This study provides an empirical test of the Bockstael-McConnell (1980) household production function (HPF) framework for evaluating wildlife recreation. This is perhaps the first study in which both taste and technology parameters have been estimated with a theoretical model specification. The results suggest that for steelhead sport fishing in Oregon, the HPF methodology provides a promising recreation valuation technique. Also, some theoretical results are presented which extend Barnett's (1977) formulation of the HPF model to nonconstant returns to scale technologies. Conditions are identified under which it is possible to estimate structural taste and technology parameters.

There is also a discussion on welfare analysis in the HPF framework. It is shown that welfare changes can be evaluated in either the input or the commodity markets. Different techniques for calculating two exact welfare measures — compensating and equivalent variations — are presented.

In the HPF model estimated in this application, anglers are viewed as using market goods and their own time as inputs in the
production of fishing experiences from which they derive utility. The two utility-yielding components of a fishing experience are defined as the fishing trip itself and the per trip fish catch. The major difference between this study and most previous studies of angler demand is that fish catch is treated here as an endogenous rather than an exogenous variable. That is, the number of sport-caught fish is found to be influenced by the quantities of inputs used by anglers.

An advantage of the HPF framework is that it provides estimates of implicit or hedonic prices for commodities that are not priced on the market. Implicit prices, which are dependent on input prices and technology parameters, may also depend on the quantities of commodities consumed. Empirically specified implicit price functions are presented for both a fishing trip and a sport-caught fish. The results suggest that these implicit prices are not dependent on commodity quantities.

The value of a fishing experience is defined in this study as the benefits derived from taking the trip and from catching fish. Estimates of the mean value of a fishing experience are presented in terms of both compensating and equivalent variations. These empirical results may be useful for determining values of fishing sites in Oregon.

As is suggested by McConnell (1979) and Bockstael and McConnell (1980), the HPF framework can be used to determine the effects of exogenous quality changes on recreation benefits. In this study selected stream quality variables are included in the fish catch
production function. Methods are shown for evaluating the welfare effects of changes in these exogenous quality variables. A model in which one or more quality indices are included could be useful for analyzing welfare effects on anglers of forest management plans or fishery enhancement projects.

A problem which arose in this work is that the survey data used for the application was initially gathered for the purpose of applying a standard travel cost model. This led to some potentially biased parameter estimates for the HPF model. In spite of some data deficiencies, the results are theoretically plausible; but future research should be directed toward obtaining results for the HPF model which are not subject to these empirical limitations. Also, these results suggest that more research is needed to develop habitat quality indices. Future research efforts should also be directed toward developing multiple-site recreation valuation models. With such models, production relationships can vary across sites and substitution relationships among sites can be examined.
Measuring Benefits of Outdoor Recreation Services: An Application of the Household Production Function Approach to the Oregon Steelhead Sport Fishery

by

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Public concern is increasing about the tradeoffs between timber harvesting and fish habitat in the Pacific Northwest. Anadromous salmonids produced in the forest streams of the Pacific slope support extensive recreational and commercial fisheries, but the perpetuation of valuable salmonid fisheries is heavily dependent on future management activities on forest watersheds (Kunkel and Janik, 1976). Warm-water fish, lake fish, estuarine fish, and shell fish are also potentially affected by forest management practicies. Although previous research has provided well-documented evidence of logging-induced changes in the physical quality of Pacific coast streams, the complexity of river and estuarine ecosystems has seemingly slowed research on how environmental impacts of logging activities affect the productivity and value of fisheries.¹ What we seem to be lacking is a framework for determining the impacts of forest management plans and policies on recreational and commercial fishery values.

The development of such a framework calls for multidisciplinary research efforts, as the system that relates forest management practices to fishery values encompasses interactions among hydrologic, biologic, and economic components. This study primarily focuses
on the subsystem that relates water quality indicators to sport
fishery values; however, we will give some attention to how a model of
that subsystem might be integrated with a forest planning model and
used in policy analysis. Also, data needs for extending the model
will be identified.

The primary purpose of this study is to examine the relations-
ships between site quality and recreation use and benefits by utiliz-
ing the household production function (HPF) approach. In principle,
the HPF methodology is capable of evaluating the effects on wildlife
recreation of policy actions that influence wildlife stocks and
habitats. That is, the framework allows for the direct and indirect
influence of publicly provided inputs (to wildlife recreation) on
recreation demand. Public inputs might include variables such as
wildlife stocks and indicators of the physical and biological quality
of wildlife habitat. If these inputs can be related to policy-
controlled variables (such as acres of wildlife habitat or acres
of timber harvested), then the HPF approach offers a theoretically-
based method for linking policy actions to recreation use and
benefits.

In this study the HPF approach is empirically applied to data
on steelhead sport fishing activities at a selected group of Oregon
rivers. The empirically specified HPF model provides estimates of
benefits rendered to steelhead anglers and values of sport-caught
fish. Previous demand studies have typically expressed the benefits
gained by recreationists on a per trip or visitor day basis. In
many cases, however, resource allocation policies and management
plans directly influence the quality of the recreation site rather than the quantity of trips or users. This study is in part an attempt to provide a framework which is capable of linking quality characteristics of a recreation site to measures of recreation benefits, and thus estimate the benefits of quality changes.

A Critique of Alternative Approaches to Evaluating the Quality of Wildlife Recreation Experiences

There are at least three approaches which use site visitation data to estimate the influence of quality on wildlife recreation. Three alternative approaches are the HPF, the travel cost, and the hedonic price approaches. They are similar in that they derive benefit estimates from observed behavior rather than from responses to hypothetical questions (the contingent valuation technique), and they are closely related in that the HPF framework provides theoretical foundations for both the travel cost and hedonic price techniques (McConnell, 1979, and Meullbauer, 1974).

The HPF approach to modeling household (or individual) decision problems is based on the concept of viewing the household (or individual) as both a producer and a consumer of goods not sold on the market but reserved for household use, such as wildlife recreation experiences. For example, this approach perceives the angler as purchasing market goods and combining them with public goods to produce fishing experiences that give rise to utility. In any recreation demand study one of the specification problems is to define the
components of a recreational experience that can be included as arguments of the recreationist's direct utility function. Previous recreation demand studies have frequently identified the number of trips (or days) as being the sole utility-yielding decision variable associated with a recreational experience.

Comparison of the Travel Cost and HPF Approaches

The travel cost approach, which is the recreation valuation technique most widely used for empirical analysis, generally specifies the demand for trips or trips per capita as a function of constant travel costs per trip and other exogenous variables (such as income). Travel costs are used as a proxy for the "price" per visit to a recreation site. Because round-trip travel is complementary to the recreational experience, the cost of transportation can serve as a surrogate measure of the site's use value in lieu of a market price (Bowes and Loomis, 1980).

A large body of research has focused on designing and refining travel cost models. Most of this research has been directed toward improving model specifications, choosing among alternative functional forms, and extending the framework to a multiple site context. Numerous studies have contributed to obtaining a more reasonable estimate of the travel cost coefficient in the interest of obtaining a better estimate of recreation benefits. [See, for example, Brown (1976), Brown and Nawas (1973), Burt and Brewer (1971), Cesario and Knesch (1970), Dwyer, et. al. (1977), Gum and Martin (1975), McConnell (1975), and Strong (1983)].
In some studies researchers have attempted to incorporate quality variables into the demand model in order to identify relationships between site quality characteristics and recreation use and benefits. One of the questions yet to be resolved is how to relate site visitation to site quality. That is, what sort of model specification should be used (Freeman, 1979)? A related question is whether the demand model should include objective quality measures or only those that recreationists perceive. Freeman argues that quality variables should be consistent with a priori conceptions of what recreationists think are important. This notion would suggest that quality variables (such as congestion and scenic attributes) that are perceived by recreationists and that influence participation rates are appropriate exogenous variables for inclusion in recreation demand equations. In general, the underlying weakly separable utility function associated with such a demand model for a single site would be specified as \( U = U(z_1(q_1)) \), where \( z_1 \) is a measure of recreational participation at a site, and \( q_1 \) is a vector of perceived (subjective) site quality characteristics.\(^7\) A change in \( q_1 \) indirectly influences utility through changes in the demand for \( z_1 \).

Maler (1974) states that as long as \( z_1 \) and \( q_1 \) are weak complements, one can use the empirically estimated demand curve for \( z_1 \) to estimate the demand price (i.e., marginal value) for \( q_1 \) without solving for the underlying utility function.\(^8\) Weak complementarity occurs if, when the demand for \( z_1 \) is zero, the marginal utility of \( q_1 \)
(i.e., $\partial U/\partial q_1$) is zero. Given the assumption of weak complementarity, the benefits to recreationists of a change in $q_1$ from $q_1^0$ to $q_1^1$ can be determined by measuring the area above the price line and between the two demand curves for $z_1$ associated with $q_1^0$ and $q_1^1$. The benefits of a quality improvement are graphically represented by area BCDE (area ADE less area ACB) in Figure 1. If the weak complementarity condition did not hold, then this area would understate the effect of a change in $q_1$ (Freeman, 1979). What one needs for utilizing this approach are data for estimating a demand equation for $z_1$ in which $q_1$ is an explanatory variable.

Figure 1. Benefits of a Quality Improvement Measured in a Weakly Complementary Commodity Market.
With this type of demand model, if one wants to describe the link between objective quality measures and recreation benefits, one must be able to relate the perceived quality variables in $q_1$ to objective quality indicators. Freeman (1979) reviews three studies by David (1971), Dornbusch (1975), and Binkley and Hanemann (1975) that illustrate some of the difficulties and complexities of relating perceived water quality measures to both objective measures and to recreationists' behavior.

[Freeman concludes that] individuals' perceptions of water quality may sometimes be difficult to reconcile with objective water quality indicators [and] that the ability of perceptions of water quality to explain recreationists' choices among alternative sites has not been proven as yet. [Freeman (1979), p. 219].

Thus, there may be some problems associated with trying to examine the effects of policy-induced quality changes on recreation benefits using recreation demand curves conditioned on perceived (subjective) quality measures, unless relationships between policy variables and subjective quality measures can be identified.

Intuition would suggest that an angler's decisions regarding choices among alternative fishing sites and numbers of visits to each site would be influenced by expected catch rates in addition to aesthetic factors. A catch rate variable has the advantages of being one that is expressed in quantitative terms, is perceived by anglers, and, given the availability of data, can be linked to some policy variables (such as fish stocks, hatchery releases, and physical and biological measures of water quality). Since data on expected fish catch are usually not readily available, one might be tempted to use
the angler's reported catch as a proxy for expected catch in the
ger demand equation.

In two different applications of the travel cost method to
sport fishing activities, Stevens (1966) and McConnell (1979) used
reported catch rates to represent the quality of fishing experiences.
Because of data limitations, Stevens did not actually use a catch
rate variable in the demand model; but he did examine relationships
between angler effort (time) and catch rates to determine the per-
centage change in effort for a percentage change in success rates.
This unit-free measure of angler responses to changes in catch rates
is referred to as the "elasticity of success". Estimates of long-run
(yearly) elasticities of success were used to determine magnitudes
of shifts in angler demand curves caused by changes in catch rates
[Stoevener, et al. (1972)]. The areas between angler demand curves
were then used to estimate the benefits of changes in catch rates.

McConnell (1979), on the other hand, included a catch per trip
variable directly in the travel cost demand equation for fishing
trips. Adding a catch rate variable to the demand equation requires
the assumption that an angler's catch rate is independent of the num-
ber of fishing trips taken by the angler. Brown and Sorhus (1981)
identify two problems associated with this approach of using reported
fish catch as a proxy for expected catch in the demand model. First,
there is a problem of possible inconsistencies between reported and
expected numbers of fish caught. Second, some biases may be intro-
duced into all of the coefficients of the model by a correlation
between the error term of the estimated demand equation and the fish
catch variable. This problem would result from a correlation between the error of measurement in the dependent variable, fishing trips or days, and the fish catch variable. Thus, the validity of incorporating the angler's reported catch rate into the model by treating it as an exogenous variable is questionable, unless a procedure is used to correct for possible biases. One way to remove the biases is through the use of an instrumental variable (Johnston, 1972).

Brown, Singh, and Castle (1964) used this type of approach to examine the effect of fishing success expectations on the demand for fishing days in a simultaneous equations framework. They treated zonal fish catch per capita as an endogenous variable along with angler days per capita and average variable costs per day by zone. The results indicated a positive intercorrelation between fish catch per capita and angler days per capita, suggesting that the two variables are mutually dependent. The "price" or variable cost per day was specified as a function of the number of days per capita and other explanatory variables; but the number of angler days per capita was found to have no significant explanatory power. This result provides some support for the assumption of a constant "price" per day or trip that is generally made in applications of the travel cost method. Daily fish catch per capita for each zone was specified as a function of the estimated number of angler days per capita and of a set of exogenous variables. The fact that fish catch per capita was found to be significantly influenced by the number of trips per capita suggests that the fish catch variable should be treated as an endogenous rather than an exogenous quality variable. The
notion of an endogenous quality variable, such as fish catch per capita, is explored further in the following discussion on the HPF approach.

McConnell (1979) compared the travel cost approach to the HPF approach in his analysis of marine recreational fishing. He examined the implications of each approach for relationships between wildlife recreation and both endogenous and exogenous quality factors. In particular, McConnell used both the travel cost and HPF approaches to model the relationship between fishing trips and fish caught per trip. In that context, the major difference between the two approaches is that the travel cost approach assumes that anglers cannot vary their individual catch rates, whereas the HPF approach is based on the idea that anglers can influence their catch rates by employing various combinations of fishing inputs. That is, in the HPF framework the angler's catch rate can be treated as if it were an endogenous quality variable for which the angler has an effective demand and supply. Recall that the HPF approach views the angler as both a producer and a consumer of nonpriced recreational experiences.

In his version of the HPF framework, McConnell defines the number of annual fishing trips \( z_1 \) and the number of fish caught per trip \( z_2 \) as two utility-yielding commodities. In theory, the demand function for each commodity should be conditioned on implicit commodity prices and available income. The term "implicit" is used here, because the commodities are final consumption goods for which market prices do not exist. Implicit supply prices are determined on the basis of minimum amounts households (or individuals) must
spend to produce commodities. In more technical terms the implicit supply price of a commodity is equal to its marginal cost, which is defined for a given level of production as the minimum cost of producing the last commodity unit. Equilibrium commodity prices and quantities are determined at the points of intersection between marginal cost (or commodity supply) curves and commodity demand curves that are conditioned on implicit commodity prices.

In the HPF framework the marginal cost of a commodity can be an increasing or decreasing function of commodity quantities. If the value of a marginal cost function is not dependent on the quantity of the commodity produced, however, then the marginal cost curve is perfectly elastic, and the household faces a constant implicit commodity price. McConnell (1979) notes that if the marginal cost of a fishing trip is not dependent on the number of trips taken, and if fish catch rates are not influenced by the quantities of inputs used by the angler, then the HPF model collapses to the travel cost model in which per trip travel costs are constant and catch rates are exogenously determined. The travel cost model is thus simply a special case of the HPF framework.

The travel cost method requires the assumption of weak complementarity between catch rates and number of fishing days or trips in order to estimate the benefits of changes in catch rates by measuring the area between two angler demand curves. That is, the underlying subutility function must be specified in a form such that

\[ \frac{\partial U(z_1(z_2))}{\partial z_2} \bigg|_{z_1 = 0} = 0 \]
where \( z_2 \) denotes the catch rate. This condition implies that for anglers that have not visited a specific site, a change in expected catch rates at that site would not influence their levels of utility.

In contrast, the underlying subutility function associated with the HPF model for one site is of the form \( U = U(z_1, z_2) \). Since \( z_2 \) is an argument of the utility function, the benefits of changes in the catch rate or its implicit price can be directly measured in the market for \( z_2 \). Any exogenous, but perceived, quality variables which influence the demand for \( z_1 \) or \( z_2 \) can be implicit arguments of this utility function. For example, consider a utility function specified as \( U = U(z_1(q_1), z_2) \), where \( q_1 \) represents exogenous quality variables that influence the demand for \( z_1 \). For estimating the benefits of changes in \( q_1 \), the weak complementarity condition must be satisfied for the relationship between \( z_1 \) and \( q_1 \).

One of the major strengths of the HPF approach is that objective quality characteristics can be included in the model as technology parameters. For example, objective physical and biological indicators of water quality can be treated as public inputs in the production process for fish catch rates. As was pointed out by Bockstael and McConnell (1980), the HPF approach permits inclusion of policy-controlled variables as exogenous determinants of the number of fish an angler can catch with a given bundle of market goods. Bockstael and McConnell (1980) show how this approach can be used to determine the effects of policy actions on fish catch, fishing trips, and recreation benefits. Horst (1978) demonstrated how this technique
can be used to obtain marginal values for objective quality measures that serve as public inputs in the household production process.

**Comparison of the Hedonic Price and HPF Approaches**

Like the HPF approach, the hedonic price technique has been used to determine marginal values (or implicit prices) for quality characteristics. The hedonic price technique is applicable in situations where a consumer has some control over his consumption of utility-yielding quality characteristics through the selection of goods in which the quality characteristics are contained (Freeman, 1979). It is based on the idea that information on implicit prices and quantities of quality characteristics are embedded in market prices of the goods. For a class of closely related goods which differ only in regard to their quality characteristics, differences in market prices are assumed to reflect differences in quality. "The vital principle of the hedonic technique is that the added expenditures voluntarily made for an enhanced bundle of characteristics reveal the value of the extra characteristics." [Brown and Mendelsohn (1981), p. 3].

The hedonic price technique was initially developed by Griliches (1971) and others for the purpose of estimating values (price indexes) for quality changes in consumer goods, with knowledge of neither the technological relationships between goods and characteristics nor the underlying utility function defined on characteristics. Meullbauer (1974) claims that such empirical approximations to true price indexes for quality changes make sense only if the technology relating goods to characteristics is constant returns to scale.
[Meullbauer relates] the hedonic technique to a theoretical constant utility price index when quality changes are taken into account. [He] shows that the conditions under which precise statements can be made about the relationship of the usual empirical approximations to such a theoretical index are rather restrictive. [Meullbauer (1974), p. 977].

Given constant returns to scale in production, the two restrictive conditions to which Meullbauer was referring are a nonjoint production function and a homothetic utility function. If either or both of these conditions are satisfied, then it is valid to use the hedonic technique to approximate true constant utility price indexes.

By the hedonic technique described by Freeman (1979) and used by Brown and Mendelsohn (1981), the first step toward determining implicit prices for quality characteristics is to regress the price of a good against the quantities of characteristics contained in one unit of the good. Let \( x \) denote a good class of \( n \) elements, and let \( x_j \) denote the \( j \)th element of \( x \). Then, the price of \( x_j \) is specified as a function of the quality characteristics of \( x_j \):

\[
P_{x_j} = p_x(z_{1j}, \ldots, z_{mj})
\]

where \( z_{ij} \) is the amount of the \( i \)th characteristic contained in one unit of \( x_j \). The function \( p_x(z_1, \ldots, z_m) \) is called the hedonic price function, and it is estimated with \( n \) observations on the prices and characteristics of the \( n \) different elements of \( x \).

In the second step of the hedonic price technique, the implicit price equation for a characteristic is found by taking the partial derivative of the hedonic price function with respect to that characteristic. That is

\[
\partial p_x / \partial z_i = p_{z_i}(z)
\]
where \( z = (z_1, \ldots, z_m) \). If \( p_x \) is linear in \( z \), then implicit prices are constants. The value of the implicit price equation for each \( z_i \) gives the increase in expenditures on \( x \) necessary to consume one more unit of \( z_i \), *ceteris paribus*.

