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Capacity And Capacity Utilization In Fishing Industries

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CAPACITY AND CAPACITY UTILIZATION IN FISHING INDUSTRIES –

James E. Kirkley[24] and Dale Squires[25]

Abstract: The definition and measurement of capacity in fishing and other natural resource industries possess unique problems because of the stock-flow production technology, in which inputs are applied to the natural resource stock to produce a flow of output. In addition, 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. In turn, this leads to three unique issues: (1) multiple stocks of capital and the resource; (2) that of aggregation or how to define the industry and resource stocks to consider; and (3), 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 variable input utilization. This paper presents appropriate definitions of capacity and methods for measuring capacity in fishing industries taking into consideration these issues.

1. INTRODUCTION

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 levelled off, with many species fully or over-exploited and with a general excess number of vessels (FAO, 1998a). In addition, the widespread adoption of the Precautionary Principle (FAO, 1995a), 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, 1997)[26]. To this end, the Committee on Fisheries of the FAO (FAO/COFI) agreed in March 1997 to launch an initiative on managing fishing capacity, which led to the Technical Working Group (TWG) on the Management of Fishing Capacity, La Jolla, United States, 15-18 April 1998. The results from the TWG form the basis for the current FAO/COFI-led global plan of action to manage world fishing capacity. In May 1998, FAO called for a drastic reduction of at least 30 percent of world fishing capacity on the main high-valued species (FAO, 1998a). In the United States the Sustainable Fishing Act (1997) requires that resources be rebuilt to at least maximum sustainable yield (MSY) levels within a ten year period. Under the present United States regulatory regime, the only permissible option for rebuilding fish stocks is a drastic reduction in fishing activity.

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[27]. 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. Over investment occurs and an excessive amount of variable inputs are used. Excess capacity also complicates the fishery management process, particularly in regulated open access, frequently leading to microregulation. 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.

Fishing industries are particularly vulnerable to excess capacity and overcapitalization because of the open-access property right found in most fisheries. Generous subsidies found in many fisheries exacerbate the tendencies for capacity to expand with few checks (Milazzo, 1998).

Surprisingly, 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, 1999). 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.

Individual transferable quotas obviate a need to formally manage fishing capacity, by letting decentralized market forces match capacity to Total Allowable Catches (TACs), but the management of fishing capacity among the developed countries is still largely accomplished through moratoria on new entrants, limited access systems, and vessel buyout programmes. Capacity management in less developed countries, especially those in the tropics with the wide species diversity, is also likely to rely primarily upon limited access rather than individual transferable quotas given the infrastructure otherwise required to operate such a system and the species diversity.

This paper addresses this issue of defining and measuring capacity in fishing industries. The paper draws upon the corresponding background paper (Kirkley and Squires, 1999) and discussions from the Breakout Group on defining and measuring fishing capacity in the FAO

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Technical Working Group on the Management of Fishing Capacity, La Jolla, United States, 15-18 April 1998 (FAO, 1998b), the United States NMFS National Capacity Management Team meeting, La Jolla, 25-26 January 1999, and various meetings of the United States Congressional Task Force on Investment.

Capacity can be defined and measured following either a technological-engineering approach or explicitly predicated on economic optimization from microeconomic theory (Morrison, 1985a, 1985b and 1993). These papers, Kirkley and Squires (1999), 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-engineering approach is the one used by the United States 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 possess unique problems because of the stock-flow production technology, in which inputs are applied to the natural resource stock to produce a flow of output. In addition, 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 (Gréboval and Munro, 1999; Kirkley and Squires, 1999; FAO, 1998b). In turn, this leads to three unique issues: (1) multiple stocks of capital and the resource; (2) that of aggregation or how to define the industry and resource stocks to consider; and (3), 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 variable input utilization. In fishing industries, 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. Because most fisheries are multiproduct due to multiple species or product forms and may employ multiple stocks of capital, measures of capacity must contend with the corresponding special issues. Finally, in many fisheries, such as artisanal or in isolated regions, labour may be immobile and overemployed. The stock of labour may then form a fixed factor and the definition and measurement of capacity is extended to include this additional fixed factor (Gréboval and Munro, 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 (Kirkley and Squires, 1999). 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 programme.

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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 provides concluding remarks.

