morrison 1993). For example, is the capacity of a plant (e.g. fishing vessels) and equipment (e.g. nets, winches, engines) determined by the production of this plant and equipment operating throughout the day or season or year, and should downtime for repair and maintenance, offloading, institutional constraints such as holidays, and the like be considered?

The answer varies by the type of technology and institutional factors that constitute issues such as "normal" downtime (Corrado and Mattey).[10] Short-run output varies with technology type in different ways according to: (1) duration and (2) intensity or speed of operations.

Duration, rather than intensity, is generally more important in fishing industries, since biological conditions tend to dictate speed of operation such as tow or encircling rates for active gear or soaking time for passive gear. To the extent processing constrains intensity, especially when harvesting and processing are vertically integrated into one production process at sea, intensity plays a larger role in defining full utilization of variable inputs.

2.7. Latent Capacity

The definition and measurement of capacity and capacity utilization depend on the universe of active participants, i.e. which vessels to include in the industry. The great mobility of vessels -- the capital stock -- complicates defining the participating vessels. Most fishing industries have a core of active participants, some more active than others. However, there are often potential participants that fish elsewhere or on other species that are currently inactive, or active only at low levels of variable input utilization, but which could suddenly actively participate if resource stock, market conditions, or regulations change. The number of potential participants and the duration and intensity of operations of potential and existing participants lead to the issue of "latent capacity". Latent capacity could be estimated attributing the full variable input utilization rates of active participants to the currently partially or fully inactive participants and using their capital stock information.

2.8. Multiple Outputs and Heterogenous Capital Stock

Measurement of fishing capacity needs to account for multiple species or outputs and multiple resource stocks. When there are multiple outputs and production is joint, a primal scalar measure of output does not generally exist except under the restrictive conditions of homothetic output separability or changes in outputs in constant proportions giving a ray measure (Segerson and Squires 1990).[11] When production is nonjoint in inputs, measures of capacity and CU can be formed for each separate production process.

Even though theoretical constraints militate against a fully theoretically satisfactory primal measure of capacity and CU in multispecies fisheries with joint production, even with only a single stock of capital, policy makers must still form policies to manage capacity. Moreover, multispecies fisheries, especially those in the temperate latitudes, are usually managed on a species-by-species basis, leading policy makers to want capacity and CU measures on a corresponding species-by-species basis. For example, the species of the New England groundfish fishery were previously managed as single species fisheries.

In these instances, partial capacity and CU measures, denoted y_i^* and CU_i, may be useful (Segerson and Squires 1990). y_i^* provides the capacity level of output for the i^{th} product given the actual output levels for all other products (as well as the stock of capital, input prices, the state of technology, and resource stocks). CU_i is correspondingly defined as $CU_i = y_i/y_i^*$ for any given i. The numerical value of this CU measure will vary across products, and therefore it is not unique for a given firm. Consistency of the partial CU measure when applying the technological-economic approach and a single stock of capital has yet to be evaluated in the literature.

When there are both multiple outputs and multiple fixed factors, measures of capacity and CU become problematic (Berndt and Fuss).[12] However, in fisheries and other natural resource industries with stock-flow production technologies, and when the resource stock is conceived of as natural capital stock (i.e. as fixed inputs), capacity and CU can be found recognizing that these are short-run measures. Each species output flows from a corresponding resource stock. The estimates of capacity and CU can be made conditional upon the existing (or target) resource stocks, given a single stock of man-made capital. The resource stocks can alternatively be conceived as technological constraints, like the state of technology, and capacity and CU measured conditional upon their levels. Either conceptualization of the resource stocks gives equivalent empirical results. When a heterogeneous man-made capital stock is considered, the issue of multiple fixed factors once again appears.

2.9. Multiple Fisheries and the Level of Aggregation

The issue of what capacity to measure arises when there are multiple fisheries or multiple resource stocks harvested by different gear types. In general, multispecies fisheries and multiple fisheries can be approached as multiproduct industries (Kirkley and Squires, Greboval and Munro, FAO 1998a). In multispecies fisheries, in which separate TACs are established for each species, should excess capacity be assessed by individual species, species assemblages, or all species? Are specialist vessels, enjoying product-specific economies of scale, treated differently from multiproduct vessels enjoying economies of scope? The TWG concluded that stock-by-stock, fleet-by-fleet, and region-by-region approaches are all required (FAO 1998a).