The hedonic price technique can be used to estimate demand equations for quality characteristics as long as hedonic price functions are nonlinear in \( z \).\(^{11}\) Demand equations for characteristics are obtained by regressing observed quantities of \( z \) against the estimated implicit prices \( (p_z) \), incomes of consumers, and other exogenous demand determinents. According to Freeman (1979), the implicit prices can be treated as exogenous to consumers as long as supply curves for goods \( (x) \) are perfectly elastic at the observed prices.

Brown and Mendelsohn (1981) applied their hedonic travel cost method to construct demand curves for recreation-related characteristics of steelhead fishing sites in Washington. In their model the good class was composed of fishing trips to alternative sites. As in the travel cost model, travel costs per trip were used as a surrogate for "price" per visit. For any given origin, travel costs per trip to alternative sites were regressed against site quality characteristics to obtain the hedonic price function. The underlying assumption is that if an individual is willing to pay the additional cost of traveling to a more distant site, then the additional cost reflects the value placed on added characteristics. Brown and Mendelsohn estimated implicit prices and demand equations for scenery, congestion, and fish density. Although the implicit prices.
did not depend on characteristic quantities, they did vary across observations (i.e., origins); thus, demand equations could be estimated.

If quantities supplied of characteristics are also functions of implicit prices, then it is appropriate to use a simultaneous equations approach (Freeman, 1979). Rosen (1974) uses the hedonic price technique to develop a market equilibrium model under purely competitive conditions, in which implicit prices guide both consumer and producer decisions regarding quantities of characteristics bought and sold. Equilibrium implicit prices and quantities are defined at the intersections of characteristic supply and demand curves. Rosen notes that observed hedonic price functions describe relationships between equilibrium prices and quantities; they are joint-envelope functions that identify neither the underlying demand nor supply relationships. This is what is commonly referred to as an identification problem. Rosen presents a method that can be used to estimate the underlying structures of consumer preferences and producer technologies.

Similarly, the HPF methodology can be used to estimate underlying household preferences and technologies. With the HPF approach the procedure for obtaining implicit price equations for characteristics which are choice variables for the household is similar to the hedonic price technique; but, in the HPF framework the same entity is taken to be both the producer and consumer of nonmarket characteristics (i.e., commodities). In the HPF framework the cost function gives the minimum expenditures on goods required to produce (and consume) a given bundle of commodities at fixed good prices. Partial differentiation of the cost function with respect to commodities
yields implicit price (marginal cost) functions for commodities. The cost function thus plays the same role as does the hedonic price function that is estimated with the hedonic technique described above. The value of an implicit price function in the HPF framework gives the increase in expenditures on goods that is necessary for producing one more unit of a commodity. The major difference between the implicit price function of the hedonic price model and that of the HPF model is that the former is obtained from an ad hoc specification of the relationship between good prices and quality characteristics, while the latter is derived from a well-defined cost function. Unlike the hedonic price technique, the HPF approach provides a theoretical foundation for the derivation of implicit price functions.

The HPF approach also provides a theoretical foundation for the derivation of demand equations for quality characteristics. That is, the HPF approach provides a framework for deriving characteristic demand equations from a specified utility function defined on characteristics (or commodities). The other two approaches — the travel cost and hedonic price — are usually applied to estimate demand equations without knowledge of the underlying utility function.
Objectives of This Study

The major objectives of this study are to:

1. Determine whether the HPF approach is a valid procedure for ascertaining values of fishing trips and sport-caught fish. Its validity will be judged on the basis of whether anglers can significantly influence the number of fish caught and whether the production function for trips exhibits nonconstant returns to scale.

2. Obtain estimates of the values of fishing experiences at a selected group of steelhead fishing streams in terms of benefits rendered to individual anglers. The objective is to determine exact measures of angler welfare.

3. Obtain estimates of the value of a sport-caught steelhead and the value of a fishing trip.

4. Determine whether certain water quality measures have any significant effects (immediate or lagged) on numbers of steelhead caught by individual anglers.

5. Provide an analytical framework based on neoclassical production and demand theory that can be used to evaluate the effects of policy actions regarding fish habitat quality on recreation benefits.

6. Present methods one can use to calculate economic welfare changes in the HPF framework.
CHAPTER II

HOUSEHOLD PRODUCTION THEORY AND METHODOLOGY

The traditional theory of consumer behavior treats purchased goods as arguments of the household's utility function. Pioneering work by Becker (1965), Lancaster (1966), and others offers a "new approach to consumer behavior" which is based on the premise that market goods do not directly yield utility, but that they are in fact used as inputs in the production of utility-yielding commodities within the household. In Becker's (1965) formulation, a household combines purchased goods and household members' time to produce more basic commodities which directly enter the household's utility function. In Lancaster's (1966) model, market goods are taken to possess certain characteristics, and these characteristics (which we can identify with Becker's commodities) are treated as arguments of the utility function.

As developed by Becker (1965), the household production function (HPF) approach is applicable to a wide spectrum of problems, including studies of nonwork travel, fertility behavior, the "quality of children," the demand for health services, nonmarket returns to education, the effects of human capital on the efficiency of household production, and the demand for leisure. This technique extends the notion of home production to incorporate all nonmarket activities, including outdoor recreation (Michael and Becker, 1973). Since it emphasizes technical aspects of household consumption, it provides a means of attributing differences in observed behavior across
households to differences in productive efficiency. The traditional view of consumer behavior attributes behavioral differences that are not explained by price and income variations to differences in tastes, about which not much can be said, since a useful theory of the formation of tastes does not exist (Michael and Becker, 1973). If technology variables (which vary across households) appear in the cost function, then implicit commodity prices and real income will vary across households. Thus, the HPF approach, by accounting for the technical aspects of consumer behavior, "...strengthen the reliance on changes in income and prices as explanations of observed behavior, and correspondingly reduces the reliance on differences in tastes or preferences." [Michael and Becker (1973), p. 394].

The Theory of Household Production

Within the general HPF framework, the household is viewed as purchasing a vector of n market goods $x = (x_1, \ldots, x_n)$ at market prices $p = (p_1, \ldots, p_n)$, and combining them in accordance with household technology to produce a vector of m more basic commodities $z = (z_1, \ldots, z_m)$ from which the household derives utility. Household technology is described by one or more production functions, which determine the levels of output that can be produced with given bundles of goods. The household chooses to consume that bundle of commodities which maximizes household utility subject to the household technology constraint (or its ability to transform goods into commodities) and the available income (budget) constraint.
In order to simplify this discussion on household production theory, the assumption of two-stage budgeting is adopted. In the first stage of two-stage budgeting, decision-making units (households or individual consumers) allocate total income among broad commodity groups. First stage allocation decisions are based on household (or individual) income and price indexes for commodity groups. In the second stage consumer units allocate group appropriations optimally among the commodities within each group. Consumers base their second stage allocation decisions for a given group on prices of the individual commodities in the group and on the group appropriation. With the assumption that \( z \) is a weakly separable group of commodities, a household's choice of the optimal bundle of \( z \) is the solution to the second stage budgeting problem.

Weak separability is a necessary and sufficient condition for the second stage of two-stage budgeting (Deaton and Meullbauer, 1980). As was noted above, the assumption of weak separability permits the use of subutility functions for groups of final consumer goods. A weak separability restriction simplifies a model by reducing the number of explanatory variables that enter into a system of consumer demand equations. In the HPF framework quantities demanded of commodities within the same group are functions of prices within the group alone and on the amount of income allocated to the commodity group. This means that decisions within a group are made independently of decisions outside the group.

separable subutility function \( U(z) \) for the \( z \) commodity group corresponds to an "implied goods subutility function" for the goods \( (x) \) used to produce \( z \). That is,
\[
U(F(x)) = W(x).
\]

Suppose \( F(x) \) is a system of nonjoint production functions for \( z \).

Under nonjoint production, the production function for each \( z_i \) is denoted by \( F_i(x_i) \), where \( x_i \) is the vector \((x_{i1}, \ldots, x_{in_i})\) of the \( n_i \) goods used in the \( i \)th production process. Given the "implied goods utility function" \( W(X) \), where \( X \) is the vector \((x_1, \ldots, x_m)\) of \( N = \sum n_i \) total elements, the "implied marginal utility" of any good is written as
\[
\frac{\partial W}{\partial x_{ij}} = \frac{\partial U}{\partial z_i} \cdot \frac{\partial F_i}{\partial x_{ij}}.
\] (2.1)

Note that the second factor on the right hand side of this equation is the partial derivative of the production function for \( z_i \) with respect to \( x_{ij} \), which is called the marginal product of \( x_{ij} \). For any two goods used in the same production process, say \( x_{i1} \) and \( x_{i2} \), the marginal rate of substitution of \( x_{i2} \) for \( x_{i1} \) is the ratio of \( \partial W/\partial x_{i1} \) to \( \partial W/\partial x_{i2} \). From the above expression in (2.1), one finds that this ratio of marginal utilities can be written as simply the ratio of marginal products. That is,
\[
\frac{\partial W/\partial x_{i1}}{\partial W/\partial x_{i2}} = \frac{\partial F_i/\partial x_{i1}}{\partial F_i/\partial x_{i2}} = \psi(x_i).
\] (2.2)

As is evidenced by \( \psi(x_i) \), the marginal rate of substitution between \( x_{i1} \) and \( x_{i2} \) is only dependent on the goods used in the production of \( z_i \).
The ratio of marginal products for any two goods is called the marginal rate of substitution in production. From (2.2) we find that the marginal rate of substitution in consumption for two goods that are used to produce a single commodity is equal to their marginal rate of substitution in production, and is only dependent on the goods used in that single production process (Muth, 1966). Muth (1966) states that the derived utility function W(X) will be weakly separable in the Goldman and Uzawa (1964) sense with respect to the partition \{x^{(1)}, \ldots, x^{(m)}\} of the good group X = (x_1, \ldots, x_m). Each subvector x^{(i)} is composed of the goods contained in the vector x_i = (x_{i1}, \ldots, x_{in_i}). This means that W(X) is of the form

\[ W(X) = \Theta(\omega^1(x^{(1)}), \ldots, \omega^m(x^{(m)})) \]

where \(\Theta\) is a function of N goods, and each \(\omega^i\) is a function of the subvector \(x^{(i)}\) alone. Of course, as Michael and Becker (1973) point out, the existence of joint production will undermine separability in production processes.

In the simple case where two commodities comprise a weakly separable commodity group, the solution to the household's optimization problem is labeled \(z^*\) in Figure 2. This optimal combination of \(z_1\) and \(z_2\) is at the point of tangency between the transformation frontier \((\mu^0)\) and the indifference curve \((U^0)\). The transformation frontier, which is generated by the cost function C(z,p), is a locus of all of the largest possible combinations of \(z_1\) and \(z_2\) that can be secured at a given level of expenditures on x. The total differential of the cost function is written as
\[ dC = \frac{\partial C}{\partial z_1} z_1 + \frac{\partial C}{\partial z_2} z_2. \]

Since \( dC = 0 \) for movements along the transformation frontier, the slope of the tangent to \( u^0 \) at any point is given by

\[ \frac{dz_2}{dz_1} = -\frac{\partial C/\partial z_1}{\partial C/\partial z_2}, \]

where the term on the right hand side is the negative of the ratio of the marginal cost of \( z_1 \) to that of \( z_2 \). This slope is called the marginal rate of transformation between \( z_1 \) and \( z_2 \). The negative of the slope at a point gives the rate at which more \( z_2 \) can be produced when one less \( z_1 \) is produced at a constant cost. It should be noted that if the cost function is linear in \( z \), then marginal costs are not dependent on \( z \), and the transformation locus becomes a straight line with a slope equal to the negative of the ratio of constant marginal costs.

The indifference curve labeled \( U^0 \) in Figure 2 is the locus of the combinations of \( z_1 \) and \( z_2 \) yielding the same level of utility. This locus is generated by the direct utility function \( U(z_1, z_2) \), of which the total differential is written as

\[ dU = \frac{\partial U}{\partial z_1} z_1 + \frac{\partial U}{\partial z_2} z_2. \]

Since \( dU = 0 \) for movements along the indifference curve, the slope of \( U^0 \) at any point is given by

\[ \frac{dz_1}{dz_2} = -\frac{\partial U/\partial z_1}{\partial U/\partial z_2}, \]

where the expression on the right hand side is the negative of the ratio of the marginal utility of \( z_1 \) to that of \( z_2 \). This ratio has
already been identified as the marginal rate of substitution, which is defined in this case as the rate at which the consumer is willing to substitute \( z_2 \) for \( z_1 \), per unit of \( z_1 \), while maintaining a given level of utility. At the point representing the optimal combination of \( z_1 \) and \( z_2 \) (denoted by \( z^* \) in Figure 2), the ratio of marginal costs is equal to the ratio of marginal utilities. That is,

\[
\frac{\partial C/\partial z_1}{\partial C/\partial z_2} = \frac{\partial U/\partial z_1}{\partial U/\partial z_2}
\]

and hence the marginal rate of transformation is equal to the marginal rate of substitution.

Figure 2. Graphical Representation of the Two-Stage Optimization Process.
The dashed line labeled \( \pi^0 \) in Figure 2 is the separating tangent between the cost and indifference loci. The slope of this tangent is equal to the negative of the ratio of marginal costs valued at \( z^* \). In a standard utility maximization problem this line would serve as the budget constraint, and its slope would be the negative of the ratio of fixed commodity prices. The optimal combination of \( z_1 \) and \( z_2 \) would be at the point at which the highest indifference curve is tangent to the budget line. As was noted above, the transformation frontier is a straight line only when marginal costs are not dependent on commodity quantities. Given constant costs the consumer faces fixed implicit commodity prices, and thus the household's optimization problem resembles a standard utility maximization problem.

A common way to illustrate the household's decision problem is by a two-stage optimization procedure. In the first stage the household determines the cost function, which is defined as

\[
C(p,z) = \min_{x} \{ p'x \mid z = F(x) \}
\]

(2.3)

where \( p'x \) gives the level of expenditures on \( x \). The solution value for \( x \) which minimizes costs for a given \( z \) subject to the technology constraint is denoted by \( x^* = f(p,z) \). By Shepherd's lemma we know that \( \partial C / \partial p = f(p,z) \). Given the cost function one can obtain the marginal cost functions, which are written as \( \partial C / \partial z = \pi(p,z) \).

In the second-stage optimization problem the household determines the indirect utility function, which specifies utility as a function of prices and available income. Given the assumption of
two-stage budgeting, available income is the amount of money that
is allocated to the \( z \) commodity group. Accordingly, the amount of
money spent on \( z \) must not exceed the available income (denoted
by \( \mu \)). In the second stage of two-stage budgeting, \( \mu \) is taken
to be a predetermined variable. Pollak and Wachter's version of the
household's second-stage optimization problem defines the indirect
utility function as

\[
L(p, \mu) = \max_{z} \{ U(z) \mid \mu = C(p, z) \}. \tag{2.4}
\]

This formulation is based on the assumption that the budget for \( z \) is
exhausted. The function \( L(p, \mu) \) is not actually a standard theoreti-
cal indirect utility function, because it is defined on good prices
rather than commodity prices (commodities are the arguments of the
direct utility function). Moreover, since the cost function appears
in the constraint of (2.4), the function \( L(p, \mu) \) carries information
about technology in addition to tastes.

Also, in standard theoretical problems \( U(z) \) would be maximized
subject to a linear budget constraint, whereas in (2.4) \( C(p, z) \) can be
nonlinear in \( z \). The general nonlinearity of the cost function in \( z \)
can make the utility-maximizing or Marshallian commodity demands
\( z_m = g(p, \mu) \) highly nonlinear in \( p \) and \( \mu \). As Pollak and Wachter
(1975) have observed, these "quasi" demand functions do not have
standard neoclassical properties of a demand system, because their
arguments are good rather than commodity prices, and because they
describe the effects of both taste and technology changes on quanti-
ties of commodities demanded. [See Appendix A for a list of the
neoclassical demand properties].
Because of these problems associated with using the constraint \( u = C(p,z) \) in the household's optimization problem, attention has focused on the conditions under which it is possible to use the gradient of the cost function to define a vector of implicit commodity prices \( \pi = (\pi_1, \ldots, \pi_m) \) which can be used in the second stage optimization problem to form the linear budget constraint \( \mu = \pi'z \). By Euler's theorem we know that \( \pi'z = \mu \) when the cost function is linearly homogeneous in \( z \). This corresponds to a constant returns to scale (CRS) technology. It has been shown that as long as the technology is nonjoint and CRS, the implicit commodity prices are not dependent on commodity quantities (Pollak and Wachter, 1975). The indirect utility function can thus be defined as

\[
V(\pi, \mu) = \max_{z} \{ U(z) | \mu = \pi'z \}
\] (2.5)

where \( \pi = \pi(p) \) is treated as a vector of exogenous commodity prices. The Marshallian (ordinary) commodity demands can be found by application of Roy's identity:

\[
-\frac{\partial V}{\partial \pi} = \frac{\partial V}{\partial \mu} = G(\pi, \mu). \tag{2.6}
\]

Since the ordinary demands in (2.6) are defined on commodity prices, and since they isolate taste effects from technology effects, they will possess conventional neoclassical demand properties (Barnett, 1977).

Pollak and Wachter (1975) maintain that implicit (or shadow) commodity prices are only useful as explanatory variables when they are not dependent on commodity choice values. There are three possible situations under which this condition is not satisfied. First,
in the most general case of joint production and nonconstant returns to scale (NRS), each implicit price will depend on the entire \( z \) vector. Second, where NRS exists without joint production, each implicit price will depend on its own commodity quantity. Third, where both joint production and CRS exist, each implicit price will generally depend on all of the other \( m - 1 \) commodity quantities.

Pollak and Wachter (1975) contend that since most applications of the HPF approach involve joint production, the use of implicit commodity prices in the budget constraint should be rejected in favor of the derivation and estimation of commodity demand functions expressed in terms of good prices and \( \mu \) (i.e., the solutions to (2.4)).

The major problem associated with Pollak and Wachter's method for estimating the quasi demand system \( g(p,\mu) \) is that it results in a confounding of taste and technology effects. Indeed, Pollak and Wachter (1975) recognize the shortcomings of this approach, since they acknowledge that "...although it may be possible to explain consumption behavior in terms of either tastes or technical progress, the welfare implications are quite different." [p. 273]. That is, for welfare analysis it is desirable to maintain the separation between taste and technology effects on household consumption decisions. This is because an exogenous change in a taste parameter may have the same effect on the optimal commodity choice values as does an exogenous change in a technology parameter, but their respective effects on household welfare are generally quite different.

In the two-commodity case, for example, a change in tastes, _ceteris paribus_, which increases the demand for one of the commodities,
would result in greater benefits from the consumption of that commodity. Since available (nominal) income does not increase, however, demand, and hence benefits, must decline in the other commodity market. Thus, the net change in consumer benefits may be zero. These changes in demand correspond to movements along the transformation frontier. An improvement in technical efficiency in one commodity market, on the other hand, translates into a shift outward of the transformation frontier. The result is that the indifference curve that is tangent to the new transformation frontier has also shifted to the right of its initial position. This means that utility (and hence consumer benefits) increases as a result of the technical change, even though the demand for one of the commodities may have fallen. A change in technology which enhances the efficiency of production will always result in an increase in household welfare.