2. FISHING CAPACITY

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, 1999). 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[28]. Some of the names given to this concept include available fishing effort, effort capacity, harvest capacity, maximum effort utilization, 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, 1900; Smith, 1994) and refined by Gulland (1956), Beverton and Holt (1957), and others[29]. 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 Waters, 1992; Valatin, 1992). 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[30]. 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[31]. 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 if production is characterized by constant returns to scale (Berndt, 1990; Berndt and Fuss, 1989). 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, 1990).

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Fishing capacity has been conceived in other ways besides the capital stock, most notably maximum potential catch (Kirkley and Squires, 1999). 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, 1999). Economic notions of capacity define output as the economic optimum when outputs are freely varied or correspond to a target level (such as total allowable catches, or TACs) or are exogenously determined in some other manner given one or more quasi-fixed or fixed inputs[32]. 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, as developed by Berndt and Morrison (1981), Morrison (1985a, 1985b and 1986), and Nelson (1989), have been used on a limited basis[33].

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[34]. Johansen (1968: p. 52) defined capacity for the technological-engineering 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 behaviour 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 based on economic optimization.

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 maximum potential catch in fisheries is the maximal or expected harvest that fishing effort is capable of producing given the observed capital stock, other vessel characteristics, the state of technology, and the resource stock (Kirkley and Squires, 1999). The definition adopted by the

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TWG Break-Out Group is (FAO, 1998b). 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 United States National Marine Fisheries Service and a very closely related one was adopted by the United States Congressional Task Force.

A second basic approach to capacity explicitly builds upon an economic foundation (Morrison, 1985a). 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, 1985a). Berndt and Morrison (1981), Berndt and Fuss (1986), Hulten (1986), Morrison (1985a, 1985b, and 1986) and Nelson (1989) developed the dual approach with exogenous output, which measures the cost gap when actual output differs from capacity output[35]. 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[36]. The use of exogenous output contrasts with the endogenous output of the output-oriented technological-engineering 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, 1985a, 1985b; Nelson, 1989). In the technological-engineering approach that was adopted by FAO, NMFS (1998), and the United States Congressional Task Force, full CU represents full capacity and the value of CU cannot exceed one (1). A CU value 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-engineering 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 and 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. That is, the technological-engineering measure of capacity is made with full technical efficiency, so that the ratio of technically efficient output to capacity is consistent in that both numerator and denominator are technically efficient output levels. In contrast, the ratio of observed output to c capacity contains a numerator that may be technically inefficient and a denominator that is technically efficient. In turn, this may provide a capacity utilization measure that combines both deviations from full technical efficiency and full capacity.

2.3 Two stocks: capital and resource

In the short-run of stock-flow production processes in natural resource industries, two types of stocks are paramount, the stock of capital and the natural resource stock (and in some instances, the stock of labour). 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[37]. The resource stocks may best be treated as nondiscretionary. Resource stock levels lie beyond the control of the vessel captain. Nonetheless, the vessel captain has the option of selecting when and where to fish, which provides some control of the resource level available for harvesting. Calculation of capacity and technical efficiency with discretionary or nondiscretionary inputs is straightforward (Charnes *et al.*, 1994).

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). Different levels of the resource stock shift the production frontier or cost curve up or down, and can even twist their shapes depending on whether or not there are Hicks-neutral or biased relationships between the resource stock and production technology.

Capacity with either specification of the natural resource stock must contend with both of these stocks changing over time, not simply the capital stock. Five basic combinations of these stocks are possible, the existing capital and natural resource stock levels, one at the long-run equilibrium level and the other not, both at the long-run equilibrium levels, or one or both at future levels that differ from the current and long-run steady-state equilibriums; this allows for the transition path between the current stock levels and the long-run optimum. Moreover, in almost all fishing industries, some target level of output maintains the resource stock at the desired level, which might be a TAC. Capacity can be defined and evaluated with the resource stock at existing or long-run equilibrium levels.

2.4 Excess capacity

In fisheries and other renewable resource industries, excess capacity[38] should ideally be defined relative to some biological or bio-socio-economic reference point that 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, 1998b).

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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[39]. 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[40].

Excess capacity, in an output-oriented approach, can be defined as the difference between capacity output and desired or target level of capacity output, such as the TAC (OECD, 1997, Kirkley and Squires, 1999, FAO, 1998b)[41]. The target level of output was defined by the TWG as (FAO, 1998b), "... *[t]arget 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*...".[42] The TWG observed that current and target capacity need to be evaluated and compared relative to the same stock size (FAO, 1998b).

