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Analyzing the cost of harvesting and the economic structure of Florida grouper fishery

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**ANALYZING THE COST OF HARVESTING AND THE ECONOMIC STRUCTURE
OF FLORIDA GROUPER FISHERY**

A Thesis
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Agricultural Economics and Agribusiness

by
I. Cristian Nedelea
B.A., University of Bucharest, 1997
December, 2007

DEDICATION

To my parents, Maria and Ion Nedelea.

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ABSTRACT

This study uses a translog cost function to investigate the technical and economic relationships present among a sample of Florida grouper longline vessels. The existence of jointness-in-inputs and non-separability between inputs and outputs suggests that resource management should be based on multiproduct production theory, and that explicit recognition of the economic interactions among species should be incorporated in any regulatory process. The cross-price elasticities of input demands showed substitution relationships between input pairs, implying that imposed regulation on the single input will be compensated for by increases in the other inputs. Furthermore, model results showed apparently substantial economies of scope, especially between red grouper and most of the other species in the grouper fishery, product specific economies of scale and multiproduct economies of scale. The technical and economic interrelationships inferred from this study suggest that individual species regulation can generate economic inefficiency by inducing nonoptimal input and output mixes.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Fish resources are an important source of high-quality food and employment for many coastal people. Moreover, if managed efficiently, fish resources represent an important source of revenue to those who own property rights. When property rights are well defined, it is reasonable to suppose that fish resources will be managed so as to maximize profit. If property rights are not well defined, however, the profit will be dissipated as new entrants come into the fishery. The lack of property rights leads to overexploitation of fish resources as the competition among fishermen increases. The public management and regulation of multispecies fisheries is often seen as the most efficient means of preventing overexploitation of fish resources. Unknown technical and economic interrelationships among different species, however, make the efficient management and regulation of fisheries difficult. The success or failure of a regulation depends, in part, on how fisheries respond to the regulation given their technological characteristics. For example, a quota or output regulation on one species may result in increased exploitation of other species (Kirkley and Strand 1988). In light of this, analyzing the individual firm's technology and costs in a multispecies fishery allows regulators to design more effective output regulations (Squires and Kirkley 1991).

The Florida grouper fishery offers a case in which regulations were imposed with only partial knowledge of the technical and economic interrelationships within the fishery. In addition, a variety of commercial fishing regulations are currently proposed for the grouper fishery, including quotas, limited entry programs, trip limits, closed seasons and areas, and size limits. These regulations may affect, and be affected by, the cost of harvesting and the economic structure of the grouper fishing industry.

1.2 Goals and Objectives

The overall goal of this study is to investigate the technical economic structure among Florida grouper longline vessels and suggest how this information should affect managers as they attempt to design economically efficient policies. Specifically, the study will:

- Collect trip-based logbook data from a sample of Florida grouper longline vessels;
- Estimate a multioutput cost function to characterize the harvesting process among these vessels;
- Analyze the estimated cost function to determine the technical and economic interactions; and
- Based on the outcomes of the previous objectives, identify important considerations that need to be taken into account when developing strategies for the optimal management of Florida grouper fishery.

1.3 Background

Fisheries located off the coast of the United States represent an important renewable natural resource for whose protection the U.S. Congress enacted the Magnuson Fishery Conservation and Management Act in 1976 (renamed Magnuson - Stevens Fishery Conservation and Management Act in 1996). The Act established a U.S. exclusive economic zone existing between 3 and 200 miles offshore, and created eight regional fishery councils to manage fish resources within their respective regions. Among the purposes of these councils are to promote commercial and recreational fishing based on conservation and management principles, and to prepare and implement fishery management plans for each fishery requiring conservation and management in accordance with the national standards promoted by the Act, as amended. The Magnuson – Stevens Act was recently reauthorized under the name Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006. This new law authorizes the use of

annual catch limits to end and prevent overfishing, promote market-based fishery management through limited access programs, and calls for enhanced international cooperation.

1.3.1 The Grouper Fishery

One of the historically important fisheries in the Gulf of Mexico is the grouper fishery. Although the grouper fishery occurs throughout the Gulf of Mexico, it is primarily concentrated on the West Florida Shelf. As a result, the state of Florida is by far the most important grouper fishery location, accounting for nearly 90% of the Gulf shallow-water grouper (SWG) and deep water grouper (DWG) commercial landings, and is the home-port state for the vast majority of vessels in the fishery. Fishermen and grouper sales are also concentrated in Florida (Gulf of Mexico Fishery Management Council, 2005). Participants in the grouper fishery include commercial fishermen utilizing different types of gear (bottom longline, vertical line) and recreational fishermen (private anglers, head and party-boat operators and their customers).

The SWG and DWG complex is a multispecies fishery encompassing 17 species. Of these species, 13 are managed, two are prohibited from harvest (Nassau and goliath grouper), and two species are not currently considered to be in the management unit (sand perch and dwarf sand perch). SWG include red grouper, black grouper, gag, yellowfin grouper, scamp, yellowmouth grouper, rock hind, and red hind. DWG include yellowedge grouper, warsaw grouper, snowy grouper, speckled hind, and misty grouper. The most commonly landed SWG species in the commercial fishery are red grouper, gag, and black grouper, while yellowedge grouper is the most commonly landed DWG species.

Red grouper are commonly caught in the Gulf of Mexico from Panama City, Florida, to the Florida Keys, along the inner to mid-continental shelf in depths ranging from 2 to over 120 m (Moe 1969). Red grouper has accounted for nearly two-thirds of the total commercial grouper

harvest since 1986.¹ Estimates of the recreational catch of red grouper have been highly variable: about 0.6-1.0 million fish per year in the mid- to late-1980s, 0.2 million fish in 1990 following the implementation of minimum size limits, and 0.2-0.1 million fish per year during the 1996-1997 period (NMFS, 2004).²

Gag grouper is primarily caught on the west coast of Florida from Tampa Bay to the northern extent of the state (Goodyear and Schirripa 1994). Historically, gag was often confused with black grouper because they are similar in appearance and, therefore, difficult for fishers to distinguish. The next most commonly landed SWG is black grouper. The rest of SWG that can be legally harvested account for a small percentage of the overall commercial landings.

As the name implied, DWG occur farther offshore than SWG, but are occasionally caught by fishermen targeting SWG. Approximately 98-99 percent of the annual harvest of DWG is caught commercially, with recreational interests responsible for only minor harvests. Yellowedge grouper is the most abundant and longest-lived grouper, reaching a maximum age of 85 years (Cass-Calay and Bahnick, 2000), while Warsaw grouper is the largest of DWG species, reaching a maximum length and weight of 92 inches and 419 lbs (Manooch and Mason 1987).

As part of the incidental catch associated with commercial SWG and DWG fishing, snappers, jacks, and triggerfishes are frequently harvested. King and Spanish mackerel, as well as sharks, are also harvested or incidentally captured by commercial fishermen. For example, sharks represented 6.1 percent of landings by longline vessels that reported at least one harvested

¹ The greatest part of the commercial and recreational harvest comes from south of Tampa. Commercial landings of red grouper have been separated from other groupers within national records only since 1986. Before 1986 red grouper were included in catch statistics along with other grouper species as “unclassified groupers.”

² These estimated recreational harvests have been influenced by various regulations over the years. Florida enacted an 18-inch minimum size limit in 1985 for state waters, a recreational bag limit of 5 fish per day in 1986, and a 20-inch minimum size limit in 1990. The Gulf of Mexico Fishery Management Council established three conservation measures for groupers in federal waters in 1990: 20-inch minimum size, a 5 fish per day recreational bag limit, and a 9.2 million pound commercial quota for SWG.

pound of SWG or DWG in 2004 (Gulf of Mexico Fishery Management Council, 2005). What is unclear in this statistic, however, is whether grouper were the intended target species for all of the included trips.

Stock assessments are available for four grouper species – red grouper, gag, goliath grouper, and yellowedge grouper. The status of red grouper was assessed in 2002 and it was determined that the population was undergoing overfishing, but not overfished.³ The most recent stock assessment, completed in the spring of 2007, concluded that red grouper were not experiencing overfishing nor were they overfished (SEDAR 12, 2007). The obvious conclusion that might be drawn from this information is that the red grouper population had completely recovered during the ensuing 5 year period.⁴ The status of gag was most recently assessed in 2006, and it was determined that the population is undergoing overfishing (SEDAR 10, 2006). The status of yellowedge grouper and the status of goliath grouper were assessed in 2002 and 2004, respectively, and the fishing status for both were determined to be unknown (Cass-Calay and Bahnick, 2002; SEDAR 6, 2004). As previously mentioned, recreational and commercial harvests of goliath grouper are prohibited even though NOAA removed goliath grouper from the “species of concern” list (Gulf Fishery News, April-May 2006). Recently, the Southeast Fisheries Science Center (SFSC) requested that the status of goliath grouper be changed from “unknown” to “not overfished”.

The harvesting gear used in the commercial grouper fishery includes bottom longlines and vertical lines. On average, 165 bottom longline vessels took 1,410 trips per year and 894

³ The Magnuson-Stevens Fishery Conservation and Management Act defines overfishing as "a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis." A stock is considered to be overfished when the total abundance of a fish population is below a minimum specified level of abundance. Given that the definitions are dependent on the concept of sustainable yield, a finding of overfishing or overfished is dependent on the quality of empirical data concerning a stock.

⁴ A less obvious conclusion is that one or both of the stock assessments may be in error. Given that red grouper has a relatively long life-span and does not reach full reproductive maturity until 6 years of age (Fitzhugh et al. 2006), it can be considered a significant management accomplishment to achieve fisheries recovery in 5 years.

vertical line vessels took 7,600 trips per year from 1993-2000 (Waters 2001). Waters (2002) reported that, in 2000, 782 vessels in Florida and 207 vessels in other Gulf states reported landings of reef fish using vertical line, and 155 vessels in Florida and 33 vessels in the other Gulf states were using longline gear. An additional 55 fish trap vessels were located in Florida. For the reef fish vessels, 546 harvested SWG on a regular basis, and of them 138 used longlines, 353 used vertical lines, and 55 used fish traps. Waters (2002) indicated that longlines accounted for 59 percent of commercial red grouper landings, while vertical lines accounted for 24 percent, and fish traps accounted for 16 percent. For gag grouper, vertical lines accounted for 73 percent of commercial landings, longlines accounted for 25 percent, and fish traps 2 percent.

Gulf SWG and DWG accounted for 85 percent (5.6 out of 6.6 million pound gutted weight-MPGW) of the 2002-2004 average annual landings of reef fish by longline vessels, representing 74 percent of the average annual gross revenue for longline vessels, while for vertical lines grouper represented only 32 percent of the 2002-2004 average annual landings of reef fish by vertical lines, or 29 percent of their average annual gross revenue (Gulf of Mexico Fishery Management Council, 2005). Therefore, it can be inferred that the economic impact of a regulatory measure (grouper trip limits, for example) would fall to a larger degree on longline fishermen than on vertical line fishermen.

1.3.2 Regulatory History

Secretarial Amendment 1 to the Reef Fish Fishery Management Plan was implemented by NOAA's National Marine Fisheries Service (NMFS) on July 15, 2004, and established a 10-year rebuilding plan, a 5.31 million pound gutted weight (MP GW) commercial quota, and a 1.25 MP GW recreational quota for red grouper. The commercial and recreational quotas were

adopted based on the ratio of 81 percent commercial and 19 percent recreational reflecting 1999-2001 historical red grouper landings. In addition, Secretarial Amendment 1 reduced the quotas for deep-water grouper (DWG) fishery from 1.35 MP GW to 1.02 MP GW, and for shallow-water grouper (SWG) fishery from 9.35 MP GW to 8.80 MP GW. By amendment, the commercial SWG fishery closes when either the commercial quota of red grouper (5.31 MP) is reached or when the commercial SWG aggregate quota (8.80 MP) is reached, whichever occurs first. As a result, the commercial deep-water grouper (DWG) fishery was closed on July 15, 2004, the same day when Secretarial Amendment 1 was implemented, while the shallow-water grouper (SWG) fishery was closed on November 15, 2004. Another purpose of Secretarial Amendment 1 was to evaluate and control the impact of the red grouper rebuilding plan on other species. Gag and red grouper are the most commonly landed SWG species, and it is likely that regulatory measures to reduce red grouper harvest will affect gag harvest. Furthermore, measures to reduce SWG quota could result in effort shifting to target deep water grouper.

To prolong the SWG and DWG fishing seasons in 2005, NMFS established trip limits for the commercial grouper fishery. However, these trip limits were not restrictive enough to extend the fishing season, and resulted in earlier closures to the DWG and SWG fisheries in 2005: DWG fishery was closed on June 23 and SWG fishery on October 10. In 2006 the commercial DWG fishery was closed on June 27.