Fortunately, Barnett (1977) has presented a variation of the "commodity shadow price approach" (i.e., derivation of commodity demands as functions of implicit prices) which allows for a separation of taste and technology effects in the case where joint production exists in conjunction with CRS. Given the solution to the full optimization problem \( z^* \), the optimal values of the implicit price functions are \( \pi^* = \pi(p,z^*) \). Under the assumption of a CRS technology, the indirect utility function is defined as

\[
V(\pi^*,\mu) = \max_{z} \{U(z) \mid \mu = \pi^* z\}. \tag{2.7}
\]

The Marshallian commodity demands are written as

\[
- \frac{\partial V}{\partial \pi} = G(\pi^*,\mu).
\]
Given $\pi^*$ and $\mu$, the solution values for $z$ are regenerated by determining the solution values for $G(\pi^*, \mu)$.

This optimization problem in (2.7) is stated as if households make their supply decisions independently of their demand decisions, while in reality households make these decisions simultaneously. The problem is stated in this manner to illustrate that although implicit prices are dependent on commodity choice values, the same solution will be obtained whether the nonlinear constraint $\mu = C(p, z)$ or the implicit linear constraint $\mu = \pi^* z$ is used. The advantage of using the implicit linear constraint is that the resulting structural-form demand functions $G(\pi^*, \mu)$ have all of the conventional properties of neoclassical demand functions. Deaton and Meullbauer (1980) emphasize that the structural-form commodity demands...

are yielded by a standard optimization problem subject to a linear budget constraint. This means that a corpus of ready-made theory, possible functional forms, and developed intuition is available to aid in their interpretation and estimation. [p. 248].

The actual definition of the indirect utility function is written

$$V(\pi, \mu) = \max_{z} \{U(z) \mid \mu = \pi^* z\}$$

(2.8)

where $\pi = \pi(p, z)$. The structural demand functions are then expressed in the form $G(\pi(p, z), \mu)$. "The fact that $\pi$ depends on $z$ is not relevant to the properties of the function $G$. The function $G$ neither knows nor cares where the commodity shadow prices came from."

[Barnett (1977), p. 1076]. Barnett (1977) points out that the reduced form of $G$ is identical to Pollak and Wachter's quasi reduced-form system $g(p, \mu)$. 
Barnett's "commodity shadow price approach" is displayed graphically in Figure 3. Instead of determining the point of tangency between the cost and indifference loci (as in Figure 2), the objective of this version of the second-stage optimization problem is to find the point of tangency between the highest indifference curve and the linear implicit budget constraint. Given the same set of good prices and the same $\mu^0$, the optimal solutions in Figures 2 and 3 are equivalent.

Figure 3. Graphical Representation of the "Commodity Shadow Price Approach".
Recall that Barnett's "commodity shadow price approach" requires a CRS technology (or a linearly homogeneous cost function in z), so that the implicit budget constraint can be written as \( \mu = \pi^* z \).

Where the cost function is not homogeneous in z of degree one, the indirect utility function is defined as

\[
V(\pi, I) = \max \{U(z) \mid I = \pi^* z\}. \tag{2.9}
\]

where \( I \neq \mu \), and I is called the implicit valuation of income. Unless implicit income can be treated as an exogenous variable, this formulation of the problem in (2.9) does not resemble a standard utility maximization problem. At first glance, it would appear that the commodity shadow price approach is invalid when \( I \neq \mu \); however, we will show that this approach is still valid in cases where \( I \neq \mu \) as long as the cost function is homogeneous of some positive degree in z.

By using Euler's theorem, one finds that a cost function that is homogeneous of degree \( \kappa \) in z can be expressed in the form

\[
C(p, z) = \frac{1}{\kappa} \sum_{i=1}^{m} \frac{\partial C}{\partial z_i} z_i = \frac{1}{\kappa} \pi^* z. \tag{2.10}
\]

Accordingly, since the nonlinear budget constraint states that \( \mu = C(p, z) \), the implicit linear budget constraint for the household can be written as \( \kappa \cdot \mu = \pi^* z \). This equation states that the implicit valuation of z is greater than or less than nominal income (\( \mu \)), depending upon whether or not the technology is increasing or decreasing returns to scale. When implicit income can be defined as \( I = \kappa \cdot \mu \), it can be treated as an exogenous variable to the household. This means that the structural commodity demand functions of
the form $z^* = G(p^*, \kappa \cdot \mu)$ are yielded by a standard utility maximization problem subject to a linear (implicit) budget constraint.

We can write the budget constraint for two commodities as

$$\frac{\pi^*}{\kappa} z_1 + \frac{\pi^*}{\kappa} z_2 = \mu.$$  

Recall that the slope of $\mu^0$ in Figure 3 is the negative of the ratio of implicit commodity prices $\pi^*$ valued at the optimal commodity bundle $z^*$. These $\pi^*_1$'s are called the equilibrium commodity prices, because they are defined at the points of intersection between commodity demand and supply curves. The total differential of $\mu$ is now written as

$$d\mu = \frac{\pi^*_1}{\kappa} dz_1 + \frac{\pi^*_2}{\kappa} dz_2$$

and the slope of $\mu^0$ at any point is given by

$$\frac{dz_1}{dz_2} = \frac{\pi^*_1/\kappa}{\pi^*_2/\kappa} = \frac{\pi^*_1}{\pi^*_2}.$$  

In cases where the cost function is homogeneous of degree $\kappa \neq 1$, therefore, the implicit budget line is still represented by $\mu^0$ (as in Figure 3) of which the slope at the optimum is the ratio of equilibrium shadow prices. This fact, together with the fact that the reduced form of $G(p(z), \kappa \cdot \mu)$ is equivalent to Pollak and Wachter's quasi reduced-form system $g(p, \mu)$, implies that the optimization problems displayed in Figures 2 and 3 give identical solutions even when $\kappa \neq 1$.

In cases where the cost function is not homogeneous in $z$, the "commodity shadow price approach" appears to be inapplicable. The alternative way to approach the problem is to derive the quasi
reduced-form commodity demand system \( z_m = g(p, \mu) \), which generates the indirect utility function \( L(p, \mu) \) from (2.4). This indirect utility function can also be obtained by working in goods space. That is, it can be defined as

\[
L(p, \mu) = \max \{ W(x) \mid \mu = p'x \}. \tag{2.11}
\]

Because \( L(p, \mu) \) carries information about both tastes and technology, there is reason to suspect that it may not possess the conventional properties of an indirect utility function. [See Appendix A for a list of these properties]. Similarly, the Marshallian good demands \( x_m = x(p, \mu) \) cannot be expected to possess conventional neoclassical demand properties, since they do not isolate taste and technology effects. The functions \( x(p, \mu) \) are general equilibrium demand functions, because they account for equilibrium adjustments in \( z \) as \( p \) changes. One can obtain these general equilibrium demand functions when working in commodity space by replacing \( z \) in the cost-minimizing good demands \( x^* = f(p, z) \) with the quasi reduced-form commodity demand functions \( g(p, \mu) \).

One advantage of working in commodity space is that the specification of functional forms for the complete HPF model can be guided by duality theory. Because there is a one-to-one correspondence between cost and production functions, one can specify a cost function without knowing the specific form of the underlying production function, as long as certain regularity conditions are met to ensure that the underlying production function is well behaved.\(^{19}\) It is well known that this dual approach permits greater flexibility in modeling
production relationships than does the primal approach (Just, Hueth, and Schmitz, 1982). With the primal approach the cost function is determined and the cost-minimizing good demands are derived through a constrained minimization procedure, as was discussed earlier. With the dual approach, on the other hand, the cost-minimizing good demands can simply be obtained by application of Shepherd's lemma, since \( \frac{\partial C}{\partial p} = f(p, z) \).

As long as the cost function is homogeneous in \( z \), a dual approach is also applicable to modeling commodity demand relationships in the HPF framework. Because of the one-to-one correspondence that exists between direct and indirect utility functions, it is no less arbitrary to specify a functional form for the indirect utility function than to specify a direct utility function (Just, Hueth, and Schmitz, 1982). It is only necessary that the indirect utility function meet certain regularity conditions to ensure the existence of an underlying direct utility function that is well behaved. Given a specified indirect utility function \( V(\pi^*, I) \), the structural commodity demand functions are obtained through application of Roy's identity. That is,

\[
- \frac{\partial V/\partial \pi^*}{\partial V/\partial I} = G(\pi^*, I).
\]

The dual approach permits greater flexibility in modeling consumer behavior than does the primal approach, because the former involves simple differentiation, while the latter involves finding the solution to a constrained maximization problem. Using duality theory makes it easier to apply the HPF approach in a multiple goods/multiple commodities context.
It seems that the dual approach to modeling household demand relationships is not applicable in goods space, because there apparently are no known conditions for \( L(p,\mu) \) to satisfy in order to guarantee that \( W(x) \) is a well-behaved implied utility function. Still, the equilibrium good demands can be found by using Roy's identity:

\[
\frac{\partial L}{\partial p} = x(p,\mu).
\]

Deaton and Muellbauer (1980) argue that in goods space...

when the technology changes, this is formally equivalent to a change in "tastes" in the utility function defined on \([x]\). And indeed, one of the main points of the household production approach is to avoid such arbitrary attribution whenever possible. [p. 250].

Michael and Becker (1973) discuss several advantages of the two-stage formulation of determining the cost function and then the indirect utility function in commodities space, which render that approach more useful than the maximization with respect to \( x \) of the derived utility function \( W(x) \) subject to the linear budget constraint \( \mu = p'x \).

Previous Estimation Techniques and Potential Problems

Both technology parameters from the cost function and taste parameters from the utility function are present in a specified HPF model. Deyak and Smith (1978) and McConnell (1979) applied the HPF approach to outdoor recreation activities, and they obtained estimates of technology and taste parameters simultaneously by estimating the system of commodity demand equations. Barnum and Squire (1979) used a different approach in their analysis of farm households by
obtaining technology parameter estimates through estimation of the cost-minimizing good demand equations, and then obtaining taste parameter estimates given the technology parameter estimates.

Barnett (1977) points out that this independent estimation of technology parameters and taste parameters may result in a simultaneous equations bias. Each of the three alternative procedures for estimating the set of technology parameters (namely, estimating the cost function, the system of m production functions, or the system of n good demand equations) involves estimation of an incomplete system. They are incomplete because the total number of endogenous variables in an HPF model is equal to the number of goods (n) plus the number of commodities (m). With each of the three procedures mentioned above, the number of equations is less than the number of unknowns. Taste parameter estimates are commonly obtained by estimation of the m ordinary commodity demand equations. Although the commodity demand system itself only contains m endogenous variables (not counting implicit commodity prices), the complete HPF model contains m plus n endogenous variables.

In order to avoid a simultaneous equations bias, Barnett (1977) proposes the simultaneous estimation of the complete system of n plus m demand equations

\[ \mathbf{x}^{*} = f(\mathbf{p}, \mathbf{z}) \]

\[ \mathbf{z}^{*}_{m} = G(\pi(\mathbf{p}, \mathbf{z}), \mu). \]

Recall that Barnett assumes a CRS technology so that \( \mu = \pi(\mathbf{p}, \mathbf{z})^{\top} \mathbf{z} \). Barnett calls the complete system of \( f \) and \( G \) the household's structural form. According to Barnett (1977), the structural good demand
functions relate solely to technology, and the structural commodity demand functions relate solely to tastes. The optimal value of the function $\pi(p,z)$ clearly depends on the choice value for $z$, but the function itself depends on the technology. Commodity demand responses to changes in $\pi$ that are caused by changes in technology or $p$ are totally based on tastes and preferences in $G(\pi(p,z),\mu)$.

[The structural form] is well designed for deriving refutable theoretical results. The properties of all of the functions [are] restricted by neoclassical demand and production theory, regardless of whether or not joint production exists [Barnett (1977), p. 1078].

The same argument should be valid in cases where the technology or technologies are NRS and joint or nonjoint production, as long as the cost function is homogeneous in $z$.

In their reply to Barnett (1977), Pollak and Wachter (1977) argue that restricting the household production model to situations in which estimation of the structural parameters of complete systems is possible severely reduces its usefulness as a framework for empirical work. (p. 1086).

They propose the simultaneous estimation of the complete system of structural good demand functions and reduced-form commodity demand functions:

$$x^* = f(p,z)$$
$$z_m = g(p,\mu).$$

An alternative procedure that they also propose is estimation of the complete reduced-form demand system:

$$x_m = x(p,\mu)$$
$$z_m = g(p,\mu).$$
Recall that Pollak and Wachter derive the quasi commodity demand functions $g(p,\mu)$ by maximizing utility subject to the cost function constraint $\mu = C(p,z)$. The underlying structural commodity demands are not obtainable through Pollak and Wachter's approach. They can only be derived through the "commodity shadow price approach". If taste and technology parameters cannot be separated in $g(p,\mu)$ and $\chi(p,\mu)$, then neither the structural technology nor taste parameter estimates are obtainable through Pollak and Wachter's approach.

Given Barnett's structural system of $f$ and $G$, providing it has a closed form solution and that there is not an identification problem, either of Pollak and Wachter's systems $(f,g)$ and $(\chi,g)$ can be used for estimation purposes, because $g(p,\mu)$ is simply the reduced form of $G(\pi(p,z),\chi \cdot \mu)$. If there exists an identification problem, then it is not possible to derive the structural parameter estimates from the reduced-form parameter estimates. Barnett (1977) points out that joint production may help in identification, because interaction terms can be introduced among the exogenous variables in the demand system. If the forms of these interaction terms vary across equations, then they may generate exclusion restrictions for the equations. This is because nonlinear functions of exogenous variables can be viewed as new variables.

Notwithstanding identification, in some cases a lack of sufficient data may not permit the joint estimation of taste and technology parameters with a complete system of equations. For example, commodity quantities may not be observable in some applications of the HPF approach. Pollak and Wachter (1975) show that even without
observations on commodity quantities, one can still obtain parameter estimates by estimating what we refer to as the equilibrium good demand equations $x_m = x(p, \mu)$. Of course, the problem with this approach, aside from the possibility of a simultaneous equations bias, is that this system confounds taste and technology parameters; however, it can still be useful for some empirical work.

Another common data problem may be a lack of sufficient variability in good prices. This problem is likely to arise when cross-section data are obtained over a relatively small geographic area. In a survey of households, for example, market prices may not vary significantly across households. Treating the constant prices as parameters, which in effect incorporates them into the constant term, is one way to estimate the system of equations. A problem with this approach is that it reduces the model's usefulness for welfare analysis. Having estimates of good and commodity demand responses to price changes is desirable for welfare analysis.

Horst (1978) obtained estimates of technology parameters in the absence of price data by estimating the production functions. This procedure only requires data on commodity and good quantities. Since the production functions will generally share parameters in common with the cost function, the parameter estimates for the cost function can be obtained through this procedure. Given the empirically specified cost function, one can obtain empirically specified good demand functions and implicit price functions. The problem with this approach is that taste and technology parameters are estimated
separately and with incomplete systems of equations. Thus, there is the potential for a simultaneity bias.

One "price" for which a household survey should provide a sufficient variation is the opportunity cost of time (or the value placed on time used in household production activities). Throughout the literature on household production theory, conceptual models include household time as a labor input to the production of commodities. The allocation of time is important for three reasons: 1) household members face time constraints as well as money income constraints, 2) household members may expend considerable time and effort in producing basic commodities, and 3) time used in producing commodities rather than working for monetary compensation may be costly in terms of foregone earnings.

Accordingly, in some conceptual models household utility is maximized subject to a constraint on the household's available time in addition to the technology and money income constraints. The household's time constraint states that the amount of time available for household production activities \( T \) is equal to total time available minus labor time \( L \). Assuming that \( L \) is fixed in the period under consideration, the time constraint simply states that time inputs to producing commodities (including leisure) must be equal to \( T \), so that \( \sum_{i=1}^{m} t_i = T \), where \( t_i \) denotes the amount of time allocated to the production of \( z_i \).\(^{23}\)

Becker (1976) combines time and money income constraints to form what is commonly called the full income constraint, which is written as \( \mu = p'x + w't \), where \( w = (w_1, \ldots, w_m) \) denotes the vector of \( m \)
opportunity costs of the time allocated to producing the $z$ vector, and $t$ denotes the vector $(t_1, \ldots, t_m)$. "Full costs" includes what is spent on $z$ both directly through purchases of goods, and indirectly through the foregoing of earned income by spending time producing commodities for household consumption rather than working for pay. The implicit price of a commodity now reflects the value of both market goods and time used to produce the last commodity unit.

In order to properly use the full income constraint, there must be only one opportunity cost of time ($\tilde{w}$) for $T$ (Becker, 1965). The amount of available full income would then be equal to $\mu = M + \tilde{w} \cdot T$, where $M$ is available money income. The budget constraint in input space would be written as $\mu = p'x + \tilde{w} \cdot t$. When this full income constraint is used in the second-stage budgeting problem, the amount of time ($T$) and money ($M$) allocated to $z$ are not longer fixed; only the level of full available income ($\mu$) is fixed. It is necessary that $\mu$ be independent of time allocations between work and household production activities. Thus, any change in $\tilde{w} \cdot T$ must be exactly offset by a change in $M$.24
CHAPTER III  
HOUSEHOLD WELFARE ANALYSIS

Since one of the objectives of this study is to determine the benefits of steelhead fishing experiences in Oregon, it seems appropriate to review some of the principles and concepts of welfare economics, which is the field of economics that provides techniques and tools for evaluating economic welfare. The major purpose of the following discussion is to describe some of the useful welfare measures for individual producers and consumers. Following that discussion is a discussion on welfare measurement for the household (or individual) in the household production function framework. The decision making unit in the HPF framework is similar to the consumer in the traditional neoclassical framework in that they are both utility maximizers, but they are different in that commodity shadow prices can be endogenous to the consumer in the HPF framework, whereas commodity prices are always fixed in the traditional model. It is shown below that this distinction has some important implications for household welfare analysis.

Economic Welfare Measures for Producers and Consumers

Welfare economics is concerned with the total welfare that individuals in society gain from producing and consuming both market and nonmarket goods and services. "The economic status of an individual is formally given by his or her utility level, which is unobservable." [Just, Hueth, and Schmitz (1982), p.3]. In applied welfare economics
it would be helpful to know the intensities of preferences, or how many "utils" are obtained by individuals through consumption of different bundles of goods and services.

A basic principle of applied welfare economics is that an observable alternative to measuring the intensities of preferences of an individual for one situation versus another is the amount of money the individual is willing to pay or accept to move from one situation to another. [Just, Hueth, and Schmitz, p. 10].

In practice, welfare gains and losses are generally expressed in monetary terms. A distinction can be made between the "old" and the "new" welfare economics on the basis of the techniques used to evaluate economic welfare changes.

[From] an empirical standpoint, the old welfare economics holds that the triangle like area [called consumer surplus] to the left of the [ordinary] demand curve and above price is a serviceable money measure of utility to consumers and that the triangle like area [called producer surplus] to the left of the supply curve and below price is an adequate money measure of welfare for producers. [Just, Hueth, and Schmitz, pp. 5-6].