Excess capacity, in an input-oriented approach, starts with a TAC (either current or long-term projection) and determines how many of each vessel type would catch this TAC, then compares to current fleet size, given full utilization of the variable inputs and the resource stock. The maximum that a given fleet could potentially catch divided by the target TAC is a measure of excess capacity.[43]

Optimal capacity, if defined, can be better defined as a range rather than a specific quantity or metric (FAO, 1998b). 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 to 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, 1998b: para 68).

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. When capacity is measured conditional upon the size and composition of the resource stock, it is a measure of the maximum potential output that could be produced at given resource stock levels, where the resource stock abundance also sets an upper limit on output in the stock-flow production technology. When capacity is defined without the resource stock, it provides a measure of the potential output that could be produced in the absence of resource constraints, such as after a resource stock as begun rebuilding beyond the current depleted level.

Whether or not to include resource abundance in a measurement of capacity depends upon the information desired by resource managers. In turn, this often depends on the time frame of concern. Inclusion of the resource stock gives greater fixity to capacity output and provides information pointed towards policy questions dealing with current resource stock levels, i.e. with short-run conditions. When capacity is calculated conditional on available resource abundance, the capacity measure is not truly indicative of the total potential catch a fishing operation or vessel could harvest when constrained by current resource conditions (which could be very low and restrictive). In contrast, exclusion of the resource stock in capacity measures pertains to a longer-term period when current resource conditions - say of a depleted stock - do not limit capacity. When resource managers seek information about capacity for the purpose of reducing overall harvesting capacity and achieving medium or long-term harvest goals, capacity should be assessed without the inclusion of resource levels, or as discussed in the previous section, at a target resource stock size.

Including the resource in the assessment of capacity makes it possible to determine whether or not certain levels of 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 resource abundance are constraining production.

2.6 Full utilization of variable inputs

Capacity output (in the technological-engineering approach) is the level of output attainable by fully employing or 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, 1998; 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, 1998)[44]. Short-run output varies with technology type in different ways according to duration and intensity or speed of operations.

Fishing vessels operate a stock-flow production technology with relatively continuous production punctuated by transit times to and from port to offload the catch, for repair and

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maintenance, and time with families. Catch from this stock-flow production process is also subject to resource availability and weather conditions, which vary by season and even over longer annual and decadal cycles. Maximum catch - given the fishing grounds and resource stock (abundance, age distribution, density, species mix), weather, other technological constraints, fishing skill, and the plant and equipment - varies with the length of time the gear is in the water, i.e. duration. Over a year, the length of time the net is in the water depends on institutionally derived downtime and markets. Moreover, as resource availability, species abundance, and weather temporally varies, maximum catch and its product mix from this stock-flow production process varies, given any full utilization of variable inputs and plant and equipment. The intensity or speed of operation in fisheries is of lesser or no importance, since biological conditions dictate speed of operation such as tow rates or soaking time for passive gear. To the extent processing constrains intensity, when harvesting and processing are vertically integrated into one production process at sea, then intensity plays a larger role in defining full utilization of variable inputs. Finally, maximum catch and full utilization of variable inputs differ from full utilization of the resource stock, and maximum catch and full utilization of variable inputs at any time face an upper bound dictated by the resource stock, weather, and other technological constraints imposed by the environment.

2.7 Latent capacity

The definition and measurement of capacity and capacity utilization depends on the universe of active participants, i.e. which firms to include in the industry. The definition of the participating firms in a fishing industry is complicated because of the great mobility of vessels - the capital stock. Most fishing industries have a core of active participants, where some are 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 or market conditions or regulations change. The property rights structure (e.g. open access or regulated open access such as limited entry) and other regulations (e.g. TACs) affect the number of potential participants. The number of potential participants and the duration and intensity of operations of potential and existing participants leads 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, for which there is quite frequently information (e.g. vessel size from permit files).

2.8 Multiple outputs and heterogeneous capital stock

Measurement of fishing capacity needs to take account of multiple species or outputs and multiple resource stocks. When there are multiple outputs and production is joint-in-outputs, a problem arises because a primal (output-based) scalar measure of output does not generally exist except under the restrictive conditions of homothetic output separability or changes in outputs in

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constant proportions giving a ray measure (Segerson and Squires, 1990)[45]. When production is non-joint 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 instance, fishery managers in the New England groundfish fishery separately manage cod, haddock, and other species.