The level of spatial, species, and gear aggregation affects the results. The more broadly based the analysis, such as a major regional fishery across all gear types instead of a more narrowly defined one, the more the effects of fleet interaction and mobility are incorporated. More broadly based analyses might indicate lower or even zero excess capacity, since high-value species might show excess capacity relative to MSY but are counter-balanced by under-capacity relative to MSY of lower-value species. For example, world-wide, many demersal (bottom dwelling) fisheries are generally believe to face excess capacity but lower-valued pelagic (surface dwelling) species may face under-capacity (FAO 1998b).

Highly aggregated analyses, such as global or regional, might best describe the issue and indicate approximate orders of magnitude, whereas capacity management might best be served by disaggregated analyses with finer resolution (FAO 1998b). Aggregated analyses may also be relevant for highly mobile tuna stocks and fisheries, but not efficacious across fishing areas or fisheries that are spatially distinct or sufficiently technologically distinct (FAO 1998b).

3. Measuring Fishing Capacity

There are a number of approaches to assess fishing capacity. The two most promising approaches for widespread, tractable application correspond to the technological-economic definition which focuses upon capacity output and does not require cost data. These are the "peak-to-peak" method of Klein (1960), and the output- and input-oriented data envelopment analysis (DEA) approach developed by Färe *et al*. (1989, 1994) and proposed for fisheries by Kirkley and Squires (1998). Both approaches are nonparametric. The strictly economic approach is well developed in Morrison (1985, 1993), Nelson (1989), Segerson and Squires (1990, 1995), Squires (1987), and Kim (in press), and hence is not further discussed here.

The peak-to-peak approach is best suited when data are especially parsimonious, such as when the data are limited to catch and vessel numbers.[13] The approach permits determining the capacity output and potential level of capital to reduce in decommissioning schemes, although it does not indicate the actual operating units to be decommissioned (Kirkley and Squires). Ballard and Roberts (1977) and Garcia and Newton (1997) are the key fisheries applications.

The stochastic production frontier provides another option, since it gives the maximum possible output (Kalirajan and Salim 1997, Kirkley and Squires). The frontier should be estimated with the stock, not the flow, of capital and with full utilization of variable inputs, not the observed level of use. Details of estimation with full variable input utilization have yet to be worked out. The stochastic frontier approach does not readily accommodate multiple outputs.

The econometric distance function approach of Coelli and Perelman (1968), however, offer a possible method for dealing with multiple outputs.

3.1. Data Envelopment Analysis

DEA is a nonparametric or mathematical programming technique to determine optimal solutions given a set of constraints. DEA can be used to calculate capacity and CU using the approach of Färe *et al.* (1989, 1994). Klein and Long developed a linear programming precursor–peak to peak. The DEA approach determines the maximal or capacity output given that the variable factors are unbounded or unrestrained and only the fixed factors and state of technology constrain output. Based on an output orientation (output is allowed to change while inputs are held constant), capacity output is determined by solving a simple linear programming problem. The maximum possible output or capacity corresponds to the output which could be produced given full and efficient utilization of variable inputs, but constrained by the fixed factors, the state of technology, and when included, the resource stock(s). The difference between observed and frontier output gives the excess capacity for that resource stock in an output-oriented approach. In many fisheries, observed industry output is often the TAC.

DEA has several unique advantages (Kirkley and Squires). DEA can estimate capacity under constraints including TACs, bycatch (incidental catch of species other than those intended), regional and/or size distributions of vessels, restrictions on fishing time, and socio-economic concerns such as minimum employment levels. DEA readily accommodates multiple outputs and multiple inputs, zero-valued output levels, and nondiscretionary inputs and outputs. DEA can also determine the maximum potential level of effort or variable inputs in general and their optimal utilization rate. The analysis accepts virtually all data possibilities, ranging from the most parsimonious (catch levels, number of trips, and vessel numbers) to the most complete (a full suite of cost data). With cost data, DEA can be used to estimate the least-cost (cost minimizing) number of vessels and fleet configuration. It can also measure capacity to any desired biomass or TAC. DEA also allows both the input- and output-oriented approach.

The DEA approach to capacity measurement effectively converts the multiple products into a single composite output because there is a radial expansion of outputs (outputs are in fixed proportions for different input levels). This gives the ray measure of capacity and CU considered by Segerson and Squires, and implicitly imposes Leontief separability among the outputs.[14]

The heterogeneous capital stock represents multiple quasi-fixed or fixed factors. By specifying a heterogeneous capital stock, the specification does not necessarily *a priori* denote any individual piece of capital as binding or fully utilized, and in fact, not all fixed factors necessarily will bind. Instead, the data can determine the individual component of the heterogeneous capital stock that binds on a firm-by-firm basis. For instance, the vessel length might bind for one firm while engine horsepower might bind for another firm.