The notion of consumer surplus as a money measure of welfare is based on the premise that the price associated with any quantity on a demand curve is the maximum price a consumer is willing to pay for the last unit consumed. The demand curve can thus be viewed as a marginal willingness-to-pay curve, and the area under the demand curve and above any price gives the maximum amount of money a consumer is willing to pay for the amount of the commodity demanded at that price, less the amount the consumer actually pays. Similarly, since a producer's short-run supply curve coincides with the marginal cost curve, the area above a supply curve and below any price gives the amount of
money received by a producer for the quantity of the commodity supplied at that price, less the sum of costs incurred to produce each successive unit.

Unfortunately, these two geometric areas do not always provide accurate money measures of welfare. The deficiency of consumer surplus was widely recognized when Samuelson (1942) demonstrated that consumer surplus is generally not a unique money measure of utility. Only under fairly restrictive conditions does consumer surplus exactly reflect the "true" willingness-to-pay measure.

Producer surplus provides an accurate money measure of producer welfare under less restrictive conditions. A producer's net benefit was defined by Marshall (1930) as the excess of gross revenues for any commodities over the additional costs incurred to produce the commodities [i.e., variable costs]. This concept is called quasi-rent, because it is a rent on the fixed factors of production for which the costs incurred by producers are "sunk" costs. Producer surplus provides an exact measure of quasi-rent in the case of fixed input prices [i.e., perfectly elastic input supply curves]. In other cases the distinction between producer surplus as a geometric area and quasi-rent as an economic concept should be made.

The new welfare economics uses welfare measures for consumers that are related to the consumer surplus measure, but they do not suffer from the same deficiencies as does consumer surplus. The two most useful welfare measures of the new welfare economics—compensating variation and equivalent variation—were first proposed by
Hicks (1943).

Compensating variation is the amount of money which, when taken away from an individual after an economic change, leaves the person just as well off as before ...

Equivalent variation is the amount of money paid to an individual which – if an economic change does not happen – leaves the individual just as well off as if the change had occurred. [Just, Hueth, and Schmitz, pp. 10-11].

These concepts provide exact money measure of consumer welfare changes in any situation. They can also be used to measure producer welfare. For producers with the objective of maximizing profits, quasi-rent is an exact measure of both compensating and equivalent variations. The profit-maximizing producer's compensating variation is always equal to the equivalent variation for any economic change.

For the utility-maximizing consumer, on the other hand, compensating variation is not always equal to equivalent variation. Compensating and equivalent variations are formally defined by using the consumer's indirect utility function $V(\pi, \mu)$. A formula for the compensating variation (CV) for a commodity price change from $\pi^0$ to $\pi^1$ can be found by solving

$$V(\pi^1, \mu^0 - CV) = V(\pi^0, \mu^0)$$

for CV. A formula for the equivalent variation (EV) for the same price change can be found by solving

$$V(\pi^0, \mu^0 + EV) = V(\pi^1, \mu^0)$$

for EV. Compensating variation can also be calculated by measuring the area under the Hicksian compensated demand curve for the commodity conditioned on the initial (pre-price change) level of utility and between prices $\pi^0$ and $\pi^1$. Similarly, equivalent variation can
be calculated by using the Hicksian demand curve conditioned on the subsequent (post-price change) level of utility.

It can be shown that for a price reduction, compensating variation is bounded by the base level of income $\mu^0$, but that equivalent variation is unbounded. Also, the change in consumer surplus is greater than compensating variation and less than equivalent variation for a price fall. These conditions are reversed for a price increase. That is, equivalent variation is bounded by income, compensating variation is unbounded, and the change in consumer surplus is greater than equivalent variation and less than compensating variation in absolute value terms. It can also be shown that the compensating variation for a price fall is equal to the negative of the equivalent variation for the corresponding price rise. Likewise, the compensating variation for a price rise is equal to the negative of the equivalent variation for the corresponding price fall.

The one circumstance under which compensating variation, equivalent variation, and the change in consumer surplus all coincide is the case of zero income effects (i.e., the change in ordinary demand with respect to a change in income is zero). With zero income effects the ordinary demand curve coincides with both of the Hicksian demand curves. This implies that the Hicksian demand curves are independent of utility if and only if the ordinary demand curve is independent of income. Movements along the resulting single demand curve reflect the pure substitution effects of price changes. With nonzero income effects, on the other hand, movements along the ordinary demand curve reflect both substitution and income effects. Income effects of price
changes result in cases where the changes in real income \((\frac{\Delta U}{\Delta Y})\) induce changes in demand. Movements along the Hicksian demand curves always reflect pure substitution effects because real income is held constant along these curves.

For multiple price changes, the necessary and sufficient conditions for an equivalence of compensating and equivalent variations are zero income effects for all of the commodities which experience price changes. Since zero income effects are not very likely in practice, it is not uncommon for compensating variation and equivalent variation to be of different magnitudes. In such cases it is necessary to decide which of the two measures should be used.

In cases where data are not sufficient to obtain estimates of compensating or equivalent variation, the analyst can use the methods outlined by Willig (1976) to calculate bounds on the percentage errors associated with using changes in consumer surplus to approximate the "true" welfare effects. These methods can then be used to obtain estimates of bounds on compensating and equivalent variations with knowledge of only the consumer surplus change, base income, and income elasticities of demand. An income elasticity is defined as the percentage change in demand with respect to a percentage change in income. If the income elasticity is zero, then the income effect is zero. Hicks (1956) states that if the income effect is "small", then the change in consumer surplus will be a "good" approximation to either compensating or equivalent variation. Willig (1976) claims that the change in consumer surplus is usually a "good" approximation, which implies that compensating and equivalent varia-
tions are usually of similar magnitudes.

Compensating and equivalent variations are useful concepts for welfare analysis, because they can be given "willingness-to-pay" interpretations. That is, compensating variation is the maximum amount of money an individual would be willing to pay for an economic change that results in a welfare gain, and equivalent variation is the minimum amount of money the person would be willing to accept as compensation for forgoing the same economic change. For an economic change that results in a welfare loss, on the other hand, compensating variation is the negative of the minimum amount of compensation an individual would be willing to accept for the change, and equivalent variation is the negative of the maximum amount of money the individual would be willing to pay to avoid the same economic change.

These willingness-to-pay measures can be used to evaluate the desirability of a proposed policy action by using the compensation criterion, which was proposed by Kaldor (1939) and Hicks (1939). The Kaldor/Hicks compensation criterion states that a change should be made if it is possible to make everyone better off, or at least to make some people better off without making anybody worse off, by some redistribution of goods or income following the change. That is, the change should be made as long as it is possible for the gainers to compensate the losers. The compensation principle is based on potential compensation rather than actual compensation. Kaldor (1939) states that there cannot be any generally acceptable principle for when compensation should actually be given, because decisions on whether compensation should be given in any particular case is a
question of income distribution.

It is unfortunate that the compensating and equivalent variations for any economic change are likely to be unequal for the consumer, because the choice between the two measures as to which one is appropriate in any given circumstance is not always clear. If the analyst adheres to the compensation principle, then the decision of which measure to use depends on property rights, provided they are clearly defined. In cases where property rights are exercised, compensating variation is the appropriate measure. In cases where the consumer does not have the explicit right to the initial situation, equivalent variation is the appropriate measure. For example, consider a private rural landowner that has permitted hunters and anglers to participate free of charge in recreational activities on his property. Suppose the landowner decides to prohibit the use of his property by recreationists, because he wants to cultivate or develop the land. In this example equivalent variation should be used to evaluate the welfare effects on recreationists of totally eliminating the recreation site, because it is within the rights of the landowner to preclude the recreational use of his land. The negative of equivalent variation gives the maximum amounts recreationists are willing to pay to continue visiting the site. The equivalent variation for the landowner gives the minimum amount he would be willing to accept for continuing to give recreationists permission to visit his property.

If, on the other hand, it is within the rights of recreationists to visit the recreation site, then compensating variation should be
used to measure the welfare effects of making the site inaccessible to recreationists. The negative of compensating variation gives the minimum amounts recreationists are willing to accept as compensation for giving up their right to visit the site. The compensating variation for the grower or developer gives the maximum amount he is willing to pay for permission to cultivate or develop the land.

In some cases, especially where public recreation sites are concerned, property rights are ambiguous, and thus it is not clear which welfare measure is the appropriate one to use. The question then arises as to whether historical land-use patterns are sufficient to establish property rights. If they are not sufficient, then the choice between compensating and equivalent variation becomes a value judgement.

Exact Welfare Measurement in the Household Production Function Framework

The next two sections cover household welfare measurement in the simplest case of constant returns to scale (CRS)/nonjoint production and the most general case of nonconstant returns to scale (NRS)/joint production. Welfare measurement in the two other possible cases -- CRS/nonjoint production and NRS/nonjoint production -- is not discussed in as much detail, but it is briefly discussed in the concluding section.
Constant Returns to Scale and Nonjoint Production

Under CRS and joint production, each commodity shadow price \( \pi_i \) is dependent on the vector of commodity prices \( p_i = (p_{i1}, \ldots, p_{in_i}) \) for the \( n_i \) goods \( x_{i1}, \ldots, x_{in_i} \) used in the production of \( z_i \), where \( i = 1, \ldots, m \). Recall from the preceding chapter that the indirect utility function is defined as

\[
V(\pi, \mu) = \max_z \{U(z) | \pi' z = \mu\}
\]

(3.1)

where \( \pi = (\pi_1, \ldots, \pi_m) \) and \( \pi_i = \pi_i(p_i) \). By inverting \( V(\pi, \mu) \), one obtains the expenditure function \( E = E(\pi, U) \), where \( E = \mu \).

Consider a multiple shadow price change from \( \pi^0 \) to \( \pi^1 \) that is induced by a multiple good price change from \( P^0 \) to \( P^1 \), where \( P = (p_1, \ldots, p_m) \). The compensating variation (CV) measure of the welfare impact is implicitly defined as

\[
V(\pi^1, \mu^0 - CV) = V(\pi^0, \mu^0).
\]

(3.2)

Taking the inverse of both sides of (3.2) yields

\[
E^0 - CV = E(\pi^1, U^0)
\]

(3.3)

Recognizing that \( E^0 = E(\pi^0, U^0) \), one can rewrite this equation as

\[
CV = E(\pi^0, U^0) - E(\pi^1, U^0)
\]

(3.4)

which is the explicit definition for CV. Letting \( E^1 = E(\pi^1, U^0) \), this definition can be expressed as

\[
CV = E^0 - E^1 = \Delta E = \int_L dE
\]

(3.5)
where $L$ represents some path of integration in shadow price space.

The total differential of $E$ with respect to $\pi$ is written as

$$
\frac{dE}{\pi} = \sum_{i=1}^{m} \frac{\partial E}{\partial \pi_i} d\pi_i
$$

By Shepherd's lemma, we know that the Hicksian demand function for $z_i$ is $\frac{\partial E}{\partial \pi_i} = z_i^* = H_i(\pi, U)$. We also know that the integrand in (3.5) is an exact differential, because one of the properties of a demand system is that $\frac{\partial z_i^*}{\partial \pi_j} = \frac{\partial z_i^*}{\partial \pi_i}$. Consequently, CV can be measured by calculating the sum of areas under Hicksian commodity demand curves over any path from $\pi^0$ to $\pi^1$, such as

$$
CV = \sum_{i=1}^{m} \int_{\pi^0_i}^{\pi^1_i} H_i(\pi_i, U^0) \, d\pi_i
$$

where $\pi_i(\pi_i) = (\pi^1_1, \ldots, \pi^1_{i-1}, \pi^1_i, \pi^0_{i+1}, \ldots, \pi^0_m)$.

Each commodity demand function is conditioned on all previously considered price changes. Since $d\pi_i = 0$ for any shadow prices that remain constant, we can conclude that the CV measure can be calculated by sequentially evaluating the areas under the demand curves for only those commodities which experience shadow price changes.

In the simple two-commodity case, measurement of household welfare impacts of a price change from $(\pi^1_1, \pi^1_2)$ is illustrated graphically in Figure 4. Starting in the market for $z_1$, the decrease in $\pi_1$ results in a welfare gain that is represented by the area labeled A. This is a CV measure of the welfare impact, because $U = U^0$. If $z_1$ and $z_2$ are interrelated markets, then the change in $\pi_1$ induces a shift in the demand curve for $z_2$. The welfare impact of a reduction in $\pi_2$ is measured under the new demand curve.
This increase in welfare is represented by area B in Figure 4. The total welfare impact is equal to the sum of areas A and B.

Recall from the preceding chapter that the indirect utility function \( L(P, \mu) \) in good space is defined as

\[
L(P, \mu) = \max_{x} \{ W(x) \mid P'x = \mu \} \tag{3.8}
\]

where \( X = (x_1, \ldots, x_m) \). The expenditure function \( e = e(P, U) \) is found by inverting \( U = L(p, \mu) \), where \( e = \mu \). By Shepherd's lemma, the compensated good demands are specified as \( \frac{\partial e}{\partial p} = X^* = K(P, U) \).

Under the condition of CRS, we know that \( e = E \), and hence from (3.4), we find that

\[
CV = e^0 - e^1 = \Delta e = \int_{L} de \tag{3.9}
\]
Thus, the CV for a multiple change in good prices from $P^0$ to $P^1$ is equal to

$$CV = \sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij} K_{ij} (\tilde{p}(p_{ij}) U^0) dp_{ij}$$

(3.10)

where $\tilde{p}(p_{ij}) = (p_{ij}^1, \ldots, p_{ij-1}, p_{ij}, p_{ij+1}, \ldots, p_{mn})$.

The path of integration is arbitrary, because the integrand in (3.9) is an exact differential. This implies that the CV for a multiple good price change can be calculated by summing the areas under good demand curves using a sequential method. Since $dp_{ij} = 0$ in (3.10) for any prices that are not changed, welfare impacts need only be evaluated in the markets for goods which experience price changes.

Welfare measurement in good markets can be performed in an alternative manner if there exists a necessary good in the production of each commodity. That is, the household welfare impact of a multiple price change can be evaluated in the necessary good markets alone. A necessary good is defined as one for which there exists a shutdown price at which the household is induced to cease production of the commodity. Without loss of generality, for example, let $x_{i1}$ denote the necessary good in the production of $z_i$. Consider again the multiple price change from $P^0$ to $P^1$. The shutdown price for each $x_{i1}$ at prices $P^r$ for all other N-1 goods is defined as

$$\hat{p}_{i1}^r = \min \{ p_{i1} | K_i(p_{i1}, P^r_{N-1}, U^0) = 0 \}$$

(3.11)

where $r = 1, 0$, and $K_i$ denotes the system of compensated demand.
functions for the \( n_i \) goods used in the production of \( z_i \). To illustrate, first consider a multiple price change for the necessary input prices from \((p_{11}^r, \ldots, p_{m1}^r)\) to \((\tilde{p}_{11}^r, \ldots, \tilde{p}_{m1}^r)\). The sequential sum of areas under the compensated demand curves for the \( m \) necessary inputs conditioned on prices \( p_{N-m}^r \) for the remaining \( N-m \) goods is defined as

\[
S_1^r = \sum_{i=1}^{m} \int K_{i1}(\tilde{p}_m(p_{i1}), p_{N-m}^r, U^0) \, dp_{i1}
\]

\[
= \sum_{i=1}^{m} \int \frac{\partial e(\tilde{p}_m(p_{i1}), p_{N-m}^r, U^0)}{\partial p_{i1}} \, dp_{i1}
\]

\[
= e(p_m^r, p_{N-m}^r, U^0) - e(\tilde{p}_m^r, p_{N-m}^r, U^0)
\]

(3.12)

where \( \tilde{p}_m(p_{i1}) = (\tilde{p}_{11}^r, \ldots, \tilde{p}_{i-1,1}^r, p_{i1}, p_{i+1,1}^r, \ldots, p_{im}^r) \).

Since no commodities are produced at shutdown prices \((\tilde{p}_{11}^r, \ldots, \tilde{p}_{im}^r)\), \( e(\tilde{p}_m^r, p_{N-m}^r, U^0) = 0 \), and hence \( S_1^r = e(p_m^r, p_{N-m}^r, U^0) = e(p_r^r, U^0) \). Since \( CV = e(P^0, U^0) - e(P^1, U^0) \), this implies that the total welfare impact of the multiple price change is equal to \( S_1^0 - S_1^1 \), which can be calculated in the necessary good markets alone.

In the two-commodity case, measurement of welfare impacts in the two necessary good markets \( x_{11} \) and \( x_{21} \) is illustrated graphically in Figure 5. Graphically, \( S_1^0 \) is represented by area \((A + B)\) plus area \((D + E)\), and \( S_1^1 \) is represented by area \((B + C)\) plus area \((E + F)\). The total welfare gain is represented by area \((A + B - B - C)\) plus area \((D + E - E - F)\), which is equal to area \((A - C)\) plus area \((D - F)\).
When there exists a necessary commodity in consumption, it can be shown that the welfare impact of a multiple price change can be completely measured in the necessary commodity market, or in the market of a necessary good for that commodity. A necessary commodity is one which has a price at which the household is induced to cease consumption of all commodities $z_1, \ldots, z_m$. Without loss of generality
suppose that $z_1$ is a necessary commodity. Let $\hat{\pi}_1^r$ denote the minimum shadow price at which the demand for $z_1$, and hence the demands for $z_2, \ldots, z_m$, are reduced to zero given shadow prices $\pi_2^r, \ldots, \pi_m^r$. That is,

$$\hat{\pi}_1^r = \min \{ \pi_1^r \mid H(\pi_1^r, \pi_2^r, \ldots, \pi_m^r, U^0) = 0 \}.$$ (3.13)

The CV for a shadow price change from $\pi_1^r$ to $\hat{\pi}_1^r$ is equal to

$$CV_1^r = - \int_{\pi_1^r}^{\hat{\pi}_1^r} H_1(\pi_1^r, \pi_2^r, \ldots, \pi_m^r, U^0) \, d\pi_1$$

$$= - \int_{\pi_1^r}^{\hat{\pi}_1^r} \partial E(\pi_1^r, \pi_2^r, \ldots, \pi_m^r, U^0) \, d\pi_1$$

$$= E(\pi_1^r, U^0) - E(\hat{\pi}_1^r, \pi_2^r, \ldots, \pi_m^r, U^0)$$

$$= E(\pi_1^r, U^0) - E(\hat{\pi}_1^r, U^0)$$ (3.14)

since $E(\hat{\pi}_1^r, \pi_2^r, \ldots, \pi_m^r) = 0$ by definition. Since $CV = E(\pi_1^0, U^0) - E(\pi_1^1, U^0)$ for a multiple price change from $\pi_1^0 = \pi(P^0)$ to $\pi_1^1 = \pi(P^1)$, it follows that $CV = CV_1^0 - CV_1^1$. Thus, CV can be entirely measured in the market for $z_1$.

Assume again that $x_{11}$ is a necessary good in the production of $z_1$. The CV for a single price change from $p_{11}^r$ to $\hat{p}_{11}^r$, given prices $p_{12}^r, \ldots, p_{mn_m}^r$ for all of the other $N-1$ goods, is defined as

$$S_{11}^r = - \int_{p_{11}^r}^{\hat{p}_{11}^r} K_{11}(p_{11}^r, p_{12}^r, \ldots, p_{mn_m}^r, U^0) \, dp_{11}$$
Since \( e(p^r_{11}, p^r_{12}, \ldots, p^r_{mn}, u^0) = 0 \) by definition, provided \( z_1 \) is a necessary commodity. This implies that \( S^0_{11} - S^1_{11} = CV \), and hence the total welfare impact of a multiple change in good prices can simply be evaluated in the market for \( x_{11} \).