In these instances, partial capacity and CU measures, denoted y_i^* and CU_i, can be formed (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. Nonetheless, under certain conditions, it might be possible to form a consistent partial CU measure[46]. Consistency of the partial CU measure when applying the technological-engineering approach and a single stock of capital has yet to be evaluated in the literature.

When there are both multiple outputs and multiple (quasi-) fixed factors, measures of capacity and CU become problematic (Berndt and Fuss, 1986)[47]. 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 quasi-fixed or fixed inputs), capacity and CU can be found recognizing that these are short-run. 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 quasi-fixed or fixed factors once again raises its head.

2.9 Multiple fisheries and the level of aggregation

The issue arises of what capacity to measure 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, 1999; Gréboval and Munro, 1999). The TWG concluded that stock-by-stock, fleet-by-fleet, and region-by-region approaches are all required (FAO, 1998b).

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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 lower-value species[48]. For example, world-wide, many demersal (bottom dwelling) fisheries are generally believed to face excess capacity but lower-valued pelagic (surface dwelling) species may face under-capacity (FAO, 1998a).[49]

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, 1998a). 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, 1998a).

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 that focuses upon capacity output and does not require cost data. This best serve the current FAO-led efforts to globally manage fishing capacity and the requirements of member nations to develop national capacity management plans. Both approaches are nonparametric in that they do not entail statistical analysis. These are the peak-to-peak method of Klein (1960), and output- and input-oriented data envelopment analysis (DEA) approach developed by Färe *et al*. (1989, 1994) and proposed for fisheries by Kirkley and Squires (1999).

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[50]. The approach permits determining the capacity output and the potential level of capital which might be targeted for reduction in decommissioning schemes, although it does not provide any information to indicate the actual operating units to be decommissioned (Kirkley and Squires, 1999). Ballard and Roberts (1977) and Garcia and Newton (1997) are the most prominent applications of the peak-to-peak method in fisheries.

The stochastic production frontier provides another option, since it gives the maximum possible output (Kalirajan and Salim, 1997; Kirkley and Squires, 1999). To conform to the technological-engineering approach to capacity, 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. The stochastic frontier approach does not readily accommodate multiple outputs.

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3.1 Data envelopment analysis

DEA is a nonparametric or mathematical programming technique to determine optimal solutions given a set of constraints (Charnes *et al.*, 1994). DEA can be used to calculate capacity and CU using the approach of Färe *et al.* (1989, 1994)[51]. 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 (i.e. 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.

The difference between observed and frontier output gives the excess capacity for that resource stock in an output-oriented approach, but may be biased downward because of the possible inefficiency in production. In many fisheries, however, observed output is usually the TAC. Thus, both measures of excess capacity should be considered.

DEA has several unique advantages (Kirkley and Squires, 1999). DEA can estimate capacity under constraints including TACs, by-catch (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 (1990, 1992, and 1995), and implicitly imposes Leontief separability among the outputs.

The heterogeneous capital stock represents multiple quasi-fixed or fixed factors[52]. 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.

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In two different ways, the DEA approach effectively converts the heterogeneous capital stock (multiple fixed or quasi-fixed factors) into a single measure of the capital stock (composite factor) to solve the indeterminancy problem raised by Berndt and Fuss (1986). First, when the DEA measure of capacity is output-oriented, i.e. the maximum output given (quasi-) fixed inputs, the (quasi-) 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 (quasi-) fixed inputs are in fixed proportions, an aggregate fixed input or capital stock is formed (Leontief separability). This effectively converts the multiple (quasi-) fixed factors into a composite measure.

Other issues that could be considered within the DEA framework include calculation of capacity output under various by-catch mitigation or habitat restoration policies. Adding by-catch simply requires reformulating the problem such that by-catch is treated as an undesirable output; this requires subvector disposability constraints[53].

3.2. DEA and vessel Decommissioning

Capacity reduction programmes are conceived in terms of reducing vessel numbers and the associated fishing power, such as for example, through vessel buybacks. The target capacity level, such as TAC, needs to be directly and explicitly linked to the appropriate and superfluous numbers of vessels and their composition (vessel sizes, regional distribution, engine power, gear type, and so forth).