The Gulf of Mexico Fishery Management Council initiated a Regulatory Amendment in the fall of 2004 to adjust Total Allowable Catch (TAC) and management measures necessary to maintain the rebuilding schedules specified in Secretarial Amendment 1. The purpose of this regulatory amendment was to establish more permanent trip limits for the commercial grouper fishery, thus extending the commercial grouper fishing season, and to reduce the adverse

socioeconomic effects of derby fishing.⁵ Specifically, derby fishing is expected to result in shorter fishing seasons, forcing markets to meet consumer demand for grouper fish during closures by either importing grouper or by substitution using different domestic species. These actions may have a negative economic impact on the domestic market for grouper and the commercial grouper fishery. Furthermore, the economic loss experienced by the fishery participants will have spillover effects on the associated industries (gear and supply shops, grocers, etc.) and on families and communities.

Given the adverse socioeconomic effects that may arise from derby fishing in the commercial grouper fishery, developing new regulatory measures has been a priority for the Gulf of Mexico Fishery Management Council. The Regulatory Amendment initiated by the Council considers six alternatives to control commercial landings of SWG and DWG, with alternative 1 based on quotas alone and alternatives 2-6 including trip limits in addition to quotas. The management of the commercial grouper fishery under Alternative 1 (status quo) is expected to result in increasingly shorter seasons, reduced prices, lost markets, and the worsening of economic conditions in the commercial grouper fishery. On the other hand, Alternatives 2-6 are expected to prolong the fishing season, but on the expense of a reduction in net revenue relative to the status quo. While these losses in net revenue are expected to be less than those that would occur in the long-run if derby conditions were allowed to continue, the lack of enough relevant economic information for grouper fishery increases the difficulty of making appropriate management suggestions.

⁵ Derby conditions are likely to appear in an open-access fishery restricted by quota regulations and they can alter fishing opportunities for many vessels, fishing practices among commercial fishermen, and business practices among dealers and other support industries.

1.4 Overview of Previous Related Research

Revenue, profit and cost functions have often been used to describe the technological and economic conditions experienced by fishing firms. While in the primal approach product supply and factor demand equations are obtained by explicitly solving an optimization problem, the dual approach allows one to obtain product supply and factor demand equations by partial differentiation of an indirect objective function (for example, an indirect profit function is the maximum profit associated with given product and factor prices, while an indirect cost function is the minimum cost of producing the given product). The dual approach overcomes problems associated with unknown input quantities because duality uses prices as independent variables (Jensen 2002). In the case of the dual cost function this means that one needs to know only total cost and input prices to determine optimal input quantities. Pope (1982) argues that the dual approach is easier to use in characterizing multiproduct technology properties, more flexible in measurement, and no first-order conditions need to be solved, suggesting that the dual approach can be applied to many functional forms.

Most fishing firms are multiproduct; they produce several outputs by employing a range of different inputs. The failure to recognize the technical and economic interrelationships among different species may lead to negative outcomes for multispecies fisheries management (Kirkley and Strand 1988, Squires and Kirkley 1991, and Diop and Kazmierczak 1996). Thus, the present study will be based on dual cost function to describe technical and economic interrelationships present among grouper longline vessels. The empirical literature that employs this approach to analyze the technological properties of industries is reviewed below, with a focus (although not exclusive) on studies that examined fisheries.

Kirkley and Strand (1988) applied a dual revenue function to the New England multispecies fishery, and indicated that the more commonly advocated forms of stock

management (e.g., unit stock and biomass) are inappropriate given that managers are also concerned about the exploitation of other species. Both hypotheses of nonjointness-in-inputs and separability between inputs and outputs were rejected by the authors. The results revealed that restrictions placed on one species will result in increased exploitation of the other species.

Squires and Kirkley (1991) found that a quota on the individual firm's production of sablefish may be inappropriate, as this may result in excessive discard of regulated species. They suggested alternative management strategies, including license limitation, individual transferable quotas (ITQ), and trip quotas.

Applying a dual revenue function derived from a generalized Leontief form, Diop and Kazmierczak (1996) analyzed technical and economic interactions in the Mauritanian cephalopod fishery. Model results indicated the existence of jointness in inputs and non-separability between inputs and outputs in the fishery. In addition, cross price elasticities indicated a number of substitute and complementary relationships. These results indicate that the management on a species-by-species basis may lead to unintended outcomes, including over-exploitation of the resource.

Squires (1987a,b,c) and Alam, Ishak, and Squires (2002) employed the multiproduct profit function to describe the profit-maximizing firm. Squires (1987a) and Squires (1987b) used a translog profit function to analyze the New England otter trawl industry. Although both studies used similar data, the results indicated different input-output separability results. Squires (1987b) found weak separability for roundfish (cod and haddock) and flatfish (yellowtail and other flounders), and input-output separability is rejected. A different result was found in Squires (1987a), where input-output separability was accepted. In Squires (1987c) the multiproduct profit function was used to estimate long-run, multiproduct costs, including economies of scope, product-specific returns to scale, and multiproduct returns to scale. All three studies indicated

elastic own-price elasticities. In Squires (1987b, c) Marshallian elasticities indicated a complementary relationship between capital, labor and fuel.⁶

A translog profit function was also used by Alam, Ishak, and Squires (2002) to evaluate the harvesting technology and cost and revenue structure of Peninsular Malaysian fishing trawlers to design an area licence limitation program under conditions of asymmetric information. Both global separability of outputs and variable inputs and separability between outputs and variable inputs were rejected. Non-jointness-in-inputs was also rejected, indicating that all inputs were required to produce each output. Hicksian elasticities showed substitution between input factors⁷, and the technology exhibited increasing product-specific returns to scale and decreasing multiproduct economies of scale. Alam, Ishak, and Squires concluded that the current policy of licensing vessels should be augmented in order to limit the number of vessels through the use of non-transferable licences.

Dupont (1991) used a quadratic restricted profit function to evaluate the harvesting technology and substitution possibilities for the British Columbia commercial salmon fishery. Elasticities of intensities were used to describe the impact that a change in a restricted input would have on an unrestricted input. Dupont showed that restrictions on fishing days could be an effective way to reduce fishing effort in industry with few substitution possibilities.

Lipton and Strand (1992), Bjorndal and Gordon (2001), and Weninger (1998) all used the behavioral hypothesis of cost minimization to describe firms operating under output regulation. In their article, Lipton and Strand (1992) analyzed the effect of stock size and regulations on the fishing industry cost and structure in the Atlantic clam fishery. The assumption made is that firms minimize the cost of harvesting subject to an output level. The authors concluded that the

⁶ The Marshallian elasticities measure both pure substitution (changes in the input mix along a given isoquant) and expansion effects (inputs change along the expansion path).

⁷ Hicksian elasticities measure pure substitution effects among input pairs along an isoquant.

optimal industry configuration, under a limited-access management regime, would be achieved with an increase in the number of vessels and a decrease in the catch per vessel of surf clams and an increase in the catch of ocean quahogs.

Bjorndal and Gordon (1993) tested for optimal vessel size in the Norwegian fishing fleet, comparing actual vessel size to optimal conditions, under alternative scenarios defining the opportunity cost of capital. The econometric results showed that adjustments in vessel size are necessary in response to changes in economic and biological conditions and that the introduction of an ITQ to regulate the fishery would lead to optimal sized vessels. Bjorndal and Gordon (2001) used a multi-output cost function to analyze the harvesting process for three vessel types (purse seiners, coastal vessels, and trawlers) in the Norwegian spring-spawning herring fishery. Because catch levels were set by quota, they assumed that fishing vessel attempt to minimize the cost of harvesting the set quota level subject to vessel type. They estimated a translog cost function from which can be calculated input demand elasticities, economies of scale, and output cost elasticities. The own-price elasticity estimates showed a strong inelastic response to prices for each vessel type for each year. The estimates of economies of scale for each vessel type for each year showed increasing returns to scale. The cost elasticities associated with each output group for each vessel type showed an inelastic response of total cost to changes in harvest levels. The authors concluded that purse seiners and trawlers are cost efficient in terms of capturing available economies of scale; however, trawlers harvest only a small share relative to purse seiners.

A dual cost function was also used by Weninger (1998) to analyze harvest sector efficiency gains from an ITQ in the Mid-Atlantic surf clam and ocean quahog fishery. It was assumed that fishers try to minimize the cost of harvesting surf clam and ocean quahog subject to exogenous prices, technology, and stock levels. The author estimated variable cost associated

with fuel and gear, by specifying a trans-log cost function. The variable cost technology exhibited overall and product-specific increasing returns to scale, scope diseconomies, and nonjoint-in-inputs, with fixed costs declining for larger vessels. Consequently, the author concluded that important sources of efficiency gains in the clam fishery are associated with 1) the elimination of redundant harvesting capital and the realization of scale economies and 2) returns to specialization or single species production.

Generalized cost functions like the translog have provided a convenient framework for analyzing agricultural production. An important characteristic of the translog cost function is its flexibility, allowing testing for specific characteristics of technology. Binswanger (1974) and Ray (1982) used translog cost functions to derive estimates of elasticities of demand and elasticities of substitution for the agricultural sector in U.S. Binswanger estimated a single output cost function using cross-section and time-series data, while Ray treated crops and livestock as two distinct outputs. Labor was found to be a substitute for the other inputs in both studies. However, Binswanger found complementarity between labor and fertilizers, in contrast with Ray's findings of increased substitutability between labor and fertilizers.

A generalized translog functional form was used by Caves et al. (1980) and Caves et al. (1981) to analyze productivity growth in U.S. railroads. The estimates of productivity growth based on the total cost function for 1981 were significantly lower than those reported in the 1980 paper. The primary reason for this difference is the fact that, in 1980 paper, the authors analyzed industry totals rather than firm data. Caves et al. (1981) used a variable cost function to estimate the structure of production and productivity growth for U.S. railroads. The results were then compared to those from the total cost function, showing that although the two cost functions have similar estimates of returns to scale, they yield different estimates of productivity growth. Akridge and Hertel (1986) estimated a short-run translog cost function to analyze multiproduct

cost relationships for retail fertilizer plants. The results strongly supported the existence of economies of scope between anhydrous ammonia and the rest of outputs taken as a group, and product-specific scale economies in producing anhydrous ammonia. Akridge and Hertel suggested that plants could lower average cost by increasing output and by diversifying into anhydrous ammonia.

1.5 Organization of the Thesis

The organization of the remaining parts of thesis proceeds as follows. Chapter 2 presents the cost function, with emphasis being given to how the dual cost function is employed to describe technical and economic interrelationships present in grouper fishery. An empirical model for the grouper fishery is developed and presented in Chapter 3, along with the data used in estimation. In Chapter 4, the results associated with the estimated model are presented and discussed. In the final chapter, a summary of the key findings is presented, along with a discussion of some of the management and policy implications.

CHAPTER 2: THEORETICAL MODEL - COST FUNCTION

The cost function represents the minimum cost of producing any given level of output and is expressed as a function of input prices and output. The existence of a well defined cost function is based on a set of assumptions concerning cost minimization behavior of the firms. Specifically, this set of assumptions includes the presumption that the level of output y produced by the firm is predetermined, that the input prices are fixed and exogenous, and that the firm chooses input quantities so as to minimize the cost of producing output y . Therefore, corresponding to a production function that indicates the maximum output y given any combination of inputs, there is a dual cost function relating the minimum cost of producing a given level of output to the input prices and the level of output y . This dual cost function can be written as $C = C^*(\mathbf{r}, y)$ where \mathbf{r} is a vector of input prices. The advantages of a cost function approach relative to a production function approach were summarized by Binswanger (1974):

1. A cost function is linearly homogeneous in input prices regardless of the homogeneity properties of the production function, meaning that a doubling of all prices will double the cost but will not affect factor ratios;
2. A cost function uses input prices as independent variables rather than factor quantities, and thus managers make decisions on factor use according to exogenous prices;
3. In production function estimation, input quantities tend not to be independent of one another, leading to a possible problem of multicollinearity.⁸ Since there is usually little multicollinearity among input prices⁹, this problem does not arise in cost function estimation.

⁸ For many production processes, input quantities are used in fixed or relatively fixed proportions. Thus, within the context of a single production activity, the use of inputs is highly correlated.

⁹ Input prices in the market will be less correlated than the use of inputs themselves in a production process to the extent that they are demanded in many different types of production.

2.1 Cost-Minimizing Input Choices

The cost function is a mathematical representation of the cost minimization problem.