In this section it has been shown that with a CRS and nonjoint technology it is possible to measure household welfare impacts of good price changes in either the good or the commodity markets. The next section will extend these results to the more general case of an NRS and joint production technology.

**Nonconstant Returns to Scale and Joint Production**

In the case of NRS and joint production, each commodity shadow price is dependent on the entire price vector \( p = (p_1, \ldots, p_n) \) of goods \( x_1, \ldots, x_n \) and on the entire commodity vector \( z = (z_1, \ldots, z_m) \). A change in one or more good prices is not easily translated into a change in commodity shadow prices, since the shadow prices depend on commodity choice values which adjust optimally to the changes in good prices. In the general case, therefore, it is more convenient to work in good space rather than commodity space for measuring welfare impacts of good price changes.
As in the preceding section, the CV for a multiple price change from $p^0$ to $p^1$ is implicitly defined as

$$L(p^0, u^0 - CV) = L(p^1, u^0)$$

and is explicitly defined as

$$CV = e(p^0, U^0) - e(p^1, U^0)$$

(3.16)

(3.17)

As before, $\partial e/\partial p = K(p, U)$ by the envelope theorem. Thus, CV can still be measured by calculating areas under compensated demand curves for goods. By the sequential method, CV is equal to

$$CV = - \sum_{j=1}^{n} \int_{p_j^0}^{p_j^1} K_j(\hat{p}(p_j), U^0) \, dp_j$$

(3.18)

where $\hat{p}(p_j) = (p_1^1, \ldots, p_{j-1}^1, p_j, p_{j+1}^0, \ldots, p_n^0)$.

With total joint production, CV can be totally evaluated in the market of a good which is necessary in the production of all commodities $z_1, \ldots, z_m$. Without loss of generality, let $x_1$ be a necessary input in the production of $z_1, \ldots, z_m$. The shutdown price for $x_1$ given prices $p_2^r, \ldots, p_n^r$ is defined as

$$\hat{p}_1^r = \{p_1 \mid K(p_1^r, p_2^r, \ldots, p_n^r, U^0) = 0\}$$

(3.19)

where the function $K$ denotes the system of $n$ compensated good demand functions. To illustrate, first consider a single price change from $p_1^r$ to $\hat{p}_1^r$. The CV for this price change is equal to

$$S_1^r = \int_{p_1^r}^{\hat{p}_1^r} k_1(p_1, p_2^r, \ldots, p_n^r, U^0) \, dp_1$$
\[
\begin{align*}
&= - \int_{p_1^r} \frac{\partial e(p_1, p_2^r, \ldots, p_n^r, U^0)}{\partial p_1} \, dp_1 \\
&= e(p_1^r, U^0) - e(\hat{p}_1^r, p_2^r, \ldots, p_n^r, U^0) \\
&= e(p_1^r, U^0) 
\end{align*}
\]}

(3.20)

since \(e(p_1^r, p_2^r, \ldots, p_n^r, U^0) = 0\) by definition. This implies that \(S_1^0 - S_1^1 = CV\), and hence the CV for a multiple price change can simply be evaluated in the \(x_1\) market alone. Measurement of total CV in the \(x_1\) market for a price change from \(p_0^1\) to \(p_1^1\) is illustrated graphically in Figure 6. Area \((A + B)\) represents \(S_1^0\) and area \((B + C)\) represents \(S_1^1\). Total CV is thus represented by area \((A + B - B - C) = A - C\).

\[\text{Figure 6. Welfare Measurement in a Necessary Good Market with Joint Production.}\]

Welfare impacts of good price changes can always be evaluated in the good markets whether the cost function is homogeneous in
commodities or not. If the cost function is homogeneous of degree \( \kappa \) in \( z \) (which is associated with a joint production function that is homogeneous of degree \( 1/\kappa \) in \( z \) and \( x \)), however, then we can easily present a graphical interpretation of \( CV \) in the commodity markets. Since \( C(p,z) = \frac{1}{\kappa} (\pi^* z) \), we find that

\[
e(p, U) = \frac{1}{\kappa} \cdot E(\pi(p,z^*), U).
\] (3.21)

Recall that the implicit expenditure function \( E \) is defined as

\[
E(\pi(p,z^*), U) = \min_{z} \{ \pi^* z \mid U(z) = U \}
\] (3.22)

and that \( \pi^* = \pi(p,z^*) \). This implies that for the multiple good price change,

\[
CV = \frac{1}{\kappa} (E^0 - E^1) = \frac{1}{\kappa} \cdot \int_{\Pi} dE
\]

where \( E^0 = E(\pi(p^0,z^0), U^0) \) and \( E^1 = E(\pi(p^1,z^1), U^0) \), and \( z^* \) is the optimal choice value for \( z \) given good prices \( p^r \) (\( r = 1,0 \)). Thus, the \( CV \) for a multiple good price change is equal to \( 1/\kappa \) times the integral of \( dE \) over the corresponding commodity shadow price change, provided the cost function is homogeneous of degree \( \kappa \) in \( z \).

For the multiple shadow price change from \( \pi^0 = \pi(p^0,z^0) \) to \( \pi^1 = \pi(p^1,z^1) \), the total differential of \( E \) is written as

\[
dE = \sum_{i=1}^{m} \frac{\partial E}{\partial \pi_i} d\pi_i.
\] (3.23)

Since \( E = \pi^* z^* \), by the envelope theorem we know that

\[
\frac{\partial E}{\partial \pi_i} = z_i^* = H_i(\pi(p,z^*), U).
\] (3.24)

This implies that

\[
CV = - \sum_{i=1}^{m} \int_{\pi^0}^{\pi^1} \frac{1}{\kappa} \cdot H_i(\pi(p,z), U^0) d\pi_i.
\] (3.25)
where \( \bar{\pi}(\pi_i) = (\pi_i^1, \ldots, \pi_i^{1-1}, \pi_i^0, \pi_i^{i+1}, \ldots, \pi_m^0) \).

Graphically, the CV thus corresponds to areas under Hicksian commodity demand curves which are adjusted by some constant factor \( \frac{1}{\kappa} \).

For the simple two-commodity case, the CV for a multiple good price change from \( p_0 \) to \( p_1 \) is graphically illustrated in commodity markets in Figure 7. The bold line to the left of \( H_1(\pi_1, \pi_2, U^0) \) in the upper diagram is \( (1/k) \cdot H_1(\pi_1, \pi_2^0, U^0) \), where \( k > 1 \); this means that the technology is decreasing returns to scale. As the \( n \) good prices fall simultaneously, the marginal cost curve \( \pi_1(p, z) \) shifts to the right (downward). Note that the new marginal cost curve is defined on a new optimal choice value for \( z_2 \) \( (z_2^01) \) associated with \( \pi_1^1 \) and \( \pi_2^0 \). This shift in the marginal cost curve induces a decline in the equilibrium shadow price for \( z_1 \) from \( \pi_1^0 \) to \( \pi_1^1 \). These equilibrium shadow prices are defined at the points of intersection between marginal cost curves and \( H_1(\pi_1, \pi_2^0, U^0) \). Although the original (actual) demand curve \( H_1(\pi_1, \pi_2^0, U^0) \) determines equilibrium shadow prices and quantities, it is the adjusted demand curve \( \frac{1}{\kappa} \cdot H_1(\pi_1, \pi_2^0, U^0) \) under which areas are measured to calculate CV.

In the \( z_2 \) market the demand curve which determines equilibrium shadow prices is now conditioned on \( \pi_1^1 \), and the marginal cost curve is now conditioned on \( z_1^1 \). The initial marginal cost curve \( \pi_2(p_0, z_1^0, z_2) \), however, is conditioned on \( z_1^0 \). Welfare measurement is performed in the \( z_2 \) market in the same manner in which it was performed in the \( z_1 \) market. That is, areas are measured under the demand curve adjusted by the factor \( \frac{1}{\kappa} \) rather than under the actual demand curve \( H_2(\pi_1^1, \pi_2, U^0) \). The total CV for the multiple price
change is represented by the sum of the two shaded areas in Figure 7.

Figure 7. Welfare Measurement in Commodity Markets with a Nonconstant Returns to Scale Technology.

According to Figure 7, even with an NRS technology, CV for the household actually corresponds to a constant $\frac{1}{K}$ times the
consumer's implicit CV measure in the commodity markets [i.e.,
CV = 1/κ \cdot (E(π^0, u^0) - E(π^1, u^0)). The results presented above
also show that in order to give a graphical representation of house-
hold welfare changes in commodity space, it is necessary that the
cost function be homogeneous in z. When this is not the case, welfare
measurement can still be conducted in good space.

Summary

It was shown above that in both the simplest and most general
cases of CRS/nonjoint production and NRS/joint production, respect-
ively, household welfare changes can be evaluated in good markets.
The same procedures for conducting welfare measurement in good mar-
kets apply in both cases. The differences between these two cases
lie in the way in which welfare measurement is conducted in commodity
markets. Under CRS and nonjoint production, commodity shadow prices
are exogenous; hence, changes in good prices are easily converted
into changes in commodity shadow prices. This means that welfare
changes can be easily evaluated in commodity markets as well as good
markets. When commodity shadow prices depend on commodity choice
values, however, welfare measurement in commodity markets becomes more
difficult.

With a CRS/joint production technology, for example, each shadow
price in general depends on all of the other m-1 commodities and on
all of the n good prices. In this case any good price change would
induce shifts in the perfectly elastic supply curves for all of the
commodities, which would lead to changes in all of the equilibrium
shadow prices and quantities of commodities. Since the cost function is homogeneous of degree one in \( z \) with a CRS technology, household welfare changes can be measured by using a sequential procedure to calculate the areas under compensated commodity demand curves which are defined on shadow prices. In order to translate good price changes into shadow price changes, however, it is necessary to determine the optimal commodity quantities associated with the subsequent good prices.

With an NRS/nonjoint production technology, commodity supply curves are not perfectly elastic, because each \( \pi_i \) depends on the choice value for \( z_i \). If the technology is NRS and joint production, then each \( \pi_i \) depends on the entire \( z \) vector. In both cases, as long as the cost function is homogeneous of degree \( \kappa \) in \( z \), welfare impacts can be evaluated in commodity markets by using a sequential procedure to measure areas under compensated commodity demand curves that are adjusted by a constant factor of \( \frac{1}{\kappa} \). This is equivalent to multiplying the implicit welfare impact of a change in \( \pi \) by \( \frac{1}{\kappa} \). (The implicit welfare impact is calculated by using the expenditure function defined on shadow prices or the compensated commodity demand functions defined on shadow prices.) This result is contrary to Bockstael and McConnell's (1980) statement that household welfare is equal to the sum of producer and consumer welfare measures. Although the usual measure of producer welfare is nonzero for technologies that are decreasing (increasing) returns to scale, the above results suggest that a fraction of (a multiple of) the usual consumer welfare measure in commodity space picks up the total welfare impact on the household.
CHAPTER IV
METHODOLOGICAL PROCEDURES

The main objective of this study is to develop an empirically specified pricing model for sport fishing activities using the Bockstael-McConnell (1980) household production function (HPF) framework. In this study the HPF framework is applied to 1977 data on steelhead sport fishing at 29 prominent rivers in Oregon. The two utility-yielding commodities in this model are defined as the number of steelhead fishing trips taken per quarter and the number of steelhead fish caught per quarter. The angler is assumed to use market goods and time as inputs in the production of the nonmarket recreation commodities.

Description of Data

The data on steelhead fishing activities were obtained from the subset of 404 relevant questionnaires of a larger set of questionnaires that were mailed to a random sample of Oregon anglers in 1977. [See Appendix B for a copy of the questionnaire.] A different number of questionnaires was sent to a different sample of anglers immediately following each quarter of the year. [Details of the survey are discussed in Sorhus, Brown, and Gibbs (1981)]. Respondents reported the total number of times they went fishing primarily for salmon and steelhead during the previous quarter. To avoid potential problems with memory bias, the questionnaire did not instruct anglers to
recall details about all of their fishing trips. The anglers were only asked to provide relatively detailed information about expenditures and fish catch for the last three trips taken during the previous quarter. They were also asked to note the rivers at which they fished on those three trips and how much time they spent fishing.

For the model specification used in this application, it is necessary to estimate quarterly trips, fish catch, and expenditures by river for each respondent. In order to determine the distribution of quarterly steelhead fishing trips among rivers and to determine quarterly expenditures and fish catch by river, it is assumed that the last three fishing trips in a given quarter are representative of all of the trips taken during that quarter. Of the last three trips, only those that are primarily for steelhead fishing are used in this study. Each angler recorded how many hours were spent fishing per trip for each species. A "multiple species trip" is considered to be a "primarily steelhead trip" if the angler spent more time fishing for steelhead than for any other species. The per trip data are averaged over the relevant trips of the last three trips, and then the averages are multiplied by the estimated total number of trips taken to a given river per quarter to calculate quarterly expenditures, fishing time, and fish catch by river for each angler.

Because of the way in which the questionnaire was constructed, each angler could visit a maximum of only three different rivers during a given quarter. This restriction encumbers the construction of a multiple-site model that would allow site substitutions. Instead, the model explains consumption and production relationships for a
representative river. This approach is based on the assumption that
the rivers are homogeneous, except in regard to any site specific
variables that are included in the model. The model also describes
relationships for a representative quarter, because the number of
observations per quarter is not large enough to permit estimation of
a separate model for each quarter. Dummy variables are included in
the model to pick up any differences in production efficiency across
quarters. The model specification is also based on the assumption
that tastes and the state of technology are homogeneous across house-
holds.

The 1977 angler survey provides a considerable amount of useful
information for an application of the HPF approach. In addition to
eliciting data on per trip traveling expenditures, fishing expendi-
tures, fishing time and fish catch, the questionnaire also elicited
information on capital goods (e.g., fishing tackle, boating equip-
ment, and camping equipment), and on socioeconomic characteristics
(e.g., income, number of weekly hours worked, and household size). As
was noted above, the major data problem is that data on variable
inputs (including market goods and angler's time) are not available
for each and every trip taken by an angler during a given quarter,
but only for the last three trips taken. Also, fish catch data
and geographical data are provided for only the last three trips.
If per trip costs are constant across all of the trips of a given
quarter, then the last one to three trips are representative of the
quarterly trips as is assumed in this application.
It does not seem unreasonable to assume that per trip travel costs and travel time for a given angler are invariant to changes in the number of trips, holding all other variables constant. It is hypothesized that this assumption leads to the existence of constant returns to scale in the production function for fishing trips. In order to adequately test the suitability of constant returns to scale, one would need independent observations on quarterly quantities of fishing trips and inputs. Such data are not available for this study.

The assumption that fish catch per trip is constant across trips may be more questionable, however, even if time and effort expended per trip are constant. It can be argued that as an angler catches more fish and gains more experience, the marginal cost per fish caught would decrease, and thus for the same level of inputs and over the same length of time more fish would be caught. If this were true, then the technology would be increasing returns to scale. On the other hand, fishing experience gained over a three-month period by the average angler may not be great enough to significantly influence marginal costs of catching a fish, and thus the technology may be constant returns to scale. There seems to be no theoretically-based hypothesis regarding the magnitude of the returns-to-scale parameter for the fish catch production function.

In addition to the lack of independent observations on quantities of commodities and goods, another data problem is that prices and quantities of market goods are not independently given, because the data are expressed only in terms of expenditures per trip. As
long as market prices are constant across households, expenditures on each good could be easily converted into quantity figures. In the questionnaire, however, some goods were aggregated to form good classes. One class of goods, for example, includes guide service, bait, and lures. Even if market prices were constant across households, it would be difficult to obtain reasonably good estimates of quantities for a good class unless prices were equal across all of the goods in the class. An alternative to converting expenditure data into quantities is to let expenditures serve as a proxy for input quantities. This procedure would have the effect of weighting each good by its market price, thereby measuring each component of a good class in common units. This type of weighting procedure is appropriate only if it can be assumed that prices are homogeneous across households, and that the level of expenditures on each good in a good class reflects that good's relative importance in producing the commodity. If these assumptions are acceptable, then little information is lost by grouping goods into good classes and using expenditures as a proxy for quantity.

The expenditure data are expressed in terms of expenditures made by each fishing party as a whole. These group expenditure figures need to be adjusted to reflect expenditures made by the respondent. Assuming each respondent is the head of a household, and that heads of households cover the expenses of other household members, expenditures per respondent should include the respondent's own expenses plus those of other household members. This is because the amount an angler is willing to pay for the last fishing trip is reflected by
the amount actually paid, which includes the angler's own expenses plus the amount spent for other household members. (There should be no double counting as long as only one questionnaire was sent to each household in the sample.) Although the questionnaire elicited information on the sizes of fishing parties, it did not elicit information on the composition of fishing parties, such as the number of related individuals. Estimates of the number of people in a fishing party that are from the same household as the respondent are made on the basis of the results of a recent telephone survey of a small random sample of the Oregon anglers originally surveyed in 1977.

This sample was drawn from the 404 anglers that took at least one trip during 1977 to primarily fish for steelhead. Each interviewee was asked questions about his or her most recent group fishing trip for steelhead in 1982. Of the thirty anglers that took at least one group fishing trip in 1982, ten took their most recent trip with at least one member of their respective households. According to the survey results, on the average about one out of every four people that accompany the head of a household on a steelhead fishing trip is a member of that angler's household. Thus, in computing expenditures on goods for each household, about 25 percent of the group expenses (less the respondent's own expenses) are added to the respondent's own expenses. It is assumed that all persons in a group would incur approximately the same costs per trip; so the respondent's own expenses are estimated by dividing the total group expenses by the number of people in the fishing party.
Model Design and Analysis

Two main objectives of this study are to obtain estimates of implicit prices for steelhead fishing trips and sport-caught steelhead, and to obtain estimates of angler benefits in the fishing trips and sport-caught fish markets. More specifically, the objectives are to empirically specify: 1) the joint-commodity cost function, which is used to derive marginal cost (implicit price) functions for commodities, and 2) the indirect utility function, which leads to estimates of exact measures of angler benefits. The empirical analysis is performed in three stages.

In the first stage estimates of household technology parameters are obtained. These parameter estimates are determined in a manner similar to the way in which technological relationships between output and factor inputs for firms are analyzed. Although the dual approach to modeling production relationships permits greater flexibility regarding functional forms than does the primal approach, it is not applicable in this study due to a lack of data on input (good) prices. Price data are required for estimating the cost function or the system of input demand equations. Fortunately, price data are not required for estimating production functions; hence, the primal approach is applied in this study, and production functions are estimated to determine estimates of technology parameters.