The DEA approach, in two different ways, effectively converts the heterogeneous capital stock (multiple fixed factors) into a single measure of the capital stock (composite fixed factor) to solve the indeterminancy problem raised by Berndt and Fuss. First, when the DEA measure of capacity is output-oriented, i.e. the maximum output given fixed inputs, the fixed inputs or heterogeneous capital stock are held constant at observed levels, and as discussed above, that individual component of the heterogeneous capital stock that is fully utilized (binding) is the individual capital stock that determines capacity. Second, and perhaps more importantly, the DEA measure of capacity entails a radial expansion of outputs and inputs, that is, outputs are in fixed proportions for any output levels and inputs are in fixed proportions for any input levels. When fixed inputs are in fixed proportions, an aggregate fixed input or capital stock is formed (Leontief separability). This effectively converts the multiple fixed factors into a composite measure.

Other issues which could be considered within the DEA framework include calculation of capacity output under various bycatch mitigation or habitat restoration policies. Adding bycatch simply requires reformulating the problem such that bycatch is treated as an undesirable joint output -- a "bad"; this requires weak subvector disposability constraints.[15]

3.2. DEA and Vessel Decommissioning

The need for vessel decommissioning in capacity reduction programs can be directly addressed using the DEA approach (Kirkley and Squires). Because DEA can be either output- or input-oriented, different aspects of vessel decommissioning can be addressed. The input-based measure considers how inputs may be reduced relative to a desired output level, such as a TAC.[16] Hence, it would allow determining the optimal vessel or fleet configuration and actual vessels which should be decommissioned in a fishery corresponding to a TAC.

The output-based measure indicates how output could be expanded to reach the maximum possible output level, given the capital stock and full utilization of variable inputs. The output-oriented DEA measure allows fishery managers to identify the level of output and vessels which would maximize output subject to given full utilization of variable inputs and fixed factors and (optionally) resource constraints. Hence, it can be used to identify operating units (individual vessels or vessel size classes) which can be decommissioned. By rearranging observations in terms of some criterion, such as capacity by region and vessel size class, the number of operating units can be determined by adding the capacity of each operating unit until the total reaches the target. Moreover, given a TAC, the output-based measure could yield a precautionary level of total inputs and vessels which yield maximum technical efficiency.

The DEA solution with multiple products calculates the capacity output level for each output. Each output's capacity, summed over all firms in a relevant region and time period, gives the industry capacity which can be compared to that output's TAC. All outputs can also be summed and compared to the sum of all TACs. Analysis of vessel decommissioning can proceed as discussed above.

3.3. The DEA Framework

Following Färe *et al.* (1989), let there be $j = 1,...,J$ observations or firms in an industry producing a scalar output $\mu^j \in R_+$ by using a vector of inputs $x^j \in R^N_+$. We also assume that for each n, $\sum_{j=1}^{J} x_n^j \rangle 0$, and for each j, $\sum_{n=1}^{N} x_n^j \rangle 0)$.

The first assumption states that each input n is used by some firm j. The second assumption indicates that each firm uses some input. A remaining assumption is that each firm produces some output, $u^j > 0$ for all j.

The following output-oriented data envelopment analysis (DEA) problem calculates Johansen's notion of capacity (Färe *et al.* 1989, 1994):

$$\max_{\theta\lambda z} \theta$$

$$\text{s.t. } \theta u_j \leq \sum_{j=1}^{J} z_j u_j \text{ , } \sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, n \in \alpha \qquad [1]$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \text{n} \in \alpha^\wedge$$

and $z_j \geq 0$, $j = 1,2,..., J$ *and* $\lambda_{jn} \geq 0, n \in \alpha^\wedge$. The variable factors are denoted by $\alpha^\wedge$, the fixed factors are denoted by α, and the z_j define the reference technology. Problem (1) enables full utilization of the variable inputs and constrains output with the fixed factors. Moreover, the vector λ is a measure of the ratio of the optimal use of the variable inputs (Färe *et al.* 1989, 1994). λ gives the capacity utilization rate of the n^{th} variable input for the j^{th} firm for $x_{jn} > 0$, $n \in \alpha^\wedge$. Problem (1) imposes constant returns to scale, but it is a simple matter to impose variable returns to scale (i.e., variable returns to scale requires the convexity constraint $\sum_{j=1}^{J} z_j = 1$.