The need for vessel decommissioning in capacity reduction programmes can be directly addressed using the DEA approach (Kirkley and Squires, 1999). 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[54]. Hence, it would allow determining the optimal vessel or fleet configuration and actual vessels that 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) that 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

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target[55]. Moreover, given a TAC, the output-based measure could yield a precautionary level of total inputs and vessels that yield maximum technical efficiency.

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 u^jÎR$_+$ by using a vector of inputs $x^j \in R_+^N$. We also assume that for each *n*, $\sum_{j=1}^{J} x_n^j > 0$ and for each *j*, $\sum_{j=1}^{N} x_n^j > 0$.The first assumption states that each input is used by some firm. 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):

$$\max_{qlz} q$$

$$\text{s.t.} \quad \theta u_j \le \sum_{j=1}^{J} z_j u_j$$

$$x_{jn} \ge \sum_{j=1}^{J} z_j x_{jn},\, n \in \alpha \qquad (1)$$

$$\lambda_j x_{jn} = \sum_{j=1}^{J} z_j x_{jn},\, n \in \hat{\alpha}$$

$$z_j \ge 0,\ \lambda_{jn} \ge 0\ \forall\, n \in \hat{\alpha}$$

The variable factors are denoted by $\hat{\alpha}$, the fixed factors are denoted by a 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 l is a measure of the ratio of the optimal use of the variable inputs (Färe *et al.*, 1989, 1994). l gives the capacity utilization rate of the nth variable input for the jth firm for $x_{jn} > 0$, *n*Î $\hat{\alpha}$. 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 $Sz_j=1$.

The parameter q is the reciprocal of an output distance function and is an output-oriented measure of technical efficiency relative to capacity production, q ^{3} 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 $q^*_j u^j$ equals the maximum amount of u^j that can be produced given observed levels of fixed factors a and full utilization of variable inputs $\hat{\alpha}$ capacity output for output u^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 and fixed factor input usage by the technical efficiency measure corresponding to capacity output (i.e. the solution to problem (1) in which variable inputs $\hat{\alpha}$ are fully utilized).

To obtain a measure of TE corresponding to observed input usage, Färe *et al.* (1989) suggest that TE of the jth firm, ($q(x^j)$), may be obtained as a solution to a linear programming problem:

$$\max_{qlz} q$$

$$\text{s.t.} \quad \theta u_j \le \sum_{j=1}^{J} z_j u_j$$

$$x_{jn} \ge \sum_{j=1}^{J} z_j x_{jn} \ \forall\, n \qquad (2)$$

$$z_j \ge 0$$

where the input vector x includes both the fixed and variable inputs.

Problem (1) provides a measure of TE, q_1, which corresponds to full capacity production. Problem (2) provides a measure of TE, q_2, which corresponds to technically efficient production given the usage of the variable inputs. The ratio of the two q_s, q_2/q_1, is an unbiased measure of capacity utilization (Färe *et al.*, 1989). Solutions to problems (1) and (2) provide estimates of

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technical efficiency, capacity, capacity utilization, and optimal input utilization relative to a best practice frontier[56]. The solutions are not indicative of absolute efficiency and capacity.

The optimal levels of the fixed factors (which would approximately correspond to the long-run level of capacity) can be calculated under constant returns to scale. Alternatively, it is possible to assess the optimum levels of the fixed and variable factors that correspond to scale efficiency and use those levels as benchmarks for assessing capacity in the long-run. We defer these other possible approaches to future research because there is no comparative basis upon which to evaluate the corresponding results. More important, though, is that even if the approach cannot provide measures of capacity and capacity utilization for the long-run, it can still provide measures useful for determining the potential capacity removed with vessel reduction programmes. Also, it is highly probable that any capacity reduction programme implemented by resource managers would have additional constraints on the existing vessels such that capacity would not be allowed to increase in a short to intermediate time period.

4. CONCLUDING REMARKS

The economic issue of excess capacity, its biological twin of overfishing, and their management are the single dominant issues in world fisheries today. They are currently the subject of considerable attention at the national and international levels. Nonetheless, considerable confusion has reigned over a definition and a tractable means of measuring capacity and excess capacity in fishing industries.

The paper provides both technological-engineering and economic definitions of capacity and excess capacity in fishing industries. The paper recommends the technological-engineering approaches to measuring capacity and excess capacity. Either output- or input-oriented approaches are possible. The paper provides definitions and a tractable approach to measurement using Data Envelopment Analysis.