Given that minimizing cost for a given level of output is a necessary condition for profit maximization, the cost minimization problem can be written as

$$\text{Minimize } C = r_1x_1 + r_2x_2 \quad \text{subject to } y_0 = f(x_1, x_2) \quad 2.1$$

where x_1 and x_2 are input quantities, r_1 and r_2 are input prices, and y_0 is an output level. From the Lagrangian

$$L = r_1x_1 + r_2x_2 + \lambda (y_0 - f(x_1, x_2)) \quad 2.2$$

the first order conditions for a constrained minimum are

$$\partial L / \partial x_1 = r_1 - \lambda f_1 = 0 \quad 2.3$$

$$\partial L / \partial x_2 = r_2 - \lambda f_2 = 0 \quad 2.4$$

$$\partial L / \partial \lambda = y_0 - f(x_1, x_2) = 0 \quad 2.5$$

where $f_1 = \partial f(x_1, x_2) / \partial x_1$ and $f_2 = \partial f(x_1, x_2) / \partial x_2$. Dividing equation 2.3 by equation 2.4 yields

$$\frac{r_1}{r_2} = \frac{f_1}{f_2} = RTS. \quad 2.6$$

Condition 2.6 requires that the cost-minimizing firm should equate the rate of technical substitution (RTS) for the two inputs to the ratio of their prices. The rate of technical substitution is the rate at which one variable input is substituted for another variable input, holding the level of output constant.

The sufficient second-order condition for the cost minimization is that the following bordered Hessian determinant be negative:

$$H = \begin{vmatrix} -\lambda f_{11} & -\lambda f_{12} & -f_1 \\ -\lambda f_{21} & -\lambda f_{22} & -f_2 \\ -f_1 & -f_2 & 0 \end{vmatrix} < 0. \quad 2.7$$

The elements of this determinant are the second partial derivatives of the Lagrangian with respect to x_1 , x_2 , and λ , or the first partial derivatives of the first order equations with respect to x_1 , x_2 , and λ . Graphically, the second order condition relates to the shape of the isoquants. An isoquant is a locus of points representing input combinations that yield the same level of output. Production isoquants must be convex in order that the tangency point between isoquant and isocost curves be a minimum cost for a specified output.

Assuming that the second order condition is satisfied, the first order conditions of equations 2.3 – 2.5 can be solved for x_1 and x_2 , yielding the conditional factor demand equations

$$\begin{aligned} x_1^* &= x_1^*(r_1, r_2, y) \\ x_2^* &= x_2^*(r_1, r_2, y). \end{aligned} \tag{2.8}$$

Solving the first order conditions for λ yields

$$\lambda^* = \frac{r_1}{f_1} = \frac{r_2}{f_2} \tag{2.9}$$

where f_1 and f_2 can be interpreted as marginal products of x_1 and x_2 . At the least-cost combination of inputs, λ^* is equal to marginal cost, or the additional cost associated with an additional unit increase in output.

Mathematically, the cost function is derived by substituting the conditional factor demand equations x_1^* and x_2^* into $C = r_1x_1 + r_2x_2$. Then, the cost function becomes

$C = C^*(r_1, r_2, y)$, where C^* is the minimum cost of producing output y given that the input prices are constant.

The cost-minimizing combination of inputs is illustrated graphically in Figure 2.1. Given the output isoquant associated with y_0 , the objective of the firm is to shift to a lower isocost curve, thus reducing the cost, until the least-cost combination of inputs is obtained for output y_0 . An isocost curve is a locus of points where the total cost is the same for alternative input

combinations. It is clear from Figure 2.1 that the minimum cost of producing y_0 is at point A where the isocost curve C_0 is tangent to the isoquant y_0 . Assuming that the isoquant is convex, the cost-minimizing input combination is x_1^* , x_2^* . The line OE in Figure 2.1 represents the cost-minimizing tangencies for successively higher levels of output. This line is called the firm's expansion path and shows how inputs expand as output expands, holding the prices of the inputs constant.

2.2 Cost Function

Average and marginal cost functions are two different unit cost measures associated with the cost function. The average cost function is defined as

$$AC = \frac{C^*}{y}.$$

The marginal cost function is defined as the change in cost for a change in output

$$MC = \frac{\partial C^*}{\partial y}.$$

Given the expansion path in Figure 2.1, the cost function is represented graphically by plotting output levels with their corresponding minimum cost. Information from the total cost curve (Figure 2.2, top) can be used to construct the average and marginal cost curves (Figure 2.2, bottom). Long-run marginal cost (LMC) is simply the slope of long-run total cost (LTC) curve, while long-run average cost (LAC), for some level of output, is the slope of a chord through the origin intersecting the LTC curve at that output level. As illustrated in Figure 2.2, LAC is at a minimum when the chord is tangent to the LTC curve. On the other hand, LMC reaches a minimum at the point of inflection of LTC curve. So long as LMC is below LAC, LAC is falling, when LMC is above LAC, LAC is rising, and $LMC = LAC$ when LAC is at a minimum.

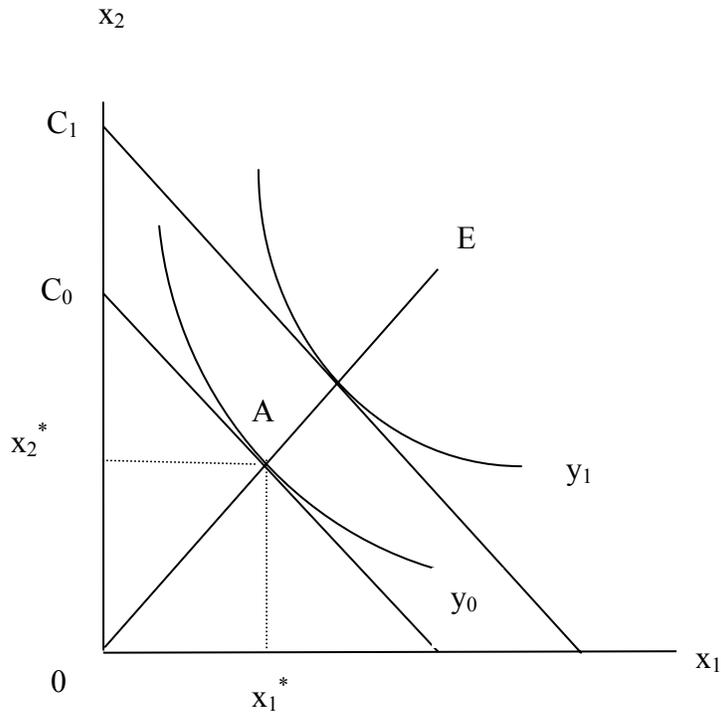


Figure 2.1. Minimizing cost for a given level of output.

Assuming it is possible to proportionally change all inputs, one important characteristic of the production function is the concept of returns to scale. This is a measure of how output changes with a proportionate change in inputs. Specifically, the production function $y = f(x_1, x_2)$ exhibits constant returns to scale if

$f(\alpha x_1, \alpha x_2) = \alpha f(x_1, x_2) = \alpha y$, for any $\alpha > 0$. For example, if all inputs are doubled, then output would also double. Decreasing returns to scale exists if $f(\alpha x_1, \alpha x_2) < \alpha f(x_1, x_2) = \alpha y$, implying that a doubling in all inputs results in less than a doubling of output. Increasing returns to scale exists if $f(\alpha x_1, \alpha x_2) > \alpha f(x_1, x_2) = \alpha y$, implying that a doubling in all inputs results in more than a doubling of output.

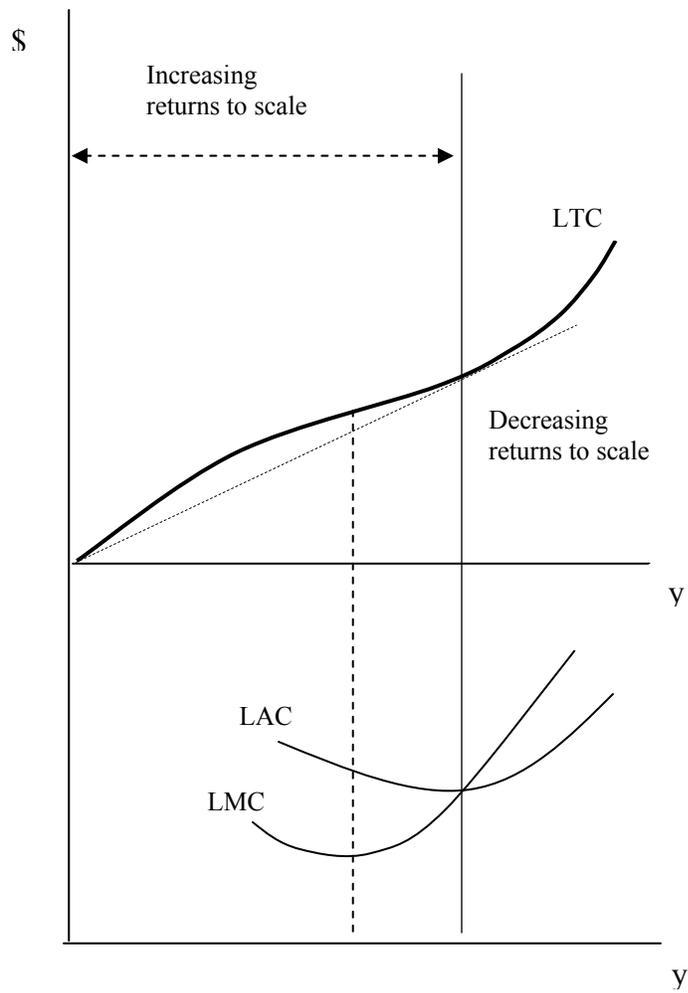


Figure 2.2. Long-run cost curves.

The concept of returns to scale is directly related to the cost curves. As illustrated in Figure 2.2, increasing returns to scale is in that region where the LAC curve is declining, $\partial LAC/\partial y < 0$, or where increases in total cost are proportionally smaller than an increase in output. Similarly, decreasing returns to scale is in that region where LAC curve is increasing, $\partial LAC/\partial y > 0$, or where increases in total cost are proportionally larger than an increase in output. Constant returns to scale are where $\partial LAC/\partial y = 0$, and this corresponds to the minimum point of LAC curve.

Returning to the cost minimization problem, it can be demonstrated that conditional factor demands respond to changes in prices and output. Specifically, we are interested in the determination of the sign of the partial derivatives $\frac{\partial x_i^*}{\partial r_j}$ and $\frac{\partial x_i^*}{\partial y}$. The first step in this comparative statics analysis, as stated by Silberberg (1978), is to substitute x_1^* , x_2^* and λ^* into the first-order conditions (equations 2.3 – 2.5) and differentiate the resulting identities with respect to r_1 , r_2 and y . Taking partial derivatives with respect to r_1 yields

$$\begin{aligned}
 1 - \lambda^* f_{11} \frac{\partial x_1^*}{\partial r_1} - \lambda^* f_{12} \frac{\partial x_2^*}{\partial r_1} - f_1 \frac{\partial \lambda^*}{\partial r_1} &= 0 \\
 -\lambda^* f_{21} \frac{\partial x_1^*}{\partial r_1} - \lambda^* f_{22} \frac{\partial x_2^*}{\partial r_1} - f_2 \frac{\partial \lambda^*}{\partial r_1} &= 0 \\
 -f_1 \frac{\partial x_1^*}{\partial r_1} - f_2 \frac{\partial x_2^*}{\partial r_1} &= 0.
 \end{aligned} \tag{2.10}$$

The equations can be written in matrix form as

$$\begin{pmatrix} -\lambda^* f_{11} & -\lambda^* f_{12} & -f_1 \\ -\lambda^* f_{21} & -\lambda^* f_{22} & -f_2 \\ -f_1 & -f_2 & 0 \end{pmatrix} \cdot \begin{pmatrix} \frac{\partial x_1^*}{\partial r_1} \\ \frac{\partial x_2^*}{\partial r_1} \\ \frac{\partial \lambda^*}{\partial r_1} \end{pmatrix} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}. \tag{2.11}$$

Using Cramer's rule,

$$\frac{\partial x_1^*}{\partial r_1} = \frac{f_2^2}{H} < 0 \tag{2.12}$$

$$\frac{\partial x_2^*}{\partial r_1} = -\frac{f_2 f_1}{H} > 0.$$

Repeating the same sort of calculations to analyze the response to a change in r_2 , we find

$$\frac{\partial x_1^*}{\partial r_2} = -\frac{f_1 f_2}{H} > 0$$

$$\frac{\partial x_2^*}{\partial r_2} = \frac{f_1^2}{H} < 0. \tag{2.13}$$

By symmetry, $\frac{\partial x_1^*}{\partial r_2} = \frac{\partial x_2^*}{\partial r_1}$, or the “cross-price” effects of changing input prices on input use must

be equal for any input pair at the optimum. On the other hand, the own-price effects must be negative, meaning that the conditional factor demands are downward sloping.