The two production functions for a representative angler and a representative river are specified as
\[ z_1 = F_1(x_1, t_1, d, k_1) \]

and

\[ z_2 = \begin{cases} 
F_2(x_2, t_2, q, s, k_2) & \text{if } z_1 > 0 \\
0 & \text{otherwise} 
\end{cases} \]

where

\( z_1 \equiv \) quarterly number of fishing trips taken to primarily fish for steelhead,

\( z_2 \equiv \) quarterly number of steelhead caught,

\( x_1 \equiv \) quarterly expenditures on gas, vehicle maintenance, food, and lodging (proxy for quantity of transportation goods),

\( x_2 \equiv \) quarterly expenditures on guide service, bait, and lures (a proxy for quantity of market fishing goods),

\( t_1 \equiv \) time spent traveling on fishing trips per quarter,

\( t_2 \equiv \) time spent fishing per quarter,

\( d = (d_1, d_2, d_3), \)

\( d_1 = \begin{cases} 
1 & \text{if distance to river is 0-30 miles} \\
0 & \text{otherwise} 
\end{cases} \)

\( d_2 = \begin{cases} 
1 & \text{if distance to river is 31-60 miles} \\
0 & \text{otherwise} 
\end{cases} \)

\( d_3 = \begin{cases} 
1 & \text{if distance to river is 61-90 miles} \\
0 & \text{otherwise} 
\end{cases} \)

\( q = (q_1, q_2, q_3), \)

\( q_i = \begin{cases} 
1 & \text{if quarter } i \\
0 & \text{otherwise} 
\end{cases} \quad (i = 1, 2, 3) \)

\( s \equiv \) vector of water quality characteristics,

\( k_1 \equiv \) total depreciated present value of camping equipment, and
k_2 \equiv \text{total depreciated present value of fishing tackle, boating equipment, and special clothing.}\;28

Note the absence of any jointness in the production of z_1 and z_2. The only dependency between the two production functions is that fish catch is contingent upon whether or not any trips are taken—if no trips are taken, then no fish are caught.

These production functions include the exogenous technology variables d, q, k, and s because each of these variables may influence an angler's ability to combine x and t to produce z. As distance increases (ceteris paribus), for example, one would expect z_1 to decrease, because fishing parties traveling longer distances generally need to spend more money and more time traveling per trip. This means that the production process becomes less efficient as distance increases, which corresponds to shifts downward in the production curve and shifts upward in the marginal cost curve.\;29 Accordingly, it is hypothesized that the coefficients to the distance dummy variables will decrease as distance increases. The indicator variables q_1, q_2, and q_3 are included to determine whether time of year has any influence on the efficiency of production in the z_2 market. It is hypothesized that time of year will make a difference, because of differences in fish stock densities and in the catchability of fish.

Both k_1 and k_2 represent capital stock variables that are fixed for each household in the short run, but that vary
across households, because different households are in different stages of production. The hypothesized signs on the coefficients for $k_1$ and $k_2$ are positive. Finally, the variables comprising $s$ would ideally be indexes of fish stocks for each river. In the absence of fish population data, water quality parameters that can affect fish abundance and catchability can be included in the model. If water quality or fish stock variables are included in the model, then the quarter dummy variables can probably be dropped without significantly influencing the model's explanatory power.

The joint cost function is obtained from the empirically specified production functions. In this application the joint cost function is defined as

$$ C(w,z,d,k,q) = \sum_{i=1}^{2} \min \{x_i + w_i t_i \mid z_i = F_i(x_i, t_i, A_i)\} $$

where $w_i$ is the opportunity cost of time for $t_i$, and $A_i$ denotes the relevant set of technology variables for the $i$th production function. The cost-minimizing equations for $x$ and $t$ are specified as

$$ x_1 = x_1(w_1, d, k_1, z_1), $$
$$ x_2 = x_2(w_2, q, s, k_2, z_2), $$
$$ t_1 = t_1(w_1, d, k_1, z_1), $$
and
$$ t_2 = t_2(w_2, q, s, k_2, z_2). $$
Only the $t_1$ and $t_2$ functions can be referred to as input demand functions, because $x_1$ and $x_2$ denote expenditures rather than quantities. The time input demand functions can be found by application of Shepherd's lemma, since $\partial C/\partial w = t(\cdot)$, where $w = (w_1,w_2)$. Since market input prices and quantities are not separated in the cost equation, however, the cost-minimizing demand functions for market inputs are not obtainable.

The implicit price functions for $z_1$ and $z_2$ are specified as

$$\pi_1 = \partial C/\partial z_1 = \pi_1(w_1,d,k_1,z_1)$$

and

$$\pi_2 = \partial C/\partial z_2 = \pi_2(w_2,q,s,k_2,z_2).$$

In theory, the cost function should depend on prices of all inputs. Similarly, $\pi_1$ and $t_1$ should depend on the prices of market goods as well as $w_1$. Perhaps it is reasonable to assume that the technology parameter estimates obtained by using input expenditures ($x_1,x_2$) as proxies for quantities in the production functions will compensate for the omission of market input prices from the $C$, $t$, and $\pi$ functions.

In the second stage of the empirical analysis, household taste parameters are estimated given the previously estimated technology parameter estimates. Estimated ordinary (Marshallian) demand equations for $z_1$ and $z_2$ can provide estimates for taste parameters of the utility function as long as these taste parameters appear in the
ordinary commodity demand equations. Depending on the technology parameter estimates, either the structural or the quasi-reduced-form commodity demand equations are estimated in the second stage.

In this study the structural commodity demands are estimable only if the implicit expenditure equation \( I = \pi'z \) is homogeneous in \( z_1 \) and \( z_2 \). Also, if this homogeneity condition is satisfied, then the dual approach to modeling angler consumption decisions is applicable. This homogeneity condition is satisfied only if the joint cost function is homogeneous in \( z = (z_1, z_2) \). In fact, a cost function that is homogeneous of degree \( \kappa \) in \( z \) will generate an implicit expenditure equation that is also homogeneous of degree \( \kappa \) in \( z \). If the homogeneity condition is satisfied, then implicit income \( I \) can be treated as an exogenous variable in the structural commodity demand functions.

To illustrate, consider a homogeneous cost function of the form

\[
C = z_1^\kappa \cdot \phi_1(w_1,d,k_1) + z_2^\kappa \cdot \phi_2(w_2,q,s,k_2)
\]

where \( \phi_1 \) and \( \phi_2 \) only depend on exogenous technology and price variables. The implicit expenditure equation is written as

\[
I = \frac{\partial C}{\partial z_1} \cdot z_1 + \frac{\partial C}{\partial z_2} \cdot z_2
\]

\[
= \kappa[z_1^\kappa \cdot \phi_1(w_1,d,k_1) + z_2^\kappa \cdot \phi_2(w_2,q,s,k_2)] = \kappa \cdot C.
\]

In this case the variable \( I \) can be replaced by an instrumental variable \( \hat{I} \) for purposes of estimating taste parameters, where \( \hat{I} \) is equal to the product of \( \hat{\kappa} \) (the estimate for \( \kappa \) determined from the estimated production functions) and \( \mu \) (the total amount of full income allocated to the production of \( z_1 \) and \( z_2 \)). In this application if
\( w_1 = w_2 = w \), then \( \mu = M + w \cdot T \), where \( M \) denotes money income allocated to steelhead fishing per quarter and \( T \) denotes time allocated to steelhead fishing per quarter.

In principle, when \( \hat{I} \) can be used as an exogenous instrumental variable for \( I \), the structural taste parameters can be estimated by way of estimating the ordinary commodity demands in their structural forms. Recall from Chapter II that the indirect utility function associated with the structural demands is defined as

\[
V(\pi, I) = \max \{U(z) \mid \pi'z = I\}.
\]

The structural commodity demand functions can be found by application of Roy's identity. That is

\[
\frac{\partial V}{\partial I} = G(\pi, I) = G(\pi, \kappa \cdot \mu)
\]

In this application the joint cost function is homogeneous in \( z \) of degree \( \kappa \) only if each production function is homogeneous in \( x_i \) and \( t_i \) of degree \( 1/\kappa \). If this is not the case, then estimation of the structural commodity demand functions is not feasible, because implicit expenditures \( (I) \) cannot be treated as an exogenous variable. In this case, taste parameters can be estimated through estimation of the quasi-reduced-form commodity demand functions, which are defined on good prices rather than commodity shadow prices and on \( \mu \) rather than \( I \). The indirect utility function associated with these demand functions is defined as

\[
L(w, d, q, s, k) = \max \{U(z) \mid \mu = C(w, z, d, q, s, k)\}.
\]

In this application the quasi-reduced-form commodity demands are specified as
\[ z_1 = g_1(w, d, q, s, k) \]

and

\[ z_2 = g_2(w, d, q, s, k). \]

They are the solutions to the above maximization problem, but they can also be obtained by solving the structural commodity demands

\[ z_1 = G_1(w_1, d, k_1, z_1), \pi_2(w_2, q, s, k_2, z_2), \kappa \cdot \mu \]

and

\[ z_2 = G_1(w_1, d, k_1, z_1), \pi_2(w_2, q, d, k_2, z_2), \kappa \cdot \mu \]

for their reduced forms. This latter procedure is applicable only if \( I = \kappa \cdot \mu \).

In the third and final stage of the empirical analysis, estimates of angler benefits in both the fishing trips and sport-caught fish markets are determined. Per unit values are also determined. In this framework angler benefits are calculated by measuring household welfare impacts of eliminating \( z_1 \) and \( z_2 \) from the market. Several formulas for computing exact measures of household welfare changes were presented in the preceding chapter. The simplest of these formulas is used in the following chapter to calculate angler benefits.
Some Methodological Issues

One problem associated with using the two-stage procedure for estimating technology and taste parameters is that both systems of production functions and commodity demand functions are incomplete systems. This is because the number of endogenous variables in the model is equal to the number of goods \((n)\) plus the number of commodities \((m)\). Each of these systems only contains \(m\) equations, and hence the number of equations is less than the number of unknowns. As was mentioned above, Barnett (1977) contends that the taste and technology parameters should be estimated with a complete system of demand equations for goods and commodities.

The complete model describes demand and supply relationships for an individual angler. In this respect the fishing trips demand component of this model is different than the traditional travel cost model in which individual observations are grouped in accordance with distance zones around the site. In the traditional travel cost model the dependent variable is defined as the number of trips per capita for each zone, and independent variables are expressed in terms of zonal averages. Travel cost demand equations have also been estimated with individual observations—a procedure which seems to have resulted in substantial efficiency gains.

Brown et al. (1983) question the validity of specifying a demand model with the dependent variable defined as trips per recreationist, however, because such a model would not reflect cases where lower percentages of populations in more distant zones
participate in the recreational activity. In such cases one would expect a demand curve for trips per capita to be more elastic than a demand curve for trips per angler. Brown et al. (1983) illustrate that estimating a travel cost model from individual observations can lead to a downward bias in the travel cost coefficient, unless individual observations on the dependent variable are adjusted to a per capita basis. Even if the dependent variable were adjusted, a bias in the travel cost coefficient may still result from errors in individual recreationists' estimates of travel costs (Brown et al., 1983). This bias is not apparent in the traditional travel cost model, because zonal averages rather than individual travel costs are used to represent the "price" per trip.

As far as the demand function for trips in this model is concerned, the major difference between the HPF and travel cost approaches is that the former treats marginal cost per trip \( \pi_1 \) as the implicit price of a trip, whereas the latter views travel costs as the constant "price" per trip. Despite this difference in model specifications, the implicit price coefficient in the HPF model may still be subject to the same biases as is the travel cost coefficient in the travel cost model. A bias in the implicit price coefficient that would result from individual measurement errors in \( \pi_1 \) should be remedied by replacing \( \pi_1 \) with \( \hat{\pi}_1 \) (the expected value for \( \pi_1 \)) in the structural commodity demand equations for estimation purposes. This substitution process is part of the two-stage parameter estimation procedure outlined in the preceding section. Expected values of implicit prices depend on technology parameter estimates,
which are determined in the first stage. There is still a potential bias associated with using individual observations to estimate the demand equation for fishing trips; however, the dependent variable is not adjusted to a per capita basis in this application, for the sake of maintaining consistency between commodity demand equations and production functions, the latter of which is estimated with individual observations.
CHAPTER V

EMPIRICAL RESULTS FOR THE HOUSEHOLD PRODUCTION MODEL

The empirical results are presented in three major parts. The first section covers estimation of household technology parameters and specification of implicit price functions. In the second section taste parameter estimates are presented and welfare measurement in commodity markets is discussed. Estimates of angler welfare gains from participating in steelhead fishing activities in Oregon are presented in the third section. Values per recreational experience, per fishing trip, and per fish caught are provided, as are estimates of the net value of steelhead fishing in Oregon.

**Angler Technology and Implicit Price Equations**

It has already been noted that the primal approach will be used to specify technological relationships between goods and commodities. The first step in empirically specifying a household production model by the primal approach is to choose an appropriate functional form for the production function(s). In this model the technology is non-joint, since traveling inputs and fishing inputs are not used in the same production process. The two production functions for fishing trips \(z_1\) and fish catch \(z_2\) are thus separable functions. In choosing a functional form for each production function, it is
desirable in this application to select a specification that is associated with a homogeneous cost function in the commodity. If the single-commodity cost functions are both homogeneous of the same degree in their respective commodities, then the joint cost function is homogeneous in both commodities. Under nonjoint production, the joint commodity cost function is the sum of the single-commodity cost functions.

Due to the absence of a priori (theoretically-based) criteria for choosing among alternative functional forms, consideration is first given to those functional forms which are the most "popular" for empirical analysis. The Cobb-Douglas is one of the most widely used functional forms for empirical estimation of production functions (Intrilligator, 1978). Since the Cobb-Douglas function is homogeneous in inputs, and is therefore associated with a homogeneous cost function in the commodity, it is considered as a potential candidate for the $z_1$ and $z_2$ production functions. The two production functions are written in Cobb-Douglas form as

$$z_1 = e^y_{10} + y_{11}d_1 + y_{12}d_2 + y_{13}d_3 + x_1^{\alpha_1} + t_1^{\alpha_2} + k_1^{\beta_1} + u_1$$

and

$$z_2 = \begin{cases} e^{y_{20} + y_{21}d_1 + y_{22}d_2 + y_{23}d_3 + x_2^{\alpha_1} + t_2^{\alpha_2} + k_2^{\beta_2} + u_2} & \text{if } z_1 > 0 \\ 0 & \text{otherwise} \end{cases}$$

where $e = e^{ln^{-1}(1)} = 2.71828$, and $u_1$ and $u_2$ denote random disturbance terms, accounting for variations in productive capabilities among
anglers in the sample. Note that the \( q_i \)'s act as intercept shifters in the production function for \( z_2 \).

One of the characteristics of the Cobb-Douglas production function is that input elasticities are constant. An input elasticity measures the percentage change in output produced for a percentage change in the quantity of the input used. In a more flexible functional form, input elasticities might be allowed to vary with the quantities of inputs used; but in a Cobb-Douglas function the exponent of each input is equal to the input's elasticity. That is,

\[
\alpha_{11} = \frac{x_i}{z_i} \frac{\partial z_i}{\partial x_i}, \quad \alpha_{12} = \frac{t_i}{z_i} \frac{\partial z_i}{\partial t_i}
\]  

for \( i = 1, 2 \). Also, the sum of input elasticities in the Cobb-Douglas function equals the degree of homogeneity of the production function in inputs.

Another characteristic of the Cobb-Douglas production function is that the elasticity of substitution \( \sigma \) is unity. This elasticity is defined as the proportionate change in the input ratio over the proportionate change in the ratio of marginal products. Recall that the ratio of marginal products is called the marginal rate of technical substitution, which is equal to the ratio of input prices for a cost-minimizing producer. For \( x_i \) and \( t_i \), \( \sigma_i \) is defined as

\[
\sigma_i = \frac{\frac{d\ln(t_i/x_i)}{d\ln(p_i/w_i)}}{\frac{d(t_i/x_i)}{d(p_i/w_i)}} = \frac{(p_i/w_i)}{(t_i/x_i)} \frac{d(t_i/x_i)}{d(p_i/w_i)}. 
\]

The elasticity of substitution is thus a measure of the rate at which input proportions change in response to a proportionate change in relative input prices, ceteris paribus. In other words, \( \sigma \) gives the
rate at which input substitution takes place, or the substitutability of inputs for one another. An elasticity of unity means that a percentage increase in relative prices elicits an equivalent percentage increase in the reciprocal of the input ratio.

The Cobb-Douglas function imposes the condition that all of the inputs are indispensable in the production of output. It also imposes the condition that if all inputs are used, then a positive output is produced. The latter condition is reasonable in this application as far as the fishing trips production function is concerned. This may not be the case with the fish catch model, however, because a number of anglers in the sample did not catch any fish even though they employed market goods and expended time fishing. Fish catch is influenced by skill and environmental factors, some of which are marked by uncertainty and are not controllable by individual anglers. None of these factors are fully represented in the $z_2$ production function as specified above. This model in Cobb-Douglas form would predict a positive fish catch for any angler that uses positive quantities of both inputs and has some stock of capital. Thus, this model would not be useful for predictive purposes.

The Cobb-Douglas production function cannot be estimated with observations for which $z_2 = 0$. Excluding these observations from the sample for estimating the production function would likely result in biased parameter estimates; but adding a small positive number to the dependent variable (so that all of the observations could be used) would also lead to biased parameter estimates. The former procedure seems to be preferable in this application.
The major purpose of this study is to determine angler benefits in the fishing trips and sport-caught fish markets. For anglers with a zero fish catch, zero benefits are realized in the sport-caught fish market, because apparently the amount they are willing to pay to catch a fish is less than the actual marginal cost. It seems that the relevant sample of anglers for estimating production relationships in the $z_2$ market (for welfare measurement purposes in the $z_2$ market) are only those anglers that caught at least one fish.

Because the Cobb-Douglas function is linear in the logarithms of the variables, we can use linear regression analysis to estimate the two Cobb-Douglas production functions. Linear transformations of (5.1) and (5.2) are written as

$$\ln(z_1) = \gamma_{10} + \gamma_{11}d_1 + \gamma_{12}d_2 + \gamma_{13}d_3 + \alpha_{11}\ln(x_1) + \alpha_{12}\ln(t_1) + \beta_{11}\ln(k_1) + u_1$$

and

$$\ln(z_2) = \gamma_{20} + \gamma_{21}q_1 + \gamma_{22}q_2 + \gamma_{23}q_3 + \alpha_{21}\ln(x_2) + \alpha_{22}\ln(t_2) + \beta_{21}\ln(k_2) + u_2.$$  

The first set of ordinary least squares (OLS) regression results are presented in Table 1. The variable $k_1$ was dropped from the $z_1$ production model, because its estimated coefficient lacked statistical significance and its negative sign was contrary to the hypothesized sign. The remaining coefficients in the $z_1$ model are highly significant. In fact, some of the coefficients appear to be unusually high multiples of their standard errors.

In previous studies parameter estimates for Cobb-Douglas production functions have been very large relative to their standard errors,
### Table 1. Technology Parameter Estimates.

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Dependent Variable</th>
<th>Number of Fishing Trips</th>
<th>Number of Fish Caught</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$ - Traveling expenditures</td>
<td>.15740&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.04763)</td>
<td></td>
</tr>
<tr>
<td>$t_1$ - Travel time (hours)</td>
<td>.63351&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.04668)</td>
<td></td>
</tr>
<tr>
<td>$d_1$ - 0 to 30 miles</td>
<td>2.01639&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.87308)</td>
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<tr>
<td>$d_2$ - 31 to 60 miles</td>
<td>1.02982&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.08451)</td>
<td></td>
</tr>
<tr>
<td>$d_3$ - 61 to 90 miles</td>
<td>.57682&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.09498)</td>
<td></td>
</tr>
<tr>
<td>Constant term</td>
<td>-1.69634&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.10578)</td>
<td>-1.91455&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>$x_2$ - Fishing expenditures</td>
<td>.24682&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.06675)</td>
<td></td>
</tr>
<tr>
<td>$t_2$ - Fishing time (hours)</td>
<td>.75947&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(.08996)</td>
<td></td>
</tr>
<tr>
<td>$k_2$ - Value of capital goods</td>
<td>.10994&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(.07295)</td>
<td></td>
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<tr>
<td>$q_1$ - First quarter</td>
<td>-.15012</td>
<td>(.22223)</td>
<td></td>
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<tr>
<td>$q_2$ - Second quarter</td>
<td>-.39200&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(.24685)</td>
<td></td>
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<tr>
<td>$q_3$ - Third quarter</td>
<td>-.31565&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(.24207)</td>
<td></td>
</tr>
</tbody>
</table>

**Statistics**

<table>
<thead>
<tr>
<th></th>
<th>Number of Fishing Trips</th>
<th>Number of Fish Caught</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted $R^2$</td>
<td>.748</td>
<td>.635</td>
</tr>
<tr>
<td>F Statistic</td>
<td>222&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>(5,368)</td>
<td>(6,86)</td>
<td></td>
</tr>
<tr>
<td>Durbin-Watson Statistic</td>
<td>1.59</td>
<td>2.09</td>
</tr>
</tbody>
</table>

<sup>a(b)</sup> Denotes significance at the .005(.10) level.