The parameter θ is the reciprocal of an output distance function and is an output-oriented measure of technical efficiency relative to capacity production, $\theta \geq 1.0$. It provides a measure of the possible (radial) increase in output if firms operate efficiently given the fixed factors, and their production is not limited by the availability of the variable factors of production (e.g., a value of 1.50 indicates that the capacity output equals 1.5 times the current observed output). If * denotes an optimum, then $\theta^*_j \mu^j$ equals the maximum amount of μ^j that can be produced given observed levels of fixed factors α and full utilization of variable inputs $\alpha^\wedge$ – capacity output for output μ^j.

The CU measure of observed output divided by capacity output may be downward biased because the numerator in the traditional CU measure, observed output, may be inefficiently produced. Färe *et al.* (1989) demonstrate that an unbiased measure of CU may be obtained by dividing an output-oriented measure of technical efficiency corresponding to observed variable input and fixed factor usage by the technical efficiency measure corresponding to capacity output (i.e., the solution to problem (1) in which variable inputs $\alpha^{\wedge}$ are fully utilized).

To obtain a measure of technical efficiency corresponding to observed input usage, Färe *et al.* (1989) suggest that the technical efficiency of the j[th] firm, ($\theta(x^j)$), may be obtained as a solution to a linear programming problem:

$$\max_{\theta z} \theta$$

$$\text{s.t. } \theta u_j \leq \sum_{j=1}^{J} z_j u_j \, , \qquad [2]$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, \; n = 1,2,...,N$$

and $z_j \geq 0$, $j = 1,2,...,J$. The input vector x includes both the fixed and variable inputs.

Problem (1) provides a measure of TE, θ_1, which corresponds to full capacity production. Problem (2) provides a measure of TE, θ_2, which corresponds to technically efficient production given the usage of the variable inputs. The ratio of the two θs, θ_2/θ_1, is a an unbiased measure of capacity utilization (Färe *et al.* 1989). Solutions to problems (1) and (2) provide estimates of technical efficiency, capacity, capacity utilization, and optimal input utilization relative to a best practice frontier.[17] The solutions are not indicative of absolute efficiency and capacity.

4. Empirical Application: The U.S. Northwest Atlantic Sea Scallop Fishery

The U.S. northwest Atlantic sea scallop fishery was traditionally one of the most important U.S. fisheries. The northwest Atlantic sea scallop is harvested primarily from Georges Bank and various Mid-Atlantic resource areas. The primary gear type is the dredge. The primary landed product form is meats after at-sea processing (shucking).

We calculate capacity, capacity utilization, and input utilization with and without resource levels under variable returns to scale. We treat resource abundance as a discretionary input. Resource abundance may not be discretionary, since captains do not have control of the resource levels. Captains, however, control the selection of fishing areas, and scallops are stationary in a region.

4.1. Data and Input Specification

The panel data set for 10 scallop vessels contains trip-level observations for 1987-1990 on output and input levels, resource abundance, and fixed factors. Data were directly obtained from settlement sheets provided by vessel owners. Output is measured in terms of pounds of sea scallop meats landed per trip. Days at sea and crew size per trip are variable inputs. Days at sea reflects capital, energy, materials, and labor, and may be considered as an intermediate output of the first stage of a nonseparable two-stage technology. Crew size is a stock and not a flow variable, but the services may be assumed to be proportional to total crew size. GRT, engine horsepower, and dredge width in feet are fixed factors. Stock abundance measures, in number of baskets per standard tow, are fishery dependent, but were obtained from previous monitoring programs in which vessels made one tow at the end of a trip to provide information about resource abundance, state of reproduction, and age-class distribution (Kirkley *et al.* 1995).

4.2. Full Variable Input Utilization

Capacity and CU were calculated on a per vessel per trip basis. To extrapolate the per trip measures to an annual basis, we established two maximum annual variable input utilization levels for days at sea: (1) the observed maximum of 285 days at sea (for vessel number 4 in 1990) and (2) the average number of days per year per vessel between 1987 and 1990 of 248.5 days at sea.

For each vessel, we calculate two capacity outputs for each year by multiplying the capacity output per trip per vessel times these two annual measures of full variable input utilization. We also limited the number of days a vessel may fish within a shorter interval of time (e.g., if a vessel is already working 28 to 30 days a month, it cannot make another trip in that month). Complete details are available from the authors upon request.