2.3 Short-Run Cost and Long-Run Cost

To this point the focus has been on long-run total cost, or the minimum cost necessary for obtaining a given level of output when all inputs are variable. In the short-run, one or more factors of production are fixed and the short-run total cost (STC) is the sum of short-run variable cost (SVC) and short-run fixed cost (SFC),

$$STC = SVC + SFC.$$

SVC is the cost of those inputs that can be varied in order to change the output level. On the other hand, SFC is the cost associated with inputs that cannot be varied in the short run. Short-run average total cost (SATC) can be defined as

$$SATC = \frac{STC}{y} = \frac{SVC}{y} + \frac{SFC}{y} = SAVC + SAFC \tag{2.14}$$

where SAVC is short-run average variable cost and SAFC is short-run average fixed cost.

Short-run marginal cost (SMC) is given as:

$$SMC = \frac{\partial STC}{\partial y} = \frac{\partial SVC}{\partial y} . \quad 2.15$$

Graphically, the short-run cost functions are shown in Figure 2.3. The relationship between SMC and SAVC is derived as follows:

$$SMC = \frac{\partial SVC}{\partial y} = \frac{\partial(SAVC \cdot y)}{\partial y} = SAVC + \frac{\partial SAVC}{\partial y} y \quad 2.16$$

$$\frac{\partial SAVC}{\partial y} < 0 \Rightarrow SMC < SAVC$$

$$\frac{\partial SAVC}{\partial y} > 0 \Rightarrow SMC > SAVC \quad 2.17$$

$$\frac{\partial SAVC}{\partial y} = 0 \Rightarrow SMC = SAVC$$

Since $SMC = \frac{\partial STC}{\partial y} = \frac{\partial SVC}{\partial y}$, the relationship between SMC and SATC can be derived in the same way.

In the short-run, a firm can increase its output by adding variable inputs to the fixed inputs. However, the “Law of Diminishing Marginal Returns” implies that as more of a variable input is added to a constant amount of fixed inputs, the marginal product of the variable input will eventually decline. Thus, where the SMC curve is positively sloped there are diminishing marginal returns, and where the SMC curve is negatively sloped there are increasing marginal returns. A consequence of the Law of Diminishing Marginal Returns is that SMC, SAVC, and SATC will eventually rise with increases in output.

In general, a short-run production function is divided into three stages of production. As Figure 2.3 shows, Stage I includes the area where SAVC is falling, up to the point where SAVC reaches a minimum, which also corresponds to an increasing average product.

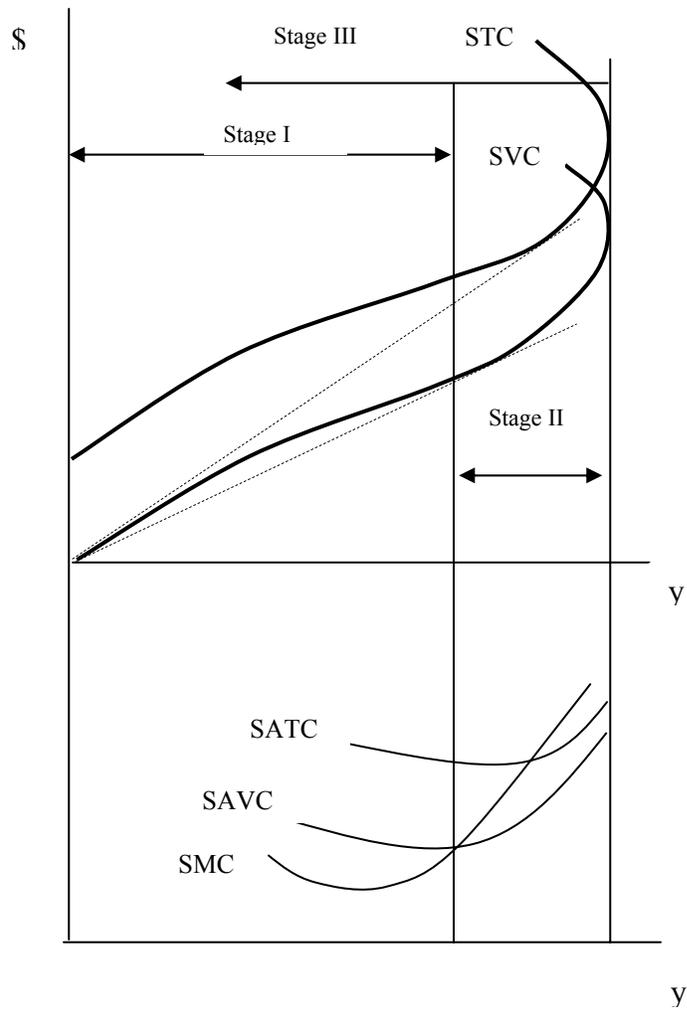


Figure 2.3. Short-run cost curves and stages of production.

In Stage I the variable input is limited relative to the fixed inputs; therefore the firm can increase the output by adding variable input as long as average product is rising. Stage III starts where marginal product of the variable input is zero, or SMC is undefined, and includes the area of negative marginal product for the variable input. In Stage III, STC and STVC are still increasing but output is declining as more of the variable input is added. A rational profit-maximizing producer would never knowingly operate in Stage I or Stage III of production. Firms aim to operate in Stage II of production, which includes the area where SAVC is rising as output increases. Within this stage, both average product and marginal product of the variable input are positive but declining.

The relationship between long-run and short-run cost curves is shown in Figure 2.4. Consider two inputs, x_1 and x_2 , where in the long-run both inputs are variable, but in the short-run we assume that x_2 is fixed. Figure 2.4 shows that while there is a single long-run total cost curve (LTC), we can draw an infinite number of short-run cost curves, one for every level of fixed input x_2 . For example, STC_0 and STC_1 are short-run total cost curves when input x_2 is fixed at x_2^0 and x_2^1 , respectively. STC curves are tangent to LTC curve at that level of fixed input x_2 that is the long run optimal input usage, making the long-run total cost curve an envelope curve of the short-run total cost curves. Figure 2.4 also demonstrates that the cost of producing y_1 when x_2 is fixed at x_2^1 is given by point B. However, in the long-run the cost of y_1 is minimized if x_2 is adjusted from x_2^1 to x_2^0 . This is shown graphically as a tangency between STC_0 and LTC, given by point A.

From the long-run cost curve and short-run cost curves we can derive long-run average cost curve (LAC) and short-run average cost curves (SAC). Where STC curves are tangent to LTC curve, SAC curves are also tangent to LAC curve. Note, however, that this point of tangency does not necessarily occur at the minimum point of SAC curve.

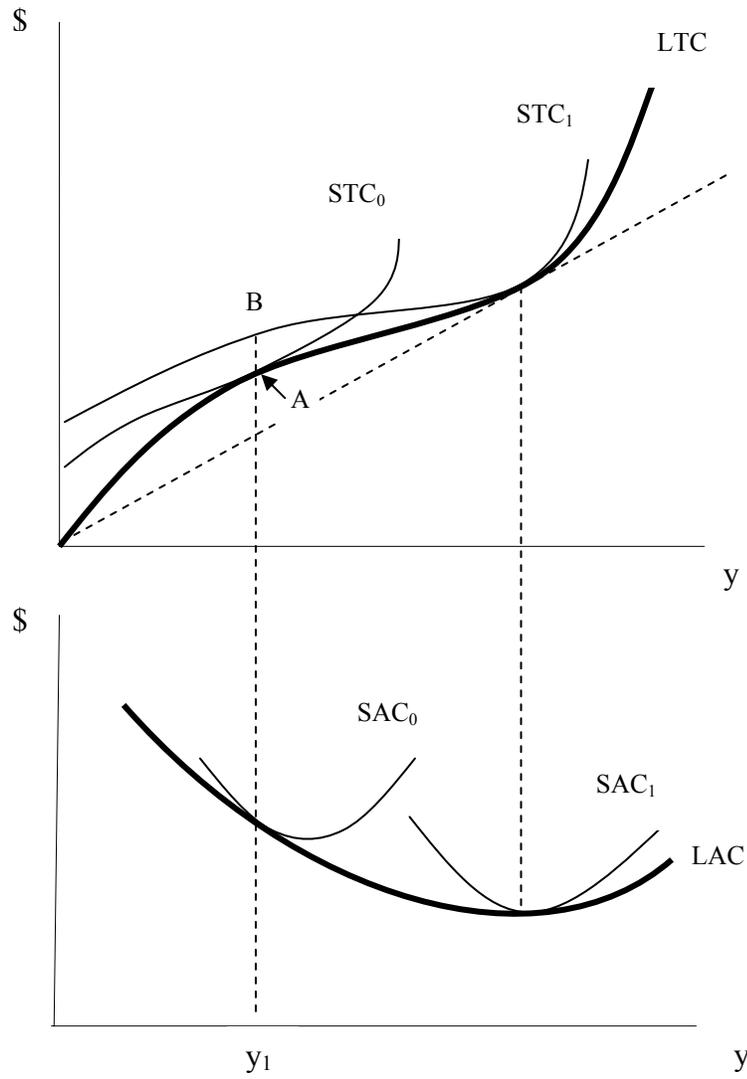


Figure 2.4. Short-run total cost and long-run total cost curves.

Similarly to the relationship between STC curves and LTC curve, the LAC curve is an envelope of the SAC curves.

2.4 The Duality of the Cost Function

The importance of the dual approach, as stated by Beattie and Taylor (1985), resides in the fact that it “allows one to obtain product supply and factor demand equations by partial differentiation of an indirect objective function.” Two important concepts are associated with duality. One concept is that of an indirect cost function, which is defined as the minimum cost of producing a specified output y , at given factor prices. That is $C = C^*(\mathbf{r}, y)$, where \mathbf{r} is a vector of input prices. The properties of this indirect cost function can be summarized as (Chambers, 1988):

1. Nonnegativity: if $\mathbf{r} > 0$ and $y > 0$, then $C^*(\mathbf{r}, y) > 0$.
2. Nondecreasing in \mathbf{r} : if $\mathbf{r}' > \mathbf{r}$, then $C^*(\mathbf{r}', y) > C^*(\mathbf{r}, y)$. This indicates that increasing any input price must not decrease the cost.
3. Homogeneous of degree one in \mathbf{r} : $C^*(t\mathbf{r}, y) = tC^*(\mathbf{r}, y)$, since factor demand functions are homogeneous of degree 0 in \mathbf{r} . So, as long as input prices only vary proportionately, the cost minimizing choice of inputs will not vary, but we would expect cost C^* to vary proportionately.
4. Concave and continuous in \mathbf{r} .
5. Nondecreasing in y : if $y > y'$, then $C^*(\mathbf{r}, y) > C^*(\mathbf{r}, y')$.

Another important concept in duality is the envelope theorem. Assuming that the conditional factor demands are x_1^* and x_2^* , the indirect cost function is

$$C^* = r_1x_1^* + r_2x_2^* \tag{2.18}$$

and the envelope theorem states that

$$\frac{\partial C^*}{\partial r_1} = \frac{\partial L}{\partial r_1} = x_1^* . \quad 2.19$$

Equation 2.19, also known as Shepard's lemma, points out that the rate of change in the indirect cost function, C^* , with respect to a parameter, r_1 , allowing all x_i to adjust, is equal to the partial derivative of the Lagrangian with respect to the same parameter r_1 , holding all x_i fixed.

A proof of the envelope theorem is given in Silberberg (1978) by taking partial derivatives of $C^* = r_1 x_1^* + r_2 x_2^*$ with respect to r_1

$$\frac{\partial C^*}{\partial r_1} = x_1^* + r_1 \frac{\partial x_1^*}{\partial r_1} + r_2 \frac{\partial x_2^*}{\partial r_1} . \quad 2.20$$

From the first order conditions, $r_1 = \lambda f_1$, $r_2 = \lambda f_2$, and substituting these into equation 2.20 yields

$$\frac{\partial C^*}{\partial r_1} = x_1^* + \lambda \left(f_1 \frac{\partial x_1^*}{\partial r_1} + f_2 \frac{\partial x_2^*}{\partial r_1} \right) . \quad 2.21$$

Differentiating the constraint identity $y_0 = f(x_1^*, x_2^*)$ with respect to r_1 yields

$$f_1 \frac{\partial x_1^*}{\partial r_1} + f_2 \frac{\partial x_2^*}{\partial r_1} = 0 \quad 2.22$$

which is exactly the expression in parentheses in equation 2.21. Hence, as the envelope theorem

states, $\frac{\partial C^*}{\partial r_1} = x_1^*$.