Numbers in parentheses are standard errors.
even in cases where intercorrelations between explanatory variables were strong. "The coefficients are generally high multiples of their standard errors" (Koutsoyiannis, 1977, p. 238). High t-statistics coupled with multicollinearity is thus not uncommon in Cobb-Douglas production functions. Multicollinearity exists when two or more explanatory variables are linearly dependent.35

The Farrar-Glauber test was performed to determine the existence, severity, location, and pattern of multicollinearity in the \( z_1 \) production model. [See Koutsoyiannis (1977) pp. 242-249 for a description of this test.] Although the test results indicate a significant degree of multicollinearity in the model, the regression results in Table 1 suggest that the multicollinearity is not a serious problem. That is, all of the estimated coefficients have the hypothesized signs, they are all statistically different than zero, and their relative magnitudes seem to be acceptable on a theoretical basis. Firstly, the relationships among the coefficients to the distance dummy variables are consistent with the hypothesized relationships in that the production function shifts downward as distance from the site increases. Secondly, we should expect the input elasticity for \( t_1 \) \( (\alpha_{12}) \) to be greater than the elasticity for \( x_1 \) \( (\alpha_{11}) \), because travel time should have a greater influence on the number of trips for any given distance zone than do traveling expenditures on gas, food, and lodging. Expenditures per trip can be different for two anglers taking trips of the same distance and with the same travel time, because there may be differences in group size, type of lodging (e.g., campground or motel), type of restaurant, etc. Thus, it is probably
reasonable that percentage changes in traveling expenditures have relatively minor influences on the number of trips in this application.

It should be reiterated that travel time was computed by dividing total miles traveled by an estimated traveling speed (in miles per hour). The time spent dining and resting while on a trip was not included in the travel time variable, because the required data were not available. As a result, $t_1$ is equivalent for different anglers that traveled the same distance by the same mode of transportation. In reality, their travel times may vary, depending upon how many stops were made along the way and on the duration of each stop. The anticipated result of defining $t_1$ as a linear function of miles is a considerably higher output elasticity for $t_1$ than for $x_1$. The results do suggest that $\alpha_{11}$ is significantly greater than $\alpha_{12}$.

Similarly, the estimated coefficients $\hat{\alpha}_{21}$ and $\hat{\alpha}_{22}$ in the $z_2$ production function suggest that the fishing time input $t_2$ has a higher output elasticity than does the composite market input $x_2$ comprising guide service, bait, and lures (See Table 1). Both $t_2$ and $x_2$ have statistically significant coefficients at the .5 percent level. In Table 1 the capital goods variable $k_2$ is defined as the present (depreciated) value of fishing tackle and special clothing. The inclusion of boating equipment in the capital goods variable had no significant effect on the variable's explanatory power. As is shown in Table 1, the coefficient to $k_2$ is significantly different than zero at the 10 percent level. It is also of the theoretically correct positive sign.

The estimated coefficients to $q_1$, $q_2$, and $q_3$ in Table 1 suggest
that the number of fish caught per quarter is dependent on the quarter in which the trips are taken. Actually, since the coefficient to $q_1$ is not significantly different than zero, there seems to be no significant difference between fishing success in the first and fourth quarters, ceteris paribus. Also, there is no significant difference between the estimated coefficients to $q_2$ and $q_3$, suggesting that fishing success in those two quarters is similar. These results suggest that the fish catch production curves for the first and fourth quarters lie to the left (or upward) of the curves for the second and third quarters. Consequently, the estimated marginal cost curves for $z_2$ in quarters one and four lie to the right (or downward) of the marginal cost curves in quarters two and three.  

Although the Cobb-Douglas production functions seem to have provided reasonable parameter estimates, they do impose some restrictive conditions (e.g., the input elasticities and elasticity of substitution restrictions). A more flexible alternative to the Cobb-Douglas is the translog production function. "In general this function is quite flexible in approximating arbitrary production technologies in term of substitution possibilities" (Intrilligator, p. 280). Although the translog production function has a flexibility advantage over the Cobb-Douglas function, it is associated with a cost function that is not homogeneous in the commodity. Thus, it is not entirely consistent with the needs of this study. The translog production functions for $z_1$ and $z_2$ are estimated only to test the empirical appropriateness of the Cobb-Douglas production functions. The translog production functions are written as
\[
\ln(z_1) = A_1 + \alpha_1 \ln(x_1) + \beta_1 \ln(t_1) + \delta_{11} \ln(x_1) \ln(t_1) \\
+ \delta_{12} (\ln(x_1))^2 + \delta_{13} (\ln(t_1))^2 + \epsilon_1
\] (5.7)

and

\[
\ln(z_2) = A_2 + \alpha_2 \ln(x_2) + \beta_2 \ln(t_2) + \delta_{21} \ln(x_2) \ln(t_2) \\
+ \delta_{22} (\ln(x_2))^2 + \delta_{23} (\ln(t_2))^2 + \epsilon_1
\] (5.8)

where \(A_1\) and \(A_2\) are aggregate terms comprising the technology variables \((d)\) and \((k_2, q)\), respectively; \(\epsilon_1\) and \(\epsilon_2\) are random error terms. These functions are quadratic in the logarithms of the inputs. They collapse to Cobb-Douglas functions if the \(\delta_{ij}\)'s vanish; otherwise, the elasticities of substitution are nonunitary.

Below is the translog production function for fishing trips, which was estimated with the 374 observations for which \(x_1 \neq 0\):

\[
\ln(z_1) = -1.76054 + 0.19426 \ln(x_1) + 0.46015 \ln(t_1) \\
(0.14771) (0.14641) (0.13914) \\
-0.05050 \ln(x_1) \ln(t_1) - 0.00703 (\ln(x_1))^2 \\
(0.06598) (0.03759) \\
+ 0.13881 (\ln(t_1))^2 + 2.07339 d_1 \\
(0.03480) (0.08262) \\
+ 1.12810 d_2 + 0.64727 d_3
\] (5.9)

where the numbers in parentheses are the standard errors of the estimated coefficients. The estimated coefficients to \(\ln(t_1)\), \((\ln(t_1))^2\), \(d_1\), \(d_2\), and \(d_3\) are significantly different than zero at the .1 percent level and the coefficient to \(\ln(x_1)\) is significant at the 10 percent level. The fact that the coefficients to neither \((\ln x_1)(\ln t_1)\) nor \((\ln(x_1))^2\) are statistically significant suggest that these two variables can be dropped from the model; but this would not exactly reduce the model to a Cobb-Douglas specification.
The following translog production function for fish catch per quarter was estimated with the 93 observations for which $z_2, x_2 \neq 0$:

$$\ln(z_2) = -0.86117 - 0.13408\ln(x_2) + 0.37810\ln(t_2) + 0.15000\ln(x_2)^2$$

$$\ln(t_2) - 0.02027(\ln(x_2))^2 + 0.02157(\ln(t_2))^2$$

$$+ 0.10729\ln(k_2) - 0.14762 q_1 - 0.44487 q_2 - 0.29952 q_3.$$  

(5.10)

Only two variables - $\ln(x_2)\ln(t_2)$ and $\ln(k_2)$ - have statistically significant coefficients at the 10 percent level, and only $q_2$ has a significant coefficient at the 5 percent level. The fact that neither of the squared input terms ($\ln(x_2))^2$ and ($\ln(t_2))^2$ have significant coefficients and that the coefficient to the interaction term is not highly significant suggests that these variables can be dropped from the model without significantly affecting the model's explanatory power. This would reduce the model to a Cobb-Douglas production function. The parameter estimates in the resulting Cobb-Douglas function are quite different than the parameter estimates displayed in Table 1. Thus, adding the squared terms and interaction term to the Cobb-Douglas model seems to have caused the coefficients of other variables to decrease and their standard errors to increase. These results suggest that multicollinearity is present in the $z_2$ translog production function. Indeed, the Farrar-Glauber test results do indicate that all of the explanatory variables included in the translog model are multicollinear, with the exception of $\ln(k_2)$. Of all of the variables included in the Cobb-Douglas model, on the other hand, only the $q_i$'s are multicollinear. Thus, multicollinearity is a much
greater problem in the translog model than in the Cobb-Douglas model for \( z_2 \).

Based on statistical test results, the Cobb-Douglas functional form is deemed empirically appropriate for modeling technological relationships between levels of fish catch and fishing inputs. It seems to have produced reasonable technology parameter estimates (from Table 1) for both the fishing trips and fish catch models. For this reason, and for the sake of consistency, the Cobb-Douglas function is selected for modeling production relationships for fishing trips as well as fish catch.

For a given distance zone, decreasing returns to scale is exhibited by the estimated \( z_1 \) production function in Table 1, since \( \hat{\alpha}_{11} + \hat{\alpha}_{12} = 0.79 \). This seems to be reasonable, because as quantities of inputs used increase for a particular zone, distance may increase as well. Fishing trips cannot increase in proportion to the change in input usage if distance varies along the production function. For any given distance, however, it is assumed that the \( z_1 \) production function for a given angler should exhibit constant returns to scale, because the cost per trip should be constant across trips of the same distance.

If CRS were imposed on the \( z_1 \) production function as specified above, then the model would describe production relationships for an average angler in each distance zone. Since CRS is appropriate for the average angler, the hypothesis of CRS is tested below for the \( z_1 \) production function. This hypothesis is also tested for the \( z_2 \) production function, since \( \hat{\alpha}_{21} + \hat{\alpha}_{22} = 1.0063 \), which does not seem to be
significantly greater than one. The test statistic for the $z_i$ production function is defined as

$$t^* = \frac{\hat{\alpha}_{i1} + \hat{\alpha}_{i2} - 1}{\sqrt{\hat{\sigma}_{\alpha_{i1}}^2 + \hat{\sigma}_{\alpha_{i2}}^2 - 2\text{cov}^\hat{\alpha}_{i1,\alpha_{i2}}}}$$

(5.11)

where $\hat{\sigma}_{\alpha_{ij}}$ denotes the variance of the parameter estimate $\hat{\alpha}_{ij}$ and $\text{cov}^\hat{\alpha}_{i1,\alpha_{i2}}$ denotes the covariance between the two parameter estimates $\hat{\alpha}_{i1}$ and $\hat{\alpha}_{i2}$. If $t^* > t$ with $v = n - \rho$ degrees of freedom, then the null hypothesis of CRS can be rejected at the chosen level of significance, where $\rho$ is the number of explanatory variables. For the $z_1$ production function the value of $t^*$ is 2.39, which is not greater than $t$ at the 1 percent level. The value of $t^*$ for the $z_2$ function is only 0.00086. Thus, we fail to reject the null hypothesis of CRS in both production models, but at different probability levels. This means that we can adopt the assumption of equal degrees of homogeneity in inputs across the two production functions.

Two new sets of technology parameter estimates are presented in Table 2. The CRS restriction that $\alpha_{i1} + \alpha_{i2} = 1$ was imposed on both production functions by estimating the equations

$$\ln(z_1) - \ln(t_1) = \gamma_{10}^* + \gamma_{11}^* d_1 + \gamma_{12}^* d_2 + \gamma_{13}^* d_3 + \alpha_{i1}^* (\ln(x_1) - \ln(t_1)) + \beta_{12}^* \ln(d) + u_1^*$$

(5.12)

and

$$\ln(z_2) - \ln(t_2) = \gamma_{20}^* + \gamma_{21}^* q_1 + \gamma_{22}^* q_2 + \gamma_{23}^* q_3 + \alpha_{i1}^* (\ln(x_2) - \ln(t_2)) + \beta_{21}^* \ln(k_2) + u_2^*$$

(5.13)
Table 2. Constant Returns to Scale Technology Parameter Estimates.

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Number of Fishing Trips</th>
<th>Number of Fish Caught</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_1 ) - Traveling expenditures</td>
<td>( .17610^{a} )</td>
<td>(-.99935^{a} )</td>
</tr>
<tr>
<td>( t_1 ) - Travel time (hours)</td>
<td>( .82390 )</td>
<td>( )</td>
</tr>
<tr>
<td>( d_1 ) - 0 to 30 miles</td>
<td>( 2.36331^{a} )</td>
<td>( )</td>
</tr>
<tr>
<td>( t_1 ) - Travel time (hours)</td>
<td>( 1.19280^{a} )</td>
<td>( )</td>
</tr>
<tr>
<td>( d_3 ) - 61 to 90 miles</td>
<td>( .65843^{a} )</td>
<td>( )</td>
</tr>
<tr>
<td>Constant term</td>
<td>(-2.24702^{a} )</td>
<td>(-1.89935^{a} )</td>
</tr>
<tr>
<td>( x_2 ) - Fishing expenditures</td>
<td>( .24542^{a} )</td>
<td>( )</td>
</tr>
<tr>
<td>( t_2 ) - Fishing time (hours)</td>
<td>( .75458 )</td>
<td>( )</td>
</tr>
<tr>
<td>( k_2 ) - Value of capital goods</td>
<td>( .11047^{b} )</td>
<td>( )</td>
</tr>
<tr>
<td>( q_1 ) - First quarter</td>
<td>(-.14871 )</td>
<td>( )</td>
</tr>
<tr>
<td>( q_2 ) - Second quarter</td>
<td>(-.39108^{b} )</td>
<td>( )</td>
</tr>
<tr>
<td>( q_3 ) - Third quarter</td>
<td>(-.31473^{b} )</td>
<td>( )</td>
</tr>
<tr>
<td>Statistics</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>(.764 )</td>
<td>(.179 )</td>
</tr>
<tr>
<td>F Statistic</td>
<td>( 303^{a} )</td>
<td>( 5.028^{a} )</td>
</tr>
<tr>
<td>( (4,369) )</td>
<td>( (5,87) )</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a(b)}\) Denotes significance at the .005(.10) level.

Numbers in parentheses are standard errors.
and letting $\alpha_{12}^* = 1 - \alpha_{11}^*$ for $i = 1, 2$. Most of the new parameter estimates do not appear to be significantly different than their corresponding estimates from Table 1. Only the constant term and the coefficient to the time input in the $z_1$ production function seem to have changed considerably.

With CRS technologies, implicit commodity prices $\pi_1$ and $\pi_2$ are independent of commodity quantities. They are only dependent on exogenous technology variables and on fixed prices for goods; hence, they can be treated as fixed prices as well. Given the cost function $C(w, z, d, k_2, q)$ associated with the Cobb-Douglas CRS technologies, the following implicit price equations are derived:

\[
\hat{\pi}_1 = \frac{\partial C}{\partial z_1} = 15.06606(w_1)^{0.8239}(e)^{-2.3633d_1 - 1.1928d_2 - 0.6584d_3}
\]

\[
\hat{\pi}_2 = \frac{\partial C}{\partial z_2} = 11.6650(w_2)^{0.75458}(k_2)^{-0.11047}
\cdot(e)^{(0.14871q_1 + 0.39108q_2 + 0.31473q_3)}
\]

These are the expected values for $\pi_1$ and $\pi_2$. Although they are constant across commodity choice values, they generally vary across households as $w$, $d$, $k_2$, and $q$ change.

Table 3 contains estimates of implicit commodity prices for a representative angler. These $\hat{\pi}_i$'s were estimated by setting all of the exogenous variables in (5.14) and (5.15) equal to their sample mean values. Two different mean values for the opportunity cost of time vector $w$ were used to estimate $\pi$, each one being a fraction of mean hourly income. Cesario (1976) provides some empirical evidence in support of using the range of one-fourth to one-half of the wage rate to value the opportunity cost of nonwork travel time.
Table 3. Estimated Implicit Commodity Prices for a Representative Angler (1977 dollars)

<table>
<thead>
<tr>
<th>Opportunity Cost of Time (w)</th>
<th>Implicit Prices $\pi_1$</th>
<th>Implicit Prices $\pi_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{2}$ hourly income (mean $w^0 = $1.43)</td>
<td>$4.38$</td>
<td>$10.19$</td>
</tr>
<tr>
<td>$\frac{1}{2}$ hourly income (mean $w^0 = $2.87)</td>
<td>$7.77$</td>
<td>$17.18$</td>
</tr>
</tbody>
</table>

Theoretically, the opportunity cost of leisure time should reflect the value of time spent in activities that are traded off for the leisure activities. This notion is based on the premise that what a rational consumer is willing to pay for an extra hour of leisure time is at least as much as what was given up by not spending time in other activities. If the foregone activities are other non-work-related activities, then one can argue that the appropriate opportunity cost of leisure time should be zero. If the foregone activities are work related, on the other hand, then the appropriate opportunity cost is the wage rate, or a fraction of the wage rate. It can be argued that the opportunity cost should be equal to the wage rate that can be earned (which may not be equal to the regular wage rate) during time that is available for leisure activities. Cesario (1976) shows that the value placed on leisure time should be somewhat less than the wage rate in cases where there are disutilities associated with labor. In other words, the satisfaction that an individual derives from spending time in leisure activities rather than at work should be deducted from the foregone earnings.

In this application it may be appropriate to use different opportunity costs for $t_1$ and $t_2$. Cesario (1976) suggests that
the marginal value of [travel] time may be greater than or less than the value of leisure time, depending on whether travel time itself confers positive or negative utility upon the individual. In the typical case one might expect that the value of travel time would be greater than the value of leisure time itself. (p.35)

Since the disutilities associated with labor or travel are not directly observable, the choice of an appropriate opportunity cost is generally not completely based on theoretical considerations. Accordingly, only a reasonable range is presented here. 37

In cases where technologies are CRS, marginal costs for each commodity are equal to average costs. The figures in Table 3 indicate that for a representative angler, the average cost of traveling to and from a fishing site is within the range of $4.38 to $7.77 and the average cost of catching a fish is between $10.19 and $17.18, depending on the mean value of \(w\). The estimated mean implicit price of a sport-caught fish is actually higher in the second and third quarters than in the first and fourth quarters. In the second and third quarters the mean \(\bar{\pi}_2\) ranges from $11.81 to $19.82, while in the first and fourth quarters the mean \(\bar{\pi}_2\) ranges from $8.94 to $15.07.