5. Capacity, Capacity Utilization, and Input Utilization in the Sea Scallop Fishery

Solutions to the DEA problems indicate that the sample vessels' capacity output exceeded actual harvest between 1987 and 1990. In 1987, the vessels landed 1.48 million pounds [Table 1]. The catch could have reached approximately 2.08 million pounds with efficient variable input utilization (Problem 2). The fleet operating at full capacity in 1987 over 285 days, but subject to resource limitations, could have harvested 3.08 million pounds. Vessels operating at full capacity subject to resource limitations, but at the mean number of days of 248.25, could have harvested 2.73 million pounds. Vessels operating at full capacity without resource limitations, but spending 285 days at sea, had the potential to harvest 3.48 million pounds. Vessels operating at the mean number of total days per year per vessel of 248.25 and without resource limitations had the potential to harvest 3.01 million pounds.

Vessels operating efficiently could increase their total production by approximately 50.8 percent between 1987 and 1990. Improvements in just technical efficiency, given resource levels, could increase production to 37.5 percent of capacity output in 1987, 62.6 percent in 1988, 38.0 percent in 1989, and 46.7 percent in 1990. Operating at the optimum level of days at sea and crew size and over 285 days, subject to resource conditions, would allow production to increase by another 39.9 percent between 1987 and 1990.

Recent information by a group of stock assessment scientists charged with defining allowable harvests and the levels of nominal catch corresponding to overfishing suggests a sustainable harvest of approximately 20 million pounds per year (NEFSC 1997). The capacity output of 82 vessels corresponding to the same size class as the sample vessels (51-150 GRT) is approximately 29 million pounds if allowed to operate 285 days a year. The capacity output of all 175 full-time vessels exceeds 76.7 million pounds.[18] The fishery has substantial excess harvesting capacity relative to proposed long-term or sustainable yields.

Very few trips operated at the full capacity utilization levels of days at sea and crew size per trip between 1987 and 1990. In 1987, only 7 trips, conditional on resource levels, had the full capacity utilization number of days and optimum crew size. Without resource limitations, no trips had the optimum levels. 39.1 percent of all trips between 1987 and 1990 had days at sea within plus or minus one day of the optimum, given resource levels. The number of trips within plus or minus one individual of the optimum crew size, given resource conditions, was only 22 percent between 1987 and 1990. Only 14.8 and 2.2 percent of all trips between 1987 and 1990 had, respectively, the optimum days and crew size at the full capacity output without resource constraints.

What about the possibility that the controllable fixed factors rather than resource abundance constrained capacity output? Out of a total of 581 trips made by the ten vessels between 1987 and 1990, only 25 trips were not constrained by resource conditions. Those trips were associated with very high stock levels.

We report CU measures on a per vessel basis and for each year between 1987 and 1990 at the specified full utilization of days at sea of 285 days [Table 2]. Overall, we find that average CU per trip, when based on observed output and resource constraints, is quite low but is relatively high with technical efficiency. Technical inefficiency appears to be a major reason why vessels have not operated near optimal capacity. Vessel operators make shorter trips than required to operate at the optimal capacity. CU conditional on resource abundance and observed output ranged from 26.9 for vessel 4 in 1987 to 54.7 in 1990; when considered relative to the technically efficient output level, CU ranged from 39.6 for vessel 4 in 1987 to 80.2 for vessel 4 in 1990. CU falls when measured without resource abundance. For instance, CU for vessel 4 in 1987, when calculated using observed output, was 22.8; CU for vessel 4 in 1990 was only 47.9. Similarly, CU for vessel 4, when calculated using the technically efficient output level, was only 33.6 in 1987 and only 70.2 in 1990.

If we consider CU relative to the observed number of days per year, CU is considerably higher. CU conditional on resource abundance and calculated using the technically efficient output and observed number of days ranged from a low of 72.2 for vessel 2 in 1987 to a high of 96.6 for vessel 1 in 1987; in 1990, CU ranged from 72.5 for vessel 8 to a high of 85.3 for vessel 9.

6. Concluding Remarks

The economic issue of excess capacity, its biological twin of overfishing, and their management are the dominant issues in global fisheries today. They are currently the subject of considerable attention at the national and international levels. Nonetheless, considerable confusion reigns over a definition and a tractable measure of capacity and excess capacity.