An illustration of the envelope theorem applied to the cost function is shown in Figure 2.5. As Beattie and Taylor (1985) describe this graph, the indirect cost function C^* is a lower envelope to the direct cost equations $C = r_1 x_1 + r_2 x_2$. In accordance with the envelope theorem, at the tangency point A the indirect cost function C^* and the direct cost function $C(x_1^0, x_2^0)$ have

the same slope if the slope of the direct cost function is evaluated at the cost-minimizing values x_1^0, x_2^0 .

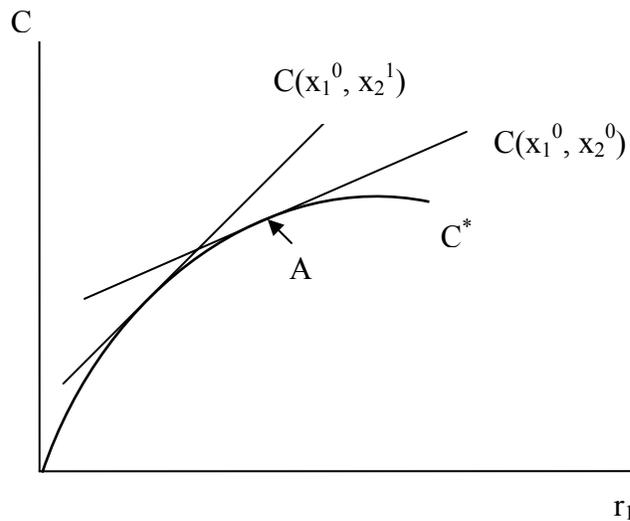


Figure 2.5. The envelope theorem applied to cost function.

2.5 Comparative Statics of the Cost Function

The questions addressed in this section are “How do cost and input demands respond to changes in input prices?” and “What happens to input utilization and cost if output increases?” To some extent, the first question was addressed in the earlier discussion of the cost minimization problem where it was shown that the responses of demand to input prices are computed from the Hessian matrix of the cost function, resulting in

$$\frac{\partial x_i^*}{\partial r_i} \leq 0$$

$$\frac{\partial x_i^*}{\partial r_j} = \frac{\partial x_j^*}{\partial r_i}.$$

2.23

Thus, conditional factor demands must be downward sloping, meaning that a rise in any input price results in a decline in the demand for that input. The conditional factor demands are

homogeneous of degree zero in input prices since the cost function is homogeneous of degree one. Mathematically this is written as

$$x_i^*(tr, y) = x_i^*(r, y), i = 1, 2, \dots, n.$$

The response of factor demands to changes in factor prices can also be described in terms of elasticity:

$$\varepsilon_{ij} = \frac{\partial x_i^*}{\partial r_j} \frac{r_j}{x_i^*} \quad 2.24$$

where ε_{ij} represents the percentage change in the factor demand x_i (holding output constant) due to one percent change in the input price r_j . When $i = j$, this is the own-price elasticity; when $i \neq j$, this is the cross-price elasticity.

The response of the conditional factor demands to a change in output is also computed from the Hessian matrix of the cost function. By Shephard's lemma

$$\frac{\partial x_i^*}{\partial y} = \frac{\partial^2 C^*}{\partial r_i \partial y} = \frac{\partial^2 C^*}{\partial y \partial r_i} = \frac{\partial(\partial C^* / \partial y)}{\partial r_i} \quad 2.25$$

where $\partial C^* / \partial y$ is marginal cost. Equation 2.25 shows that the response of the i th input to a change in output equals the change in marginal cost caused by a change in the price of the i th input. When the above equation is negative, the i th input is inferior, meaning that if the output level is increased the use of the i th input is decreased; when it is positive, the i th input is said to be normal, meaning that an increase in output leads to an increase in the use of the i th input. However, an input cannot be inferior over the whole range of output.

2.6 Multioutput Cost Function

The discussion of the multiproduct cost function is similar to that for single-output-case. Consider the cost minimization problem for an m -outputs, n -inputs technology:

$$\text{Min } C = \sum_i r_i x_i \text{ subject to } F(y_1, \dots, y_m, x_1, \dots, x_n) = 0. \quad 2.26$$

From the Lagrangian

$$L = \sum_i r_i x_i + \lambda F(y_1, \dots, y_m, x_1, \dots, x_n), \quad 2.27$$

the first order conditions yield

$$\frac{\partial L}{\partial x_i} = r_i + \lambda F_i = 0, \text{ for } i = 1, 2, \dots, n \quad 2.28$$

$$\frac{\partial L}{\partial \lambda} = F(y_1, \dots, y_m, x_1, \dots, x_n) = 0. \quad 2.29$$

Solving the (n + 1) equations generates the conditional factor demand functions

$x_i^* = x_i^*(r_1, \dots, r_n, y_1, \dots, y_m)$, for $i = 1, \dots, n$. The multioutput cost function C^* is then

determined by substituting the conditional factor demand equations into the primal cost function

C , resulting in $C^* = C^*(r_1, \dots, r_n, y_1, \dots, y_m)$. C^* gives the minimum cost for producing

specified outputs.

The sufficient second order condition for cost minimization requires that the determinants of the principal minors of the bordered Hessian be negative. Thus

$$H_1 = \begin{vmatrix} -\lambda F_{11} & -\lambda F_{12} & -F_1 \\ -\lambda F_{21} & -\lambda F_{22} & -F_2 \\ -F_1 & -F_2 & 0 \end{vmatrix} < 0$$

$$H_2 = \begin{vmatrix} -\lambda F_{11} & -\lambda F_{12} & -\lambda F_{13} & -F_1 \\ -\lambda F_{21} & -\lambda F_{22} & -\lambda F_{23} & -F_2 \\ -\lambda F_{31} & -\lambda F_{32} & -\lambda F_{33} & -F_3 \\ -F_1 & -F_2 & -F_3 & 0 \end{vmatrix} < 0 \quad 2.30$$

⋮

$$H_n = \begin{vmatrix} -\lambda F_{11} & -\lambda F_{12} & \dots & -\lambda F_{1n} & -F_1 \\ -\lambda F_{21} & -\lambda F_{22} & \dots & -\lambda F_{2n} & -F_2 \\ \cdot & \cdot & \dots & \cdot & \cdot \\ -\lambda F_{n1} & -\lambda F_{n2} & \dots & -\lambda F_{nn} & -F_n \\ -F_1 & -F_2 & \dots & -F_n & 0 \end{vmatrix} < 0$$

which implies that the production isoquants will be convex.

Technical interdependence and economic interdependence are two concepts associated with multiproduct cost function. Beattie and Taylor (1985) show that technical interdependence can be expressed as

$$\frac{\partial^2 C^*}{\partial y_i \partial y_j} = \frac{\partial MC_i}{\partial y_j}. \quad 2.31$$

Thus, the products y_i and y_j are said to be technically competing, independent, or complementary

depending upon whether the sign of $\frac{\partial^2 C^*}{\partial y_i \partial y_j}$ is positive, zero, or negative. In other words, the

products y_i and y_j are technically competing, independent, or complementary if the marginal cost of producing y_i is increased, unchanged, or decreased as the product y_j is increased. The products y_i and y_j are technically competing if, as a result of changed conditions, one product replaces the other in production. The products are complementary if they can be produced together.

Economic interdependence, as shown by Beattie and Taylor, refers to the interrelationships between two factors, two products, or a product and a factor, and involves determining what happens to quantity demanded or quantity supplied as a certain price changes.

Specifically, factors x_i and x_l are economically complementary if $\frac{\partial x_i^*}{\partial r_l} < 0$, economically

competing if $\frac{\partial x_i^*}{\partial r_l} > 0$, and economically independent if $\frac{\partial x_i^*}{\partial r_l} = 0$. For product interdependence,

with products y_j and y_k , and p_k representing the output price of y_k , $\frac{\partial y_j}{\partial p_k} < 0 \Rightarrow y_j$ and y_k are

economically competing, $\frac{\partial y_j}{\partial p_k} > 0 \Rightarrow y_j$ and y_k are economically complementary, and

$\frac{\partial y_j}{\partial p_k} = 0 \Rightarrow y_j$ and y_k are economically independent.

Regarding factor-product or product-factor cross-price effect, for normal products and normal factors, $\frac{\partial y_j}{\partial r_i} < 0$ and $\frac{\partial x_i^*}{\partial p_j} > 0$. That is, an increase in a factor price would result in a decrease in the quantity supplied of any product utilizing that factor, and an increase in a product price would generate an increase in factor demand.

A major problem associated with multioutput technology is that, in many instances, the number of outputs and inputs is too large to be handled adequately by limited data sets. The complexity of the multioutput technology can be reduced if it is possible to group several inputs or several outputs into subsets. Input-output separability is an important aggregation concept characteristic to multioutput technology. It implies that output price ratios or marginal rates of transformation are independent of factor intensities or factor prices (Hall 1973). Chambers (1988) gives the necessary conditions for input-output separability for the profit-maximizing producer as $\partial(x_i/x_j)/\partial p = 0$ and $\partial(y_i/y_j)/\partial r = 0$. The first condition implies that a change in output prices, p , does not influence the composition of inputs x_i and x_j , while the second condition implies that a change in input prices, r , does not influence the composition of outputs y_i and y_j . Rejecting input-output separability means that a change in input (output) price alters the composition of output (input) quantities.

Non-jointness in inputs is another important concept pertaining to multioutput technology. It implies a separate production function for each output. According to Hall (1973) and Shumway, Pope, and Nash (1984), the technology is nonjoint in inputs if the cost function can be written as

$$C = \sum_i y_i C_i(r, y_i), \quad 2.32$$

where C_i is the individual cost function for the i th output. Non-jointness in inputs implies that

$$\frac{\partial^2 C}{\partial y_i \partial y_k} = 0, \text{ or marginal cost of producing the } i\text{th output does not depend on the level of the } k\text{th}$$

output, $k \neq i$. A necessary condition for non-jointness in inputs is $\partial y_i / \partial p_j = 0$. That is, a price change in the j th output will not affect the supply of the i th nonjoint output.

2.7 Multiproduct Cost Concepts

An important component of the multiproduct cost structure is economies of scope. If economies of scope exist then cost savings may be obtained by simultaneously producing several different outputs in a single multiproduct firm, instead of producing each output by its own specialized firm. The condition for economies of scope (Baumol, Panzar, and Willig 1988, Akridge and Hertel 1986) is

$$\sum_i C(y_i) > C(y), \quad 2.33$$

where y_i are output vectors and y is an output vector containing all of the y_i vectors. Therefore, economies of scope exist if the total cost of the joint output of all products is less than the sum of the costs of producing the products separately. Dividing the equation 2.33 by $C(y)$ provides a measure of the degree of economies of scope, where economies of scope exists if $EOS > 0$:

$$EOS = (\sum_i C(y_i) - C(y)) / C(y) . \quad 2.34$$

Baumol, Panzar, and Willig (1988) identify two cost sources from which economies of scope can arise. The first source is cost complementarity, which implies that the marginal cost of producing one output is lowered by an increase in production of the other output:

$$\frac{\partial^2 C(y)}{\partial y_i \partial y_j} < 0 . \quad 2.35$$

The second source from which economies of scope arise is represented by subadditive fixed costs. The multiproduct cost function can be expressed as a sum of fixed costs (F) and variable costs (V), $C(y) = V(y) + F(T)$. Fixed costs depend on which product sets are produced. Two product sets T_i and T_j share some fixed costs when fixed costs are subadditive:

$$F(T_i) + F(T_j) > F(T_i \cup T_j).$$

Product-specific economies of scale and multiproduct economies of scale are two other components of the multiproduct cost structure. Product-specific economies of scale, $S_i(y)$, measure the change in costs as the quantity of a single product increases, holding constant the other output levels and input prices. An important concept in measuring product-specific economies of scale is incremental cost of product i , which is defined by Baumol, Panzar, and Willig (1988) as $IC_i(y) = C(y) - C(y_{N-i})$ where $C(y_{N-i}) = C(y_1, \dots, y_{i-1}, 0, y_{i+1}, \dots, y_N)$. The average incremental cost of the i th product is defined as

$$AIC_i(y) = IC_i(y) / y_i \quad \text{where } y_i \text{ is the quantity of the } i\text{th output produced.}$$

The condition for product specific-economies of scale (Baumol, Panzar, and Willig, 1988, and Kim, 1987) is:

$$S_i(y) = \frac{AIC_i(y)}{\partial C(y) / \partial y_i} . \quad 2.36$$

Hence, product-specific economies of scale are the average incremental costs of producing the i th output divided by the marginal cost of producing the i th output. If $S_i(y) > 1$, then product-specific economies of scale exist in the production of the i th output. If $S_i(y) < 1$, there are diseconomies of scale.