This paper applied the engineering-technological definition of fishing capacity, as the short-run maximal output given the capital stock and with and without resource stocks, to the Northwest Atlantic sea scallop fishery to estimate capacity in the harvesting sector. The paper calculated the excess capacity and corresponding number of vessels that should be removed from the fishery to satisfy a target level of fishing capacity and socio-economic goals for the distribution of decommissioned vessels.

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[26] The Kyoto Declaration's Plan of Action from the 1995 International Conference on the Sustainable Contribution of Fisheries to Food Security called for action to reduce excess capacity as soon as possible (FAO, 1997). Cooperative actions at the international level include implementation of the 1995 UN Fish Stocks Agreement and the 1993 FAO Compliance Agreement and implementation of the FAO Code of Conduct for Responsible Fisheries.

[27] Moreover, owners and crew of some vessel size classes or gear types, and in some regions or species-specific fisheries, struggle to even make a living. In turn, families and fishing communities come under stress or even their very existence and way of life is threatened.

[28] 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; Färe *et. al.*, 1994). An alternative definition of capital utilization is the ratio of capital services to the stock of capital (Schworm, 1977; 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

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capacity utilization reflects overall firm behavior, it depends on all fixed factors facing firms rather only a given amount of capital. Moreover, the capital stock may itself be heterogeneous rather than homogeneous.

[29] Garstang (1900) developed the notion of fishing power to measure relative efficiency between gear and vessel types and over time, based on total annual catch (Smith, 1994). Garstand tried to account for the greater relative efficiency of one type of fishing gear compared to another. In the process, Garstand developed the procedure of standardization. Gulland (1956) and Beverton and Holt (1957) and others subsequently further developed the notion.

[30] The heterogeneous capital stock is frequently aggregated into a single composite measure or measured by a single proxy variable, such as vessel size or numbers.

[31] 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.

[32] Quasi-fixed inputs are factors of production that can be adjusted in a time period, the short-run, but will not be adjusted all the way to the equilibrium level because of constraints such as adjustment costs.

[33] These studies include Squires (1987), Dupont (1990), Segerson and Squires (1990, 1992), Squires and Kirkley (1996), and Weninger and Just (1997).

[34] 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, 1985a, 1985b). 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 B in an economic sense B of available inputs will be the norm (Morrison, 1993).

[35] 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 firm's implicit marginal valuation (shadow price) of its capital stock and the rental or services price of that capital stock. 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. The firm's

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optimal capital stock can be derived given the firms observed output or capacity output can be derived given the existing capital stock. The primal economic capacity utilization measures capture the output gap that exists when actual output differs from capacity output but is calculated from a cost function (Morrison, 1985a, 1985b). In addition, Segerson and Squires (1992), Squires (1994), Squires and Kirkley (1996), and Weninger and Just (1997) consider CU under quotas and rations, where Weninger and Just (1997) should be referred to as the last word.

[36] 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 (1999) 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, 1999).

[37] A nondiscretionary output is an output whose production is not under the control of management (Charnes *et al.*, 1994). 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.

[38] Excess capacity differs from overcapitalization. Excess capacity refers to the excess use of inputs, including labour and capital, to produce a potential output, whereas overcapitalization refers to the excessive use of only capital. Overcapacity and overcapitalization are usually equated because of the standard use of a single composite input, fishing effort, which in turn is equated to the capital stock and capital utilization.

[39] 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.

[40] See Stone (1997: p. 513). 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

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net the "right" catch. 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.

[41] The OECD Fisheries Committee (1997) defined excess fishing capacity as in excess of the minimum amount required to harvest the desired quantity of fish at the least cost.

[42] This definition directly corresponds to the engineering-technological definition of capacity and excess capacity. Nonetheless, it can be readily extended to allow for an economic or socio-economic optimum and the corresponding definitions of capacity and CU.

[43] The TAC does not necessarily (and almost always does not) correspond to an economic or socio-economic optimum. However, in practice fisheries use TACs that correspond to solely biological objectives and limited ones at that, since they do not generally incorporate multispecies and ecosystems concerns.

[44] 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. Bosworth and Dawkins (1983) refer to capital utilization as the timing of input flows and in particular to shift work and overtime. Betancourt (1986) observed 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.