The paper provides both technological-economic and economic definitions of capacity and excess capacity in fishing industries. The paper recommends the technological-economic approaches to measuring capacity and excess capacity on a widespread basis due to data limitations. Either output- or input-oriented approaches are possible. The paper provides definitions and a tractable approach to measurement and an empirical example of the technological-economic approach using Data Envelopment Analysis.

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Table 1. Mean Performance and Input Usage, Technical Efficiency, and Potential Capacity Output

Variable	1987	1988	1989	1990
Average Catch per Trip	9773	9199	7685	9913
Average Stock Abundance per Trip	3.31	2.81	2.43	2.70
Average Technical Efficiency per Trip	1.74	1.96	2.55	1.81
Average Capacity Efficiency with Stock Abundance	3.94	3.39	6.50	4.43
Average Capacity Efficiency without Stock Abundance	5.29	3.94	7.98	5.30
Average Output Per Trip-Technically Efficient Production	13770	15098	13744	14675
Average Output per Trip–Capacity with Resource Levels	20135	20332	19414	19722
Average Output Per Trip-Capacity without Resource Levels	23061	23260	23260	23260
Average Days per Trip	13.52	15.85	15.07	17.60
Optimal Days per Trip (with stock)	18.76	19.14	18.97	19.15
Optimal Days per Trip (without stock)	19.02	19.02	19.02	19.02
Average Crew per Trip	10.36	9.63	9.51	8.92
Optimal Crew per Trip (with stock)	11.46	11.22	11.00	11.11
Optimal Crew per Trip (without stock)	12.99	12.99	13.04	13.07
Total Actual Catch (million pounds)	1.48	1.35	1.16	1.30
Potential Catch (million pounds)–Technically Efficient[a]	2.08	2.22	1.73	1.94
Potential Catch (million pounds)–Capacity with Stock[b]	3.08	2.74	2.66	2.67
Potential Catch (million pounds)–Capacity without Stock[c]	3.46	3.13	3.13	3.13
Potential Catch (million pounds)–Capacity with Stock[d]	2.73	2.41	2.34	2.36
Potential Catch (million pounds)–Capacity without Stock[e]	3.01	2.72	2.72	2.72

[a]The fleet output if vessels operated efficiently using the same level of inputs.

[b]The fleet output if the vessels operated efficiently and at full capacity (285 days) given resource levels.

[c]The fleet output if the vessels operated efficiently and at full capacity (285 days) without resource limits.

[d]The fleet output if the vessels operated efficiently and at full capacity (248.25 days) given resource levels.

[e]The fleet output if the vessels operated efficiently and at full capacity (248.25 days) without resource limits.

Table 2. Average Capacity Utilization per Vessel Conditional on Vessel Operating 285 days per Year

Vessel	1987		1988		1989		1990	
	Observed[a]	Efficient[b]	Observed	Efficient	Observed	Efficient	Observed	Efficient
With Resource:[c]								
1	60.7	85.6	55.2	82.3	47.1	80.1	51.5	76.7
2	40.4	45.9						
3	49.7	71.6	45.4	77.3	46.6	78.1	47.0	69.3
4	26.9	39.6	48.9	82.1	48.5	87.6	54.7	80.2
5	49.0	71.2	53.4	85.6	49.3	74.5	51.0	77.1
6	44.0	64.6	51.9	80.4	41.8	75.5	44.7	73.4
7	64.6	81.4	51.9	76.7	45.7	70.5	51.7	69.1
8	52.3	77.5	45.2	76.5	41.8	79.6	46.1	64.4
9	48.0	67.3	46.5	80.9	38.3	86.8	44.6	73.2
10	40.8	64.9	45.3	87.3	33.4	67.8	49.0	71.8
Fleet	48.0	67.6	49.3	81.0	43.6	77.9	49.0	72.5
Without Resource:[d]								
1	56.0	79.1	46.7	74.0	41.0	69.7	45.6	65.2
2	30.5	34.6						
3	45.2	65.1	37.3	63.5	35.4	59.4	35.3	52.0
4	22.8	33.6	43.7	73.2	42.8	77.3	47.9	70.2
5	42.9	62.4	42.3	67.8	38.9	58.7	38.8	58.7
6	40.1	58.9	47.2	73.1	37.0	66.7	39.3	64.4
7	59.0	74.4	45.8	67.7	40.0	61.7	44.8	59.9
8	47.9	71.0	40.8	69.1	37.0	70.4	39.9	55.6
9	42.6	59.7	39.9	69.5	31.8	72.0	38.9	63.5
10	36.4	57.8	39.6	76.3	28.0	56.7	43.4	63.5
Fleet	42.4	59.7	43.0	70.5	36.9	66.0	41.6	61.6

[a]Capacity utilization calculated as the ratio of observed output to the capacity output conditional on 285 days a year.