Multiproduct economies of scale, $S_M(y)$, measure the change in costs for proportional changes in all outputs and inputs. Following Baumol, Panzar, and Willig (1988) and Kim (1987), a measure of scale economies for a multiproduct firm is defined as

$$S_M(y) = C(y) / \sum_i y_i C_i(y) = 1 / \sum_i e_{C y_i}, \quad 2.37$$

where $C_i(y) = \partial C(y) / \partial y_i$ is the marginal cost with respect to the i th output, and

$e_{C y_i} = \partial \ln C(y) / \partial \ln y_i$, the cost elasticity of the i th output. If $S_M(y) > 1$, there exists economies of scale, meaning that a proportional increase in all outputs leads to a less than proportional increase in total cost. If $S_M(y) < 1$, then there exists diseconomies of scale.

An additional concept that characterizes the multiproduct cost structure is cost subadditivity (Baumol, Panzar, and Willig 1988). A cost function $C(y)$ is subadditive at y if for any and all quantities of outputs y_1, \dots, y_k , such that $\sum_{j=1}^k y_j = y$, we have

$$C(y) < \sum_{j=1}^k C(y_j).$$

In other words, a cost function is subadditive at output y if it is more expensive for two or more firms to produce y than it is for a single firm to produce y .

The cost function represents an efficient mechanism used to reveal the technical and economic interrelationships present in a firm. Because input prices are used as independent variables, the cost function overcomes problems associated with unknown input quantities. This means that one needs to know just total cost and input prices to find optimal input quantities.

CHAPTER 3: DATA AND EMPIRICAL MODEL

3.1 Data

Data used for analysis were trip-based information obtained from a set of 8 west-Florida grouper fishing vessels for 2005 and 2006. The data included information on landings per species (red grouper, gag grouper, other grouper, and other species), gross trip revenues, trip costs (including expenditures on fuel, tackle, supplies, bait, ice, food, clothing, and captain and crew costs), and the number of days spent fishing. As a result, the cost variable used in this analysis consisted of the aggregated expenditures on fuel, labor (total trip captain and crew costs), and miscellaneous items (tackle, supplies, bait, ice, food, and clothing). In terms of cost shares, labor accounted for almost 50 percent of the total cost on an average trip, while fuel and miscellaneous inputs accounted for 15 and 35 percent of the total cost, respectively.

Three input prices were used as explanatory variables in the analysis: price of fuel, price of labor (crew and captain), and an aggregate price for the other miscellaneous inputs (tackle, supplies, bait, ice, food, and clothing). The price of fuel was proxied by using a fuel price index reported for the Miami-Fort Lauderdale region, which was the geographic area closest to the primary ports used by the grouper fishermen (U.S. Bureau of Labor Statistics). The labor and miscellaneous price variables were constructed using information from the sample vessels. Specifically, the price of labor was calculated by dividing the expenditure on labor by the number of days spent fishing, thereby yielding a variable that was in terms of labor costs per day. Given the incomplete records for some trips, this approach generated a number of observations with a zero price for labor. These zero records were replaced by constructed data using the total revenue and the labor share of that revenue. In short, the mean labor share of total revenue was calculated for each vessel and used to estimate the amount of labor expenditures for the trips of that vessel that had missing labor data. These mean expenditures were then divided by the

number of days spent fishing for each particular vessel and trip. In all, 57 zero labor price observations were replaced using this method, representing 20 percents of all labor prices. The price of miscellaneous inputs was calculated by dividing the total expenditure on the miscellaneous inputs by the numbers of days spent fishing, a process that did not yield zero observations due to the completeness of that part of the log book data.

In addition to input prices, the cost function analysis required output levels, which in the present study were represented by the harvests of red grouper, gag grouper, other grouper, and other species (all measured in pounds). Given the study's focus on the grouper complex, trip records were dropped from the analysis when the sum of red grouper, gag grouper, and other grouper were zero or missing. In total, the resulting data used in the empirical analysis consisted of 208 trip observations, statistical summaries of which are presented in Table 3.1. As indicated by the information in Table 3.2, grouper on average accounted for more than 75 percent of all fish landed per trip by the vessels in the data. In addition, shallow-water grouper (red and gag) accounted on average for almost 75 percent of all grouper landed per trip. Red grouper alone on average accounted for more than 55 percent of all grouper landed per trip.

Given that information on vessels sizes was incomplete, a proxy for size was created using a (0, 1) intercept dummy variable. This dummy variable was created based on the gross total revenues of the vessels, with the assumption that large vessels and small vessels may have a significant effect on the model's parameters. Moreover, to test whether the yearly closed season has a significant influence on the model's parameters, another intercept dummy variable was created to account for this possible effect.

Table 3.1. Statistical summaries of data variables used in the estimation of the translog cost function.

Variable	N	Mean	S.E.	Min	Max
Red grouper harvested on trip (lb.)	208	1792.19	1865.11	0.01	8154.00
Gag harvested on trip (lb.)	208	541.22	707.89	0.01	3471.00
Other grouper harvested on trip (lb.)	208	881.71	1673.63	0.01	8920.00
Other species harvested on trip (lb.)	208	1025.66	1658.69	0.01	11836.00
Total trip fuel costs (\$)	208	958.39	541.25	0.00	3353.08
Total trip crew and captain costs (\$)	208	3109.09	3625.43	0.00	15008.32
Total trip misc ^a . costs (\$)	208	2248.02	1377.22	13.70	10125.41
Number of days spent fishing	208	7.32	3.73	1.00	15.00
Price of fuel (index)	208	220.03	27.44	170.50	262.20
Price of labor (\$ per day)	208	416.74	391.87	4.14	2393.00
Price of misc (\$ per day)	208	342.24	254.23	13.38	2531.35

^a Miscellaneous trip costs includes those for tackle, supplies, bait, ice, food, and clothing.

Table 3.2. Cost shares and harvest shares by species for the average trip.

	Mean	Share
Total trip fuel costs (\$)	958.40	0.1517
Total trip crew & captain costs (\$)	3109.09	0.4923
Total trip misc. costs (\$)	2248.02	0.3559
Total trip cost (\$)	6315.51	
Red grouper harvested on trip (lb.)	1792.20	0.4226
Gag harvested on trip (lb.)	541.22	0.1276
Other grouper harvested on trip (lb.)	881.71	0.2079
Other species harvested on trip (lb.)	1025.66	0.2418
Total harvest on trip (lb.)	4240.79	

3.2 Empirical Model

As indicated in Chapter Two, the cost function will be used to reveal technical and economic interrelationships present in the grouper fishery. Because maximum catch levels are set by quota, it is assumed that fishing vessels attempt to minimize the cost of harvesting the set quota. The cost function can be written as a function of output levels (Y) and input prices (r), or $C = f(Y, r)$. A specific example of how a dual cost function is estimated from a primal cost function might add to the understanding of how this process follows. Assume the following cost minimization problem:

$$\min C = r_1X_1 + r_2X_2 \text{ subject to } Y = X_1X_2 \quad 3.1$$

where X_i = input quantities, r_i = input prices, Y = output, and the production technology is multiplicative (Cobb-Douglas) in form. From the Lagrangian:

$$L = r_1X_1 + r_2X_2 + \lambda(Y - X_1X_2) \quad 3.2$$

the first order conditions for optimization yield

$$\partial L / \partial X_1 = r_1 - \lambda X_2 = 0 \quad 3.3$$

$$\partial L / \partial X_2 = r_2 - \lambda X_1 = 0 \quad 3.4$$

$$\partial L / \partial \lambda = Y - X_1X_2 = 0. \quad 3.5$$

Solving these three equations yields the optimal values of X_1 and X_2 :

$$X_1^* = Y^{1/2} r_1^{-1/2} r_2^{1/2} \quad 3.6$$

$$X_2^* = Y^{1/2} r_1^{1/2} r_2^{-1/2}. \quad 3.7$$

The dual minimum cost function C^* is then determined by substituting the demand equations X_1^* and X_2^* into the primal cost function $C = r_1X_1 + r_2X_2$ to obtain

$$C^* = 2Y^{1/2} r_1^{1/2} r_2^{1/2}.$$

This cost function must satisfy the following regularity conditions: continuity, monotonicity in input prices and outputs, concavity in input prices, and linear homogeneity in input prices. The condition of monotonicity indicates that the cost function is nondecreasing in input prices ($\partial C^*/\partial P > 0$) and output ($\partial C^*/\partial q > 0$). Concavity in input prices ($\partial^2 C^*/\partial P^2 < 0$) implies a downward-sloping input demand curve. The condition of homogeneity of degree one in input prices requires that $C^*(tP) = tC^*(P)$, where $t > 0$. For example, if all input prices double, we would expect cost C^* to double. If the cost function is homogeneous of degree one, then the conditional input demand (which is the first derivative of the cost function with respect to input price) is homogeneous of degree zero ($x(tP) = x(P)$).

For estimation, the translog functional form was used to specify C^* in this study. The translog function, introduced by Christensen et al. (1973), has been frequently used to analyze input demand and the underlying technological structure of production. A history of studies using the translog cost function includes Binswanger (1974), Ray (1982), Grisley and Gitu (1985). The translog cost function is used to analyze technological interactions in fisheries because it is technically flexible, implying that specific characteristics of technology may be tested by examining the estimated model parameters (Ray 1982). Specifically, the flexible translog cost function permits estimation of the increase in costs from a proportionate increase in all outputs (economies of scale), as well as the cost savings firms realize by producing several outputs jointly rather than specializing in the production of one (economies of scope). Finally, the translog cost function is flexible because it is not restricted to be monotonically increasing or decreasing as, for example, the Cobb-Douglas and CES specifications are. Thus one is able to estimate more realistic relationships between multiple inputs and outputs (Murray and White, 1983).

Mathematically, the translog cost function can be written for this study as:

$$\begin{aligned} \ln C = & \ln a_0 + \sum_{i=1}^3 a_i \ln P_i + \frac{1}{2} \sum_{i=1}^3 \sum_{j=1}^3 b_{ij} \ln P_i \ln P_j + \sum_{k=1}^4 c_k \ln Q_k + \frac{1}{2} \sum_{k=1}^4 \sum_{l=1}^4 d_{kl} \ln Q_k \ln Q_l \\ & + \frac{1}{2} \sum_{i=1}^3 \sum_{k=1}^4 e_{ik} \ln P_i \ln Q_k + \varepsilon \end{aligned} \quad 3.8$$

where C is harvesting cost per trip, Q_k ($k = 1, 2, 3, 4$) stands for the harvested quantity of red grouper, gag, other grouper, and other species per trip, P_i ($i = 1, 2, 3$) stands for the price of labor, fuel, and miscellaneous, and a_0 , a_i , b_{ij} , c_k , d_{kl} , and e_{ik} are the parameters to be estimated.

For this function to be homogeneous of degree one in input prices, the following conditions must

hold: $\sum_i a_i = 1$, $\sum_j b_{ij} = 0$, and $\sum_k e_{ik} = 0$. These theoretical conditions were first tested and then

imposed on the estimation (as discussed in Chapter 4), all within the context of an OLS estimator as implemented in STATA 9.2. In addition, Young's theorem shows that the second order cross partial derivatives of the translog cost function should be symmetrical, and the symmetry restrictions $b_{ij} = b_{ji}$, $d_{kl} = d_{lk}$ and $e_{ik} = e_{ki}$ were imposed on the model.

Based on Shephard's lemma, the input share equations can be derived from the translog cost function through partial differentiation with respect to the natural logarithm of each input price. For example the share equation for the i th input is:

$$\frac{\partial \ln C}{\partial \ln P_i} = P_i X_i / C = a_i + \sum_j b_{ij} \ln P_j + \sum_k e_{ik} \ln Q_k \quad 3.9$$

where X_i 's are input quantities, and the shares must add up to 1.

From the estimated coefficients of the regression function, own- and cross-price elasticities of input demand can be calculated as:

$$E_{ii} = \frac{b_{ii} + S_i^2 - S_i}{S_i} \text{ and } E_{ij} = \frac{b_{ij} + S_i S_j}{S_i}, \quad 3.10$$

where S_i and S_j are the cost shares computed at the means of the variable inputs.