[45] 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

[46] For the economic definition of capacity, let the firm's variable cost function be given by G(y, w, K), where y is a vector of outputs, w is the vector of variable input prices, and K represents one input that is quasi-fixed. Let $dG/dy_i = G_i$ and $d^2G/dy_i\, dK = G_{iK}$. Then from Theorem 1 of Segerson and Squires (1990), if $G_{iK} < 1 \; \forall$ i, exactly one of the following holds: (1) $CU_i > 1$ for all i; (2) $CU_i < 1$ for all i; or (3) $CU_i = 1$ for all i. Given the levels of all other outputs, if $y_i < y_i^*$,

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then $-G_K < P_K$ (where P_K denotes the rental or services price of K) and there is an incentive to disinvest, i.e. capacity is underutilized. This holds true regardless of the product considered, i.e. which one is allowed to adjust to equate the shadow value and the price of capital K. Thus, the question of whether the firm faces expansionary or contractionary forces has the same answer regardless of which product is used to measure capacity utilization (Segerson and Squires, 1990). The full CU measure = 1 implies $CU_i = 1$ for all i. Finally, the partial and full CU measures could converge at different rates (e.g. if costs are relatively insensitive to changes in output).

[47] With the technological-engineering 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: p. 65).

[48] Klein (1960) discussed whether measures of capacity output suffer from aggregation problems. For example, capacity outputs for firms might all be increasing and yet industry capacity output may not be consistent with the sum of the firm's individual capacity outputs because of, say, downward sloping industry demand, or upward sloping supply curves for inputs (Morrison, 1993: p. 72). Moreover, firm-level data can only be aggregated to the industry level under very stringent conditions (van Daal and Merkies, 1984; Morrison, 1993: Chapter 10).

[49] Production from most of the high-value species, and from demersal stocks in particular, has levelled off since the mid-1970s, with the world-wide growth in landings since then, except for tuna and cephalopods, accounted for by increased landings of lower-value species, much of which are reduced to fish meal (FAO, 1998b). The recent global analysis by Grainger and Garcia (1996) indicates that about 40 percent of the global resource stock, often of lower value, may have allowed for increased catch.

[50] The peak-to-peak method (also called trend line through peaks, Klein and Long, 1973) 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

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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 (1977), Garcia and Newton (1997), and Kirkley and Squires (1999) give further discussion, including its weaknesses.

[51] Klein and Long (1973: p. 746) describe an earlier approach using linear programming to measure the technological-engineering definition of capacity, "*... as the bottleneck point in expansion along a given ray corresponding to a fixed product mix*." When one product hits such a bottleneck, all others dependent on it for intermediate input are restricted at less than full CU. This provides a maximum output point while preserving a given product mix.

[52] These factors can be captured by different proxy variables, each of which measures one of the capital components. These proxy variables can include those that resource managers denote as most important at capturing production and which are most easily regulated, such as vessel length or gross registered tonnage and main engine horsepower.

[53] Disposability generally refers to the ability to stockpile or discard or dispose of unwanted commodities (Färe *et al.*, 1994). The private disposal cost distinguishes two types of disposability. Strong disposability refers to the ability to dispose of an unwanted commodity with no private cost. Weak disposability refers to the ability to dispose of an unwanted commodity at positive private cost. Thus, joint reduction of a bad output entails scaling back production of a good output. Strong disposability implies weak disposability but not vice versa.

[54] 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).

[55] The dual economic measures of CU allow direct estimation of the optimal number of vessels corresponding to the TAC.

[56] 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 1.0 in value, there is a shortage of the i^{th} variable input currently employed and the firm should expand use of that input. If the ratio is less than 1.0 in value, there is a surplus of the i^{th} variable input

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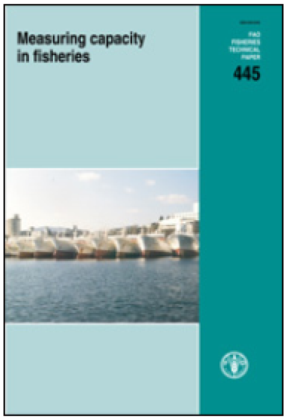
currently employed and the firm should reduce use of that input. If the ratio equals 1.0, the actual usage of the i^{th} variable input equals the optimal usage of the i^{th} variable input.



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Measuring Capacity in Fisheries

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