[b]Capacity utilization calculated as the ratio of technically efficient output to the capacity output conditional on 285 days a year.

[c]Capacity output determined conditional on resource abundance and other fixed factors.

[d]Capacity output determined without resource abundance.

Footnotes

1. This section draws heavily from Kirkley and Squires (1998), who provide an extensive literature review.

2. Capital utilization captures how much of the existing capital stock is being used and capacity utilization provides information about short-run versus long-run equilibrium and economic incentives for investment and disinvestment. Capital utilization has been defined as the ratio of the desired capital stock (given output quantity and input prices) to the actual capital stock (Berndt 1990) or as the ratio of capital services to the stock of capital (Hulten 1990). The idea of capacity is sometimes developed in the context of capital utilization rather than capacity utilization, directly implying that capital is the only important fixed input (Morrison 1993). However, since capacity utilization reflects overall firm behavior, it depends on all fixed factors facing firms rather than only a given amount of capital. Moreover, the capital stock may itself be heterogeneous rather than homogeneous.

3. As was noted in the TWG, this corresponds to a constant "q" (catchability coefficient) in the population biology model. Moreover, the vast bulk of the bioeconomics literature is actually concerned with capital utilization and optimal capital stock even though the term capacity is frequently employed; this literature also implicitly equates capital with capacity.

4. Capacity output and capacity utilization are inherently short-run concepts since the capital stock is fixed in the short run, so that optimal short-run output might differ from that in a steady-state, long-run equilibrium (Morrison 1985). However, the optimal capital stock or capacity decision is a long-run concept, and as the firm adjusts its capital stock to the long-run, steady-state optimum, capacity output adjusts to the new short-run optimal level (Nelson 1989). If all inputs are completely variable, the problem of capacity, as such, does not exist; available inputs will be utilized in terms of their most effective long-run equilibrium mixes and a given "capacity" is not defined, and full utilization – in an economic sense – of available inputs will be the norm (Morrison 1993).

5. It may be deemed dual because it does not directly compare physical output levels. Instead, it captures the cost gap when the actual output differs from capacity. This cost gap of disequilibrium is measured not by the differences in actual and capacity output levels, but by the difference between the capital stock's shadow price and the rental or services price. The dual CU measure contains information on the difference between the current short-run (temporary) equilibrium and the long-run equilibrium in terms of the implicit costs of divergence from long-run equilibrium.

6. The economic approach to capacity and capacity utilization was extended to endogenous outputs and profit maximization by Squires (1987), Segerson and Squires (1990, 1992), and Kim (in press) and to revenue maximization by Segerson and Squires (1992, 1995). The use of endogenous output gives a profit- or revenue-maximizing optimal output and incorporates the firm's *ex ante* optimization behavior, including demand information through product prices. Capacity output is then defined as the output for which the current capital stock is optimal, i.e. the output level corresponding to the tangency of the short and long-run average cost curves. The optimal and capacity output levels can differ, since optimal output corresponds to the equality of short-run marginal cost and marginal revenue. Capacity utilization corresponds to the ratio of observed output to capacity output, and measures the effects of current operations on capacity. Optimal capacity utilization corresponds to the ratio of optimal output to capacity output (Kim).

7. A nondiscretionary output is an output whose production is not under the control of management. A nondiscretionary input is an input whose level or utilization is not under the control of management. It corresponds to a quasi-fixed or fixed factor of production. It may also be viewed as a minimum required level of an essential variable input.

8. The optimal capital stock, capacity, and resource stock decisions are ultimately long-run in nature, with optimal levels in some very long-run, steady-state equilibrium, and new short-run optimal positions corresponding to intermediate stages along some approach path to this optimum.

9. Along these lines, Stone (1997, page 513) observes, "However, there is little consensus on what would constitute the 'right' capacity, or the 'right' level of inputs, against which excess capacity should be measured. For instance, the safe catch level for any stock is always controversial and fluctuates from year to year. In light of the uncertainties, it is not clear what level of fishing activity will net the 'right' catch." Stone (1997, p. 514) further observes, "The fact that fishing capacity is an artifact of regulation complicates the definition of 'excess'. ...It is unclear how much of the 'overcapacity' is an economically rational response to (suboptimal) regulation." Wilen (1979) made the same points. A related issue is the "peak load" problem. A fluctuating and stochastic resource generates periods when sufficient investment is desired to harvest this fluctuating capacity but in other periods ostensibly appears as "excess". See Hannesson (1993) for a fisheries discussion.