Two important characteristics of technology were tested with respect to the Florida grouper fishery – input-output separability and non-jointness in inputs. The aggregation of inputs and outputs in a single composite input (called fishing effort) and a single composite output is equivalent to separability between inputs and outputs. This implies that there is no specific interaction between the harvest of any one species and any one input so that composite input and output bundles can be specified to represent the harvest function. Input-output separability implies that the marginal rates of substitution between input pairs are independent of the composition of catch, while the marginal rates of transformation between species pairs are independent of the composition of inputs (Squires 1987b). For fisheries, this implies that only the aggregate levels of catch and effort require regulation, and regulation of species (input) mix does not adversely affect the optimal factor (product) combinations (Squires and Kirkley 1991). The test for input-output separability is that there is no interaction between inputs and outputs, and, with the translog cost function, this implies that $e_{ik} = 0$, for every $i \neq k$.

Another potential technological relationship, jointness-in-inputs, implies that all inputs are required to produce all outputs, while non-jointness in inputs implies that the output of any single product depends only on the inputs used in the production of that product and not on the inputs or outputs used in any other production process. A finding of non-jointness in inputs is equivalent to having separate production functions for each output or set of outputs; each production process can be separately regulated without affecting production of the other processes because there are no technological or cost tradeoffs between the output of one process and that of another (Squires and Kirkley, 1991). Non-jointness in inputs also implies that

$\frac{\partial^2 C}{\partial y_i \partial y_j} = 0$ (Chambers, 1988), or that the marginal cost of producing the i th output does not

depend on the level of the j th output, $i \neq j$. For our model, the econometric restriction needed to test for non-jointness in inputs is $d_{kl} + c_k c_l = 0$, for every $k \neq l$.

The cost structure of multiproduct firm can provide useful information with respect to regulation that is imposed to promote economic efficiency. The importance of the multiproduct cost concepts resides in the fact that they can be used to identify the output bundle that generates the greatest return to the quota asset (Weninger, 1998). An important component of the multiproduct cost technology is economies of scope. This concept refers to the possibility that cost savings may be obtained by simultaneously producing several different outputs by a single multiproduct firm, instead of producing each output by its own specialized firm. For example, in the case of two outputs, y_1 and y_2 , $C(y_1, y_2) < C(y_1) + C(y_2)$, which implies that the total cost of the joint output of the two products is less than the sum of the costs of producing the two products separately.

Lipton and Strand (1992) indicate that economies of scope will arise if there is jointness in inputs, $\frac{\partial^2 C}{\partial y_i \partial y_j} < 0$, or fixed costs are subadditive ($\sum_i F(T_i) > F(S)$, where T_i 's are a partition of S , and $F(T_i)$ represents fixed costs that depends on which product is produced).

Cost complementarity, expressed as $\frac{\partial^2 C}{\partial y_i \partial y_j} < 0$, provides a direct way of testing for economies of scope once a cost function for the firm has been estimated. It can be translated as an increase in the production of one output causes a decline in the marginal cost of the other output. With the translog cost function, cost complementarity can be determined by examining the cross derivatives of the cost elasticities. If $\frac{\partial}{\partial y_j} (\partial \ln C(y) / \partial \ln y_i) < 0$, an increase in y_j reduces the cost elasticity for y_i ($i \neq j$), indicating cost complementarity among outputs (Weninger, 1998).

An approximate test for economies of scope is $c_k c_l + d_{kl} < 0$ (Murray and White, 1983). If economies of scope exist in a multispecies fishery, then regulating one of the species might increase harvesting costs of the other species. For example, in the case of jointness-in-inputs, many species are harvested by the same gear at the same time, so that it is costly to exclude particular species (Lipton and Strand, 1992).

Product-specific economies of scale and multiproduct economies of scale are the other two components of the multiproduct cost structure. Product-specific economies of scale, $S_i(y)$, measure the change in costs as the quantity of a single product increases, holding constant the other output levels and input prices.

Ray (1982) indicates that the partial scale economy (or product-specific scale economies) may be measured as $S_i(y) = \frac{I}{\partial \ln C(y) / \partial \ln y_i}$. If $S_i(y) > 1$, a proportional increase in y_i leads to a less than proportional increase in C , indicating product-specific economies of scale. On the other hand, Ollinger et al. (2005) measure scale economies by estimating the elasticity of cost with respect to changes in an output,

$e_{C y_i} = \partial \ln C(y) / \partial \ln y_i$. If $e_{C y_i} < 1$, there are economies of scale. Product-specific economies of scale can indicate whether an expansion in the scale of production of individual products is feasible and whether specialized firms producing only a single product are possible (Squires, 1987 II).

Multiproduct economies of scale, $S_M(y)$, measure the change in costs for proportional changes in all outputs and inputs. Following Kim (1987) a measure of scale economies for multiproduct firm is defined as

$$S_M(y) = C(y) / \sum_i y_i C_i(y) = I / \sum_i e_{C y_i} \tag{3.11}$$

where $C_i(y) = \partial C(y) / \partial y_i$ is the marginal cost with respect to the i th output,

and $e_{C_i} = \partial \ln C(y) / \partial \ln y_i$, the cost elasticity of the i th output. If $S_M(y) > 1$, there exists economies of scale, meaning that a proportional increase in all outputs leads to a less than proportional increase in total cost. A measure of multiproduct economies of scale, as found in Cowing and Holtman (1983) and Akridge and Hertel (1986), is calculated using

$S_M(y) = 1 - \sum_i \partial \ln C(y) / \partial \ln y_i$. Multiproduct economies of scale exist if $S_M(y) > 0$.

CHAPTER 4: RESULTS

The translog cost function was first estimated without imposing the theoretical conditions of homogeneity of degree one in input prices and the estimated results are presented in Table 4.1. Overall, this unconstrained model is highly statistically significant (model $F_{(37, 170)} = 83.25$ for a $(Pr.>F) < 0.0001$), and explains a large part of the variation in the data (R-squared = 0.9477). The restrictions of homogeneity of degree one in input prices were tested separately, and five out of seven restrictions came out non-binding (Table 4.2), indicating that the data conformed well to the theoretical conditions of cost function. However, the joint hypothesis test for linear homogeneity in input prices ($\sum_i a_i = 1, \sum_j b_{ij} = 0, \sum_k e_{ik} = 0$) was rejected at 5 percent level of significance, and thus all the theoretical constraints were imposed on the estimation. Imposing the restrictions on the translog cost function parameters ensured that the cost minimizing bundle would not change if all prices were multiplied by the same positive number, a condition that the data used in the estimation did not completely satisfy.

The results of the translog cost function, estimated with symmetry and homogeneity conditions imposed, are reported in Table 4.3. The test of overall model significance (Table 4.4) strongly rejected the null hypothesis that all model coefficients were zero (model F value = 62.86 for a $(Pr.>F) = 0.000$), indicating that the estimated model was significant in describing cost relationships in the grouper fishery. In addition, a large proportion of the variation in the dependent variable (log (total cost)) was explained by the estimated model (R-squared = 0.9361). Of the 38 estimated model parameters, 17 were statistically significant at the 5 percent level of significance, with 4 additional coefficients significant at 10 percent level of significance. Specifically, highly significant variables were input prices (price of fuel, labor and miscellaneous), other species, interactions between input prices, and most of the

Table 4.1. Estimated coefficients and associated statistics of the unrestricted translog cost function.

Variable ^a	Parameter Estimate	Standard Error	T Value	Pr> t
Intercept	-7.65355	39.58096	-0.19	0.847
Closed season (Dummy)	-0.17193	0.15186	-1.13	0.259
Total revenue (Dummy)	0.04647	0.06191	0.75	0.454
Red grouper	-0.83061	0.38897	-2.14	0.034
Gag grouper	0.31766	0.37827	0.84	0.402
Other grouper	0.01427	0.25387	0.06	0.955
Other species	0.03200	0.43978	0.07	0.942
Fuel price	1.01765	14.1265	0.07	0.943
Labor price	0.74854	0.92792	0.81	0.421
Misc. price	3.72490	1.66402	2.24	0.026
(Red grouper) ²	0.03689	0.00562	6.56	0.000
Red grouper*gag	-0.00032	0.00311	-0.10	0.918
Red grouper*Other grouper	-0.00902	0.00235	-3.83	0.000
Red grouper*Other species	-0.02368	0.00479	-4.94	0.000
(Gag grouper) ²	0.01001	0.00611	1.64	0.103
Gag grouper*Other grouper	-0.00085	0.00268	-0.32	0.752
Gag grouper*Other species	-0.00055	0.00304	-0.18	0.858
(Other grouper) ²	0.02287	0.00392	5.83	0.000
Other grouper*Other species	-0.00845	0.00260	-3.25	0.001
(Other species) ²	0.01705	0.00515	3.31	0.001
(Fuel price) ²	0.00239	2.55691	0.00	0.999
Fuel price*Labor Price	-0.04647	0.17059	-0.27	0.786
Fuel price*Misc. price	-0.40928	0.31022	-1.32	0.189
(Misc. Price) ²	-0.09657	0.04942	-1.95	0.052
Misc. Price*Labor price	-0.11570	0.02210	-5.23	0.000
(Labor price) ²	0.06464	0.02461	2.63	0.009
Red grouper*Fuel price	0.22792	0.06989	3.26	0.001
Red grouper*Misc. price	-0.03653	0.01636	-2.23	0.027
Red grouper*Labor price	0.00217	0.00929	0.23	0.815
Gag grouper*Fuel price	-0.06870	0.06884	-1.00	0.320
Gag grouper*Misc. price	0.01078	0.01261	0.86	0.394
Gag grouper*Labor price	0.00020	0.00862	0.02	0.981
Other grouper*Fuel price	0.02761	0.04612	0.60	0.550
Other grouper*Misc. price	-0.00188	0.00959	-0.20	0.845
Other grouper*Labor price	-0.00668	0.00489	-1.37	0.174
Other species*Fuel price	0.02594	0.07446	0.35	0.728
Other species*Misc. Price	0.00294	0.01253	0.23	0.815
Other species*Labor price	0.00422	0.01010	0.42	0.677
Model F Value = 83.25 (Pr>F) = 0.0000			R-Square=0.9477	

^a All model variables were in natural logs except the dummy variables for closed season and vessel total revenue.

Table 4.2. Results of the hypothesis tests of linear homogeneity.

Hypothesis	Degrees of freedom		F	P value	Reject H0 (Yes/No)
	Numerator	Denominator			
$\sum_i a_i = 1$	1	170	0.09	0.761	No
$\sum_j b_{\text{fuel},j} = 0$	1	170	0.03	0.863	No
$\sum_j b_{\text{labor},j} = 0$	1	170	0.31	0.578	No
$\sum_j b_{\text{misc},j} = 0$	1	170	3.96	0.048	Yes
$\sum_k e_{\text{fuel},k} = 0$	1	170	4.07	0.045	Yes
$\sum_k e_{\text{misc},k} = 0$	1	170	2.24	0.136	No
$\sum_k e_{\text{labor},k} = 0$	1	170	0.00	0.995	No
Linear homogeneity in prices	7	170	5.36	0.000	Yes

interaction terms associated with red grouper and other grouper. The negative sign associated with the output interaction coefficients suggests that a cost reduction might be possible if different species are harvested at the same time. In the translog cost function, however, the many interaction terms make the individual estimated coefficients difficult to interpret directly. As an alternative, these coefficients can be used to calculate own- and cross-price elasticities of input demand, cost elasticities, and economies of scope and scale.

4.1 Hypothesis Tests

The results of the hypothesis tests for nonjointness in inputs and input-output separability are reported in Table 4.4. Nonjointness in inputs and input-output separability for all species as a group were tested and also rejected at 5 percent level of significance. The econometric restriction needed to test for nonjointness in inputs for the translog cost model is $d_{kl} + c_k c_l = 0$, for every $k \neq l$. The rejection of nonjointness in inputs suggests that there is interdependence among species

Table 4.3. Estimated coefficients and associated statistics of the restricted translog cost function.

Variable ^a	Parameter Estimate	Standard Error	T Value	Pr> t
Intercept	-0.19253	0.19164	-1.00	0.316
Closed season (Dummy)	0.03092	0.14733	0.21	0.834
Total revenue (Dummy)	0.01671	0.06539	0.26	0.799
Red grouper	-0.27813	0.36541	-0.76	0.448
Gag grouper	0.17174	0.37157	0.46	0.645
Other grouper	-0.34885	0.23591	-1.48	0.141
Other species	0.95954	0.26693	3.59	0.000
Fuel price	0.37944	0.05153	7.36	0.000
Labor price	0.26758	0.03368	7.94	0.000
Misc. price	0.35297	0.04205	8.39	0.000
(Red grouper) ²	0.03778	0.00603	6.26	0.000
Red grouper*gag	-0.00201	0.00322	-0.62	0.534
Red grouper*Other grouper	-0.00856	0.00249	-3.44	0.001
Red grouper*Other species	-0.01873	0.00489	-3.83	0.000
(Gag grouper) ²	0.00879	0.00649	1.35	0.177
Gag grouper*Other grouper	-0.00069	0.00275	-0.25	0.804
Gag grouper*Other species	-0.00269	0.00307	-0.87	0.383
(Other grouper) ²	0.02327	0.00415	5.60	0.000
Other grouper*Other species	-0.01145	0.00263	-4.35	0.000
(Other species) ²	0.01782	0.00476	3.74	0.000
(Fuel price) ²	-0.29365	0.06252	-4.70	0.000
Fuel price*Labor Price	0.06315	0.02877	2.19	0.030
Fuel price*Misc. price	0.23049	0.05500	4.19	0.000
(Misc. Price) ²	-0.09740	0.05000	-1.95	0.053
Misc. Price*Labor price	-0.13309	0.02156	-6.17	0.000
(Labor price) ²	0.06993	0.02412	2.90	0.004
Red grouper*Fuel price	0.11354	0.06516	1.74	0.083
Red grouper*Misc. price	-0.03319	0.01381	-2.40	0.017
Red grouper*Labor price	0.00519	0.00943	0.55	0.582
Gag grouper*Fuel price	-0.04864	0.06786	-0.72	0.474
Gag grouper*Misc. price	0.02246	0.01335	1.68	0.094
Gag grouper*Labor price	-0.00189	0.00899	-0.21	0.834
Other grouper*Fuel price	0.08365	0.04352	1.92	0.056
Other grouper*Misc. price	0.00804	0.00963	0.83	0.405
Other grouper*Labor price	-0.00218	0.00490	-0.45	0.657
Other species*Fuel price	-0.14857	0.04510	-3.29	0.001
Other species*Misc. Price	0.00269	0.01071	0.25	0.802
Other species*Labor price	-0.00112	0.00635	-0.18	0.860
Model F Value = 62.86			R-Square=0.9361	
(Pr>F) = 0.0000				

^a All model variables were in natural logs except the dummy variables for closed season and vessel total revenue.

landed by vessels, implying that the quantity of landings of a particular species is dependent, at least in part, on the inputs used in harvesting other species. Therefore, individual regulation of species will affect the harvest of the other species that are typically landed by these vessels. Rejecting nonjointness in inputs implies that Florida grouper fishery is characterized by jointness in inputs. The presence of jointness-in-inputs in the Florida grouper fishery may have arisen because many species are harvested by the same gear at the same time, implying that imposed regulations will probably alter the multispecies composition of harvest.

The test for input-output separability (i.e., that there is no interaction between inputs and outputs) within the translog cost function framework examines whether $e_{ik} = 0$, for every $i \neq k$. The rejection of input-output separability in this study indicates that there are interactions between inputs and outputs, and that input and output compositions are not independently determined. Moreover, rejecting input-output separability implies that input regulation might, for example, alter harvest composition. For the grouper fishery, the rejection of input-output separability and nonjointness in inputs together suggests that technical interdependence among species and joint production will make it difficult to regulate the fishery by focusing on individual species, and that attempts to do so will likely have significant spillover effects on other species in the fishery.

Table 4.4. Results of hypothesis tests.

Hypothesis	Degrees of freedom		F	P value	Reject H0 (Yes/No)
	Numerator	Denominator			
All coefficients zero	30	177	62.86	0.000	Yes
Nonjointness in inputs	6	177	6.04	0.000	Yes
Input - output separability	9	177	2.76	0.005	Yes

4.2 Elasticities of Input Demand

Although the parameter estimates from a translog function may be difficult to interpret because of the number of interactions, a summary description of the multiproduct technology can be calculated from the estimated parameters and cost shares computed at mean values of inputs (see equation 3.11). Table 4.5 reports the calculated own- and cross-price elasticities of input demand. The theory of cost and production requires that the own-price elasticities of input demand be negative. As expected, own-price input demand elasticities (main diagonal in Table 4.5) were all negative, indicating that an increase in an input price leads to a decrease in the demand for that input. Of the three inputs, the own-price elasticity of fuel was highly elastic, or price responsive, at -2.7832 . It indicates that for one percent increase in the price of fuel, quantity demanded will decrease by 2.78 percent. The least price responsive of the three inputs was labor, whose own-price elasticity was calculated to be -0.3656 , suggesting that if wages go up by 10 percent, employment falls by less than 4 percent. Labor quality might be a reason why labor is quite inelastic, since, in general, own-price elasticity of labor demand decreases with the skill level. Waters (1996) portrayed a Gulf reef fish fisherman as having an average age of 47 years, more than 12 years of formal education, and an average of 19 years fishing experience. Another reason why labor might be inelastic is that labor is a lumpy input. Given that a vessel's crew typically consists of only 2-4 individuals, it is difficult to make adjustments in labor in response to changes in wages if there is to be any fishing at all. The cross-price elasticities (off-diagonal cells in Table 4.5) were all positive, indicating substitution possibilities between input pairs. Fuel is a substitute for both labor and miscellaneous. However, the cross-price elasticity of fuel with respect to miscellaneous was found to be more elastic (1.87), indicating that one percent increase in the price of miscellaneous leads to 1.87 percent increase in the quantity demanded of fuel. On the other hand, the elasticities of labor with respect to fuel and

miscellaneous were calculated to be quite inelastic, indicating that labor is an imperfect substitute for both fuel and miscellaneous.

Table 4.5. Price elasticities of input demand.

	Fuel	Labor	Miscellaneous
Fuel	-2.7832	0.9084	1.8748
Labor	0.2800	-0.3656	0.0856
Miscellaneous	0.7992	0.1183	-0.9176

4.3 Multiproduct Cost Structure

The estimated parameters of the translog cost function can be used to determine how costs might increase given a proportional increase in outputs (economies of scale), as well as the cost savings firms might realize by producing several outputs jointly rather than specializing in the production of one (economies of scope). In the translog model, the necessary parameter condition for there to be economies of scope is $c_k c_l + d_{kl} < 0$. This nonlinear restriction cannot be directly tested in this linear model. Economies of scope can, however, be calculated from the estimated model parameters. As can be seen from Table 4.6, substantial economies of scope were found between red grouper and other species, and between other grouper and other species. This suggests that red grouper and other species, as well as other grouper and other species, enjoy cost complementarities or jointness in their production, implying that an increase in the harvest of one leads to a decline in the marginal cost of harvesting the other. Evidence of economies of scope was also found between red grouper and gag, and between gag and other grouper. Surprisingly, there were no economies of scope, or cost complementarity, between red

grouper and other grouper or between gag and other species. Red grouper is a pivotal species in the fishery because vessels enjoy cost savings by harvesting red grouper with most of the other species. Therefore, regulatory measures targeting red grouper may distort the complementarities of jointly harvested species, leading to increased harvesting costs.

Table 4.6. Economies of scope: Parameter estimates.

	$c_k c_l + d_{kl}$
Red Grouper and Gag	-0.04977
Red Grouper and Other Grouper	0.08846
Red Grouper and Other Species	-0.28560
Gag an Other Grouper	-0.06059
Gag an Other Species	0.16210
Other Grouper and Other Species	-0.34617

Product specific economies of scale were measured by calculating the cost elasticity with respect to an output: $e_{C y_i} = \partial \ln C(y) / \partial \ln y_i$. Taking the derivative of the estimated translog cost function with respect to the log of each output, cost elasticities were calculated by holding constant all variables at mean levels (Table 4.7). In all cases we measured an inelastic response of cost to changes in harvest levels, indicating product specific economies of scale for each species. In particular, cost elasticities for gag and other grouper were very small, meaning that vessels can lower unit costs by expanding the scale of production for these species. For example, a 1 percent increase in gag (other grouper) harvest results in 0.031 (0.094) percent increase in total cost. Even though product specific economies of scale are present in the grouper fishery, the development of firms specialized in harvesting a single species is unlikely because of the previously mentioned technical advantages vessels have in jointly harvesting several species.

Table 4.7. Cost elasticities.

Red Grouper	0.23675
Gag	0.03181
Other Grouper	0.09429
Other Species	0.12360

Multiproduct economies of scale, calculated as the reciprocal of the sum of cost elasticities ($1/\sum_i e_{Cyi}$), measures the change in cost for proportional changes in all outputs. The calculated value (2.055) indicates that increasing multiproduct economies of scale are present in grouper fishery, meaning that vessels enjoy cost advantages from harvesting more fish in fixed proportions, assuming that input prices and resource abundance are constant. The presence of increasing economies of scale is not surprising given that, in the presence of output regulations, fishing vessels should be trying to minimize their production costs by operating in the area of increasing returns to scale.

CHAPTER 5: CONCLUSIONS

The main goal of this study was to analyze the technical and economic interrelationships among Florida grouper longline vessels by estimating a multiproduct cost function. The hypothesis of nonjointness-in-inputs was rejected, indicating that grouper fishery is characterized by a joint production process. The existence of jointness-in-inputs suggests that, to some degree, all inputs are required to produce all outputs. Thus, from a fishery management perspective, individual regulation of species will affect the harvest of the other species. Input-output separability was also tested and rejected, indicating that there are interactions between inputs and outputs, and that input and output compositions are not independently determined. For the grouper fishery, jointness-in-inputs and non-separability between inputs and outputs suggests that resource management should be based on multiproduct production theory, and that explicit recognition of the economic interactions among species should be incorporated in any regulatory process.

A description of the multiproduct technology is provided by the own-price and cross-price elasticities of the input demand functions. The cross-price elasticities are of direct use in policy formulation, since they reveal relationships among factors that make up fishing effort. They show substitution between input pairs in the grouper fishery, implying that imposed regulation on the single input will be compensated for by increases in other inputs. Under this situation, restrictions placed on overall fishing effort might be a better alternative to regulating individual inputs. However, the multidimensionality of fishing effort makes it difficult to manage, and a reduction in fishing effort is generally possible only if all dimensions of fishing effort are simultaneously restricted (Pearse and Wilen, 1979).

Besides testing hypothesis of nonjointness-in-inputs and input-output separability and deriving input demand elasticities, the multiproduct cost structure (economies of scope and scale) of the grouper fishery was also examined for technical and economic interrelationships. The results showed important economies of scope, especially between red grouper and most of the other species in the grouper fishery, product specific economies of scale and multiproduct economies of scale. The strong cost incentives to harvesting red grouper because of economies of scope and product specific economies of scale make red grouper stock vulnerable to overfishing. However, output regulation on red grouper may distort the economies of scope, leading to cost inefficiency in the fishery and generating spillover effects on jointly harvested species.

Management strategies implemented in grouper fishery have generally not taken into account multispecies interactions and ecosystem effects. In a multispecies context, interactions between species need to be explicitly considered when deciding how to best manage harvesting strategies, and these interactions may be dependent on food-web interactions, changes in trophic structure, life history strategies, and bycatch, all of which can change ecosystem productivity (Committee on Ecosystem Effects of Fishing, 2006).

The technical and economic interrelationships empirically measured in this study indicate that ecosystem-based fishery management approaches should be employed in the grouper fishery to account for the multispecies interactions and the fishery's potential overall impact on the broader ecosystem. A management system with secure access privileges could be an alternative to the insecure access privileges currently used in grouper fishery. The key feature of this alternative system would be the creation and allocation of harvest access privileges that eliminates race-to-fish incentives. This market-based approach would, in theory, simultaneously decentralize management and encourage a change in fishing behavior from catch maximizing to value

maximizing. In addition fishing is temporally slowed, redundant inputs are eliminated, and new innovations in the market are potentially stimulated, thereby leading to an increase in the value of harvest (Committee on Ecosystem Effects of Fishing, 2006).

Of the management instruments that convey secure access privileges, individual fishing quotas (IFQ), expressed as a percentage of total allowable catch (TAC), have been proposed for the grouper fishery. One of the main benefits expected from the implementation of an IFQ program is the mitigation of overcapacity problems. Marginal and less efficient operations are expected to exit the fishery as IFQ shares are traded. Moreover, IFQ programs are expected to decrease fishermen operating cost through increased efficiency (optimal trip length and input selection) and to impact overall market conditions by eliminating seasonal product gluts and ensuring a steadier supply of fresh fish. IFQs are also expected to foster resource conservation by providing long term incentives to program participants. As this study showed, however, there are technical economic linkages not only among grouper species, but also between grouper and other reef fish species. What is not clear is how an IFQ program might be devised to simultaneously address all of the species in the harvesting complex. Additional research is needed to understand how IFQs can be used to address more inclusive ecosystem goals associated with fishery management and how they affect incentives in a multispecies setting. In addition, integrating ecological, social, and economic values into an ecosystem-based fishery management requires an enhanced understanding of both fishermen and the behavior of management institutions.

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