10. The definition of full utilization or full employment of variable factors is closely related to the capital utilization literature. For example, Betancourt (1986) refers to capital utilization as the duration of operations of productive processes. Betancourt observes that the utilization of

equipment over a given time period can be varied along two dimensions, duration and intensity (speed). The speed of operations is typically assumed constant and variations in utilization come through variations in duration over a given time period.

11. A consistent scalar measure of output in multiproduct firms exists if all outputs are homothetically separable from inputs, and a direct analogue of the single-product primal measure of capacity and CU can be developed for the multiproduct firm (Segerson and Squires 1990). When the technology is not homothetically separable, Segerson and Squires (1990) suggest two alternative ways of defining a primal CU measure: (1) outputs move along a ray, giving a ray measure of capacity and CU and (2) only output adjusts, giving a partial measure of capacity and CU.

12. With the technological-economic approach to capacity and a single output for example, CU may equal one, seemingly indicating full capacity, but when in fact one fixed factor may be fully utilized, while the other is not. Alternatively, in the economic approach to capacity, capacity corresponds to the tangency point of the short- and long-run average cost curves, where the short-run average cost curve depends on all fixed factors. This tangency occurs when the shadow prices and service/rental prices of each fixed input are each equal, and capacity utilization is defined as the output level satisfying the equality of shadow and actual total costs (Morrison 1993, p. 65). Nonetheless, its interpretation can be unclear with multiple fixed factors, since it is possible for capacity utilization to equal one (shadow and total costs are the same) even if the actual prices of the fixed factors do not equal their shadow values (e.g., if there are offsetting effects). The implications of this for investment incentives are unclear, since a unique measure of capacity output may not exist in this context even with only a single output (Morrison 1993).

13. The peak-to-peak method (also called trend line through peaks, Klein and Long) defines capacity by estimating the observed relationship between catch and fleet size. Periods with the highest ratio of catch to the capital stock provide measures of full capacity (maximum attainable output). Estimates of maximum attainable output for the most recent years are obtained by extrapolating the most recent output-capital peak and multiplying by the capital stock in the selected recent years. Capacity output is compared to actual output levels in different time periods to give measures of CU. Catch levels in all years can be adjusted for productivity levels. The method is most seriously limited by the problem that vessel tonnage or numbers are only a rough measure of capital stock, the analysis ignores other economic inputs (it essentially utilizes the average productivity of capital), and it ignores differences across gear types (which can change over time). Ballard and Roberts, Garcia and Newton, and Kirkley and Squires give further discussion, including its weaknesses.

14. A nonradial expansion following Russell (1985) is also possible. There is no existing "off-the-shelf" software for this approach with the technological-economic definition of capacity. In the interest of widespread tractability, we confine our attention to radial expansions. One advantage of radial expansions, which entail equiproportionate expansions of all outputs, is that they are invariant to the units of measurement, whereas nonradial expansions are not.

15. Disposability generally refers to the ability to stockpile or discard or dispose of unwanted commodities.

16. In an input-oriented approach, an infeasible solution is possible without constant returns to scale. A TAC is the target flow from a corresponding resource stock. Unless the resource stock level is in excess of that corresponding to the TAC, the resource stock should be held constant as a nondiscretionary input or a technological constraint. The variable inputs would be scaled under all circumstances. If the capital stock(s) is not scaled back, it should be specified as a nondiscretionary input(s).

17.The variable input utilization rate measures the ratio of optimal variable input usage to actual variable input usage, where the optimum variable input usage is that variable input level which gives full technical efficiency at the full capacity output level (Färe *et al.* 1994). If the ratio of the optimum variable input level to the observed variable input level exceeds (falls short of) 1.0 in value, there is a shortage (surplus) of the i^{th} variable input currently employed and the firm should expand (contract) use of that input.

18.The estimate of fleet capacity is based on the assumption that capacity output for tonnage class III vessels equals the capacity output for tonnage class IV and all vessels fish 285 days a year. Our estimate is likely to be substantially downward biased given that tonnage class IV vessels likely have considerably more capacity.