These average costs (or implicit prices) do not necessarily reflect the benefits an angler gains from taking a fishing trip or catching a fish. They merely represent the amounts of money an angler is willing to pay per trip and per sport-caught fish for a representative river at the given levels of commodity demand during a given quarter. If commodity demand curves are downward sloping, then the marginal willingness to pay values are decreasing functions of demand.
Since the cost function is homogeneous of degree \( \kappa \) in \( z \), recall that by Euler's theorem it can be written as

\[
\kappa \cdot C(w,z,d,k_2,q) = \frac{\partial C}{\partial z_1} \cdot z_1 + \frac{\partial C}{\partial z_2} \cdot z_2 = \pi_1 z_1 + \pi_2 z_2
\]  
(5.16)

Thus, Barnett's (1977) "commodity shadow price approach" can be used to obtain the system of commodity demands as functions of commodity shadow prices \( \pi \) and the implicit level of income \( I = \kappa \cdot \mu \), where \( \mu \) is available full income. These demand functions can be derived through application of the dual approach. More flexibility regarding specification of functional forms is thus attained if the cost function is homogeneous in \( z \). Moreover, the compensated commodity demand functions \( H(\pi,U) \) can be derived by finding the inverse of the indirect utility function \( V = V(\pi,I) \) to obtain the expenditure function \( E = E(\pi,U) \), and then by using Shepherd's lemma: \( \partial E/\partial \pi = H(\pi,U) \).

In this application the degree of homogeneity \( \kappa \) is equal to one, and hence, \( I = \mu \). In cases where \( \kappa = 1 \), the "commodity shadow price approach" to modeling the household's optimization problem is identical to conventional utility maximization problems in which commodity prices are fixed. The ordinary commodity demand functions are written as \( G(\pi,\mu) = G(\pi_1(w_1,d),\pi_2(w_2,k_2,q),\mu) \). The first step to deriving \( G(\pi,\mu) \) by the dual approach is to specify an indirect utility function \( V(\pi,\mu) \). In this application one of the important criteria in addition to the regularity conditions for selecting a specification for the indirect utility function is that the function can be used to calculate compensating variation (CV) and
equivalent variation (EV). That is, it must be possible to solve
\[ V(\pi^1, \mu^0 - CV) = V(\pi^0, \mu^0) \] (5.17)
for CV, and, equivalently, to solve
\[ V(\pi^1, \mu^0) = V(\pi^0, \mu^0 + EV) \] (5.18)
for EV.

One potential candidate is the Cobb-Douglas indirect utility function, which is written as
\[
V = A \left( \frac{\gamma_1}{\gamma_1 + \gamma_2} \right)^{\gamma_1} \left( \frac{\mu}{\pi_1} \right)^{\gamma_1} \left( \frac{\mu}{\pi_2} \right)^{\gamma_2} = \tilde{A} \left( \frac{\mu}{\pi_1} \right)^{\gamma_1} \left( \frac{\mu}{\pi_2} \right)^{\gamma_2} 
\] (5.19)

By application of Roy's identity, the Marshallian (ordinary) demand specification for \( z_i \) is of the form
\[
G_i(\pi, \mu) = -\frac{\partial V/\partial \pi_i}{\partial V/\partial \mu} = \frac{\gamma_i}{\gamma_1 + \gamma_2} \frac{\mu}{\pi_i} = \tilde{\gamma}_i \frac{\mu}{\pi_i} 
\] (5.20)

By solving (5.19) for CV, one obtains an exact equation for the CV associated with a price change from \((\pi^0, \mu^0)\) to \((\pi^1, \mu^1)\):
\[
CV = \mu^0 - (\pi_1/\pi^0_1)^{\tilde{\gamma}_1} (\pi_2/\pi^0_2)^{\tilde{\gamma}_2} \cdot \mu^0. \] (5.21)

Similarly, an exact equation for EV is
\[
EV = \mu^0 \cdot (\pi_1/\pi^0_1)^{\tilde{\gamma}_1} (\pi_2/\pi^0_2)^{\tilde{\gamma}_2} - \mu^0. \] (5.22)

Since neither CV nor EV depend on \( \tilde{A} \), estimates of parameters \( \tilde{\gamma}_1 \) and \( \tilde{\gamma}_2 \) are all that is required for estimating welfare changes using equation (5.21) or (5.22).

The taste parameter estimates for \( \tilde{\gamma}_1 \) and \( \tilde{\gamma}_2 \) can be determined through estimation of the ordinary demand equations for \( z_1 \) and \( z_2 \).
Accordingly, the following demand equations can be estimated using a multivariate regression procedure:

\[ z_1 = \tilde{\gamma}_1(\mu / \hat{\pi}_1) + e_1 \]  
(5.23)

and

\[ z_2 = \tilde{\gamma}_2(\mu / \hat{\pi}_2) + e_2 = (1 - \tilde{\gamma}_1)(\mu / \hat{\pi}_2) + e_2 \]  
(5.24)

There are two serious consequences of using estimates of the taste parameters in (5.23) and (5.24) to estimate compensating and equivalent variations. First, since the sum of \( \tilde{\gamma}_1 \) and \( \tilde{\gamma}_2 \) is set equal to one, at least one of the parameter estimates must be fairly high. When either or both taste parameters are high, the result is that the CV for a price increase can be a large multiple of available income \( u^0 \). This can be illustrated by rewriting the equation for CV as

\[ CV = u^0(1 - C) \]  
(5.25)

where \( C = (\pi^1_1 / \pi^0_1)\tilde{\gamma}_1 (\pi^1_2 / \pi^0_2)\tilde{\gamma}_2 \). For a price increase the larger \( C \) is, the larger \( |1 - C| \) becomes. The value of \( C \) is a positive function of the magnitude of the price differential and of the values of \( \tilde{\gamma}_1 \) and \( \tilde{\gamma}_2 \).

The second consequence is that the negative of EV for a price increase is bounded by \( u^0 \). This means that the angler's willingness to pay is limited by the amount of full income that was initially allocated to the commodity group of \( z_1 \) and \( z_2 \). In other words, the angler is not allowed to adjust the first-stage budgeting decisions in response to changes in prices.
The combined effect of CV being a large multiple of $\mu^0$ and EV being bounded by $\mu^0$ is that the CV for a price increase is a large multiple of the EV. Conversely, for a price decrease the EV would be a large multiple of the CV. If two-stage budgeting is assumed, and if the second-stage decisions are modeled with a separable utility function, then it appears that large deviations might exist between CV and EV estimates. One could conclude that two-stage budgeting may not be a reasonable assumption for welfare analysis, since large deviations between CV and EV are inconsistent with Willig's (1976) results.

A different model specification is thus used to obtain taste parameter estimates which seem to be more appropriate for calculating CV and EV. This new model is not based on the assumption of two-stage budgeting. The new utility function is of the form

$$U = (z_1, z_2, z_3)$$

where $z_3$ is a vector of all other commodities, some of which might actually be market goods that are purchased for direct consumption. Assuming CRS technologies in all commodity markets, we can write the linear budget constraint as

$$S = \pi_1 z_1 + \pi_2 z_2 + \pi_3 z_3 \quad (5.26)$$

where $S$ is the total amount of full income and $\pi_3$ is a vector of implicit and market prices for the commodities in $z_3$.

Total full income is equal to

$$S = V + wT \quad (5.27)$$
where $V$ is the amount of income earned at the regular wage rate plus the amount of unearned income, $T$ is the amount of time available for producing the commodities $z_1, z_2, z_3$, and $w$ is the opportunity cost of time. It is assumed that any portion of $T$ that is not used to produce commodities is used to earn $w$ per hour. When $w$ is not equal to the regular wage rate, the value of $S$ is independent of time allocations if and only if $t_1 + t_2 + t_3 \leq T$, where $t_i$ is the amount of time used to produce $z_i$.

The new Cobb-Douglas indirect utility function is specified as

$$V = A(\lambda_1)^{\gamma_1(\lambda_2)^{\gamma_2(\lambda_3)^{\gamma_3(S/\pi_1)^{\gamma_1(S/\pi_2)^{\gamma_2(S/\pi_3)^{\gamma_3}}}}}}$$

(5.28)

where $\lambda_i = \frac{\gamma_i}{\gamma_1+\gamma_2+\gamma_3}$ and $\lambda_1 + \lambda_2 + \lambda_3 = 1$. The ordinary demand equation for $z_i$ is now written as

$$z_i = \lambda_i \frac{S}{\pi_i}.$$  

(5.29)

The new equation for the CV of a change in $\pi_1$ and $\pi_2$ is written as

$$CV = S^0 - (\pi_1^1/\pi_1^0)^{\lambda_1}(\pi_2^1/\pi_2^0)^{\lambda_2} \cdot S^0$$

(5.30)

and the new equation for EV is written as

$$EV = S^0 \cdot (\pi_1^0/\pi_1^1)^{\lambda_1}(\pi_2^0/\pi_2^1)^{\lambda_2} - S^0.$$  

(5.31)

In this model the EV of a price increase is bounded by $S^0$. Since $\lambda_1$ and $\lambda_2$ are likely to be very small, the CV for a price increase should not be a large multiple of $S^0$. As a result, CV should not be a large multiple of EV.
In order to calculate the welfare effects of change in $\pi_1$ and $\pi_2$ by using equation (5.30) or (5.31), we only need to have taste parameter estimates for $\lambda_1$ and $\lambda_2$. In estimating $\lambda_1$ and $\lambda_2$, we must assume that $w_1 = w_2 = w$. Two sets of taste parameter estimates are needed, corresponding to the two different definitions for $w$. The parameter estimates in Table 4 were obtained by estimating the ordinary demand equations for $z_1$ and $z_2$ as specified in (5.29). Since the only restriction on the two parameters is that $\lambda_1 + \lambda_2 \leq 1$, the OLS regression procedure seems appropriate for estimating the two equations. In order to use full income $S$ in the model, it is assumed that $V$ is fixed and that $t_1 + t_2 \leq T$.

Table 4. Taste Parameter Estimates.

<table>
<thead>
<tr>
<th>Opportunity Cost of Time (w)</th>
<th>$\lambda_1$</th>
<th>$\lambda_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ hourly income</td>
<td>0.002456</td>
<td>0.007334</td>
</tr>
<tr>
<td></td>
<td>(0.000157)</td>
<td>(0.001059)</td>
</tr>
<tr>
<td>½ hourly income</td>
<td>0.003579</td>
<td>0.010317</td>
</tr>
<tr>
<td></td>
<td>(0.000229)</td>
<td>(0.001467)</td>
</tr>
</tbody>
</table>

$n = 292$  
Numbers in parentheses are standard errors.

The results suggest that as $w$ increases from one-fourth to one-half of hourly income, the taste parameter estimates increase slightly. What is more important, however, is whether recreation benefit estimates are very sensitive to changes in the definition of $w$. This will be determined in the following section.
Recreation Benefit Estimates

Recreation benefits can be defined as the welfare gains that are enjoyed by recreationists as a result of their participation in a recreational activity, or they can be defined as the negative of the welfare losses that would be suffered by recreationists if they could no longer participate. To determine the value of an existing site, one is interested in measuring the welfare impacts on recreationists of eliminating the site. This is equivalent to measuring the welfare impacts of pricing the recreationists out of the market for that site. In this study the two utility-yielding components of a visit to a fishing site are the trip itself and the fish that are caught on that trip. Total recreation benefits are equal to the benefits in both commodity "markets".

In measuring total recreation benefits for steelhead anglers, therefore, we are interested in estimating the compensating variation (CV) or equivalent variation (EV) for an increase in shadow prices from \((\pi_1^0, \pi_2^0)\) to the minimum prices \((\pi_1^*, \pi_2^*)\) at which demands for \(z_1\) and \(z_2\) are reduced to zero. Both CV and EV are negative values for price increases. That is, the amount of money that can be taken away from an angler after a price increase to restore his initial utility level is a negative amount. Similarly, the amount of money that must be paid to an angler in lieu of a price increase to afford him the level of utility associated with that price is also a negative amount. For a change from \((\pi_1^0, \pi_2^0)\) to \((\pi_1^*, \pi_2^*)\), the negative of CV measures the minimum amount an angler must be paid if he is to stop going fishing. The negative of EV, on the other hand, measures the maximum amount an
angler is willing to pay to avoid a price at which he could no
ger longer afford to go fishing.

When the opportunity cost of time (w) is defined as one-fourth
of the angler's hourly income, an equation for the total CV in the
$z_1$ and $z_2$ markets is written as

$$CV = S^0 - \left(\frac{\pi_1}{\pi_1^*}\right)^{.002456} \left(\frac{\pi_2}{\pi_2^*}\right)^{.007334} \cdot S^0$$

where $\pi_1^*$ is the minimum shadow price at which the demand for $z_1$ con-
tioned on $\pi_2^0, \pi_3^0, d^0$ and $U^0$ is reduced to zero, and $\pi_2^*$ is the
minimum shadow price at which the demand for $z_2$ conditioned on $\pi_1^*,
\pi_3^0, k^0, q^0$, and $U^0$ is reduced to zero. This measure of welfare can
be calculated by summing the areas under compensated demand curves
for $z_1$ and $z_2$. The graphs in Figure 8 illustrate measurement of
total CV in the commodity markets. The demand curves in Figure 8
are linear for purposes of illustration. To estimate CV by the
sequential method, the first step is to measure the area under the
curve labeled $H_1(\pi_1, \pi_2^0, \pi_3^0, U^0)$ between $\pi_1^0$ and $\pi_1^*$. An increase in $\pi_1$
induces the demand curve for $z_2$ to shift to the right if the two
commodities are substitutes. The next step is to measure the
area under the curve labeled $H_2(\pi_1^*, \pi_2, \pi_3^0, U^0)$ between $\pi_2^0$ and $\pi_2^*$. Total CV is graphically represented by the sum of the shaded areas
in Figure 8. The same total area would have resulted if the change
in $\pi_2$ rather than $\pi_1$ had been considered first; but in that case
the demand curve for $z_1$ rather than $z_2$ would have shifted to the
right.
Figure 8. Graphical Representation of Compensating Variation for Price Increases in Commodity Markets.

We have already defined $t_1$ and $t_2$ as necessary inputs. It can be shown that in the traditional neoclassical framework, total welfare gains for the producer and final consumers of a commodity are represented by the area under the general equilibrium demand curve for any necessary input (Just, Hueth, and Schmitz, 1982). If the technology is CRS, then this area represents total consumer welfare, because the producer welfare measure is zero. In this application, therefore, the welfare effect on an angler of increasing the "prices" of $t_1$ and $t_2$ to the minimum points $(w_1^*, w_2^*)$ at which no more of those inputs are demanded should give the welfare impact of eliminating $z_1$ and $z_2$ from the market. To measure these welfare effects,
one can use the equations for CV and EV in which the implicit price equations from (5.14) and (5.15) have been substituted for \( \pi_1 \) and \( \pi_2 \).

The CV equation for a price increase from \((w_1^0, w_2^0)\) to \((w_1^*, w_2^*)\) when the opportunity cost of time is defined as one-fourth of hourly income can be written as

\[
CV = S^0 - \frac{\pi_1(w_1^*, d^0)}{\pi_1(w_1^0, d^0)} \cdot 0.002456 \left[ \frac{\pi_2(w_2^*, k_2^0, q^0)}{\pi_2(w_2^0, k_2^0, q^0)} \cdot 0.007334 \cdot S^0 \right]
\]

\[
= S^0 - \frac{(w_1^*/w_1^0) \cdot 0.82390 \cdot 0.002456 \cdot (w_2^*/w_2^0) \cdot 0.75458 \cdot 0.007334 \cdot S^0}{S^0} = S^0 - \frac{(w_1^*/w_1^0) \cdot 0.002023 \cdot (w_2^*/w_2^0) \cdot 0.005534 \cdot S^0}{S^0}.
\]

In estimating the two taste parameters \( \lambda_1 \) and \( \lambda_2 \) it was assumed that \( w_1 = w_2 = w \). Thus, the equation for CV can be written in the form

\[
CV = S^0 - \frac{(w^*/w_1^0) \cdot 0.002023 \cdot 0.005534 \cdot S^0}{S^0} = S^0 - \frac{(w^*/w_1^0) \cdot 0.007557 \cdot S^0}{S^0}.
\]

(5.33)

With shutdown prices of infinity, estimates of CV are of infinite magnitudes. To obtain realistic estimates for CV, therefore, we must choose a reasonable shutdown price for \( t_1 \) and \( t_2 \). Assuming that the sample of steelhead anglers used in this study is a random sample that is representative of the entire population of steelhead anglers in Oregon, an appropriate choice for \( w^* \) would be the maximum value of \( w \) in the sample. The fact that none of the anglers in the sample had an opportunity cost of time greater than \( w_{max} \) implies that the probability that anglers with opportunity costs greater than \( w_{max} \) would go steelhead fishing is very small or zero.
Of course, even if there is a minute probability that an angler with an opportunity cost greater than \( w_{\text{max}} \) would take at least one steelhead fishing trip, then the use of \( w_{\text{max}} \) as \( w^* \) would generate conservative estimates for recreation benefits.

Estimates of the negative of the CV for a change in \( w \) from \( w^0 \) to \( w^* \) for a representative angler are presented in Table 5, where \( w^0 \) is the sample mean opportunity cost. Different estimates are provided for the two different definitions of \( w \). The formula in (5.34) was used to compute CV per quarter when \( w \) is defined as one-fourth of hourly income. When \( w \) is defined as one-half of hourly income the formula for CV becomes

\[
CV = S^0 - (w^*/w^0) \cdot 82390(.003579) + .75458(.010317) \cdot S^0 \\
= S^0 - (w^*/w^0) \cdot 010734 \cdot S^0. 
\] (5.35)

It should be noted that \( S^0 \) changes as \( w^0 \) changes, since \( S^0 = V^0 + w^0T^0 \). Since the mean number of trips per quarter for the sample is 3.78, estimates of mean CV per visit in Table 5 are calculated by dividing 3.78 into the estimated CV per quarter. The results suggest that CV is sensitive to changes in the definition of \( w \). That is, a doubling of \( w^0 \) and \( w^* \) from one-fourth to one-half of hourly income resulted in a nearly doubling of CV.

The CV estimates in Table 5 represent net benefits per quarter and per visit rendered to a representative angler from the consumption of both \( z_1 \) and \( z_2 \). The per visit estimate gives the value of a fishing experience, which is defined here as the value of both the fishing trip itself and the fish caught per visit. Benefits per
quarter can be defined as the sum of quarterly benefits measured in the fishing trips and sport-caught fish markets.

Table 5. Compensating Variation Estimates per Quarter and per Visit for a Representative Angler (1977 dollars).

| Opportunity Cost of Time (w) | Mean |CV| per Quarter | Mean |CV| per Visit |
|-----------------------------|------|----------------|------|CV|----------------|
| ½ hourly income\(^a\)      | $81.82 | $21.64        |
| ⅓ hourly income\(^b\)      | 145.48 | 39.49         |

\(^a\) \(S^0 = \$5006.42, \bar{w}^0 = \$1.99, \) and \(w^* = \$17.00.\)

\(^b\) \(S^0 = \$6238.32, \bar{w}^0 = \$3.97, \) and \(w^* = \$34.00.\)

Because of the interrelationships between the \(z_1\) and \(z_2\) markets, it can be shown that the sum of CV's for price increases that are evaluated separately in each market is less than (in absolute terms) the total CV for price increases that are evaluated by a sequential procedure. The equation for the total CV in the \(z_1\) market is written as

\[
CV_1 = S^0 - (\pi_1^*/\pi_1^0)\lambda_1 \cdot S^0 \approx S^0 - (w^*/w^0) \cdot 82390(\lambda_1^0) \cdot S^0 \quad (5.36)
\]

and the equation for the total CV in the \(z_2\) market is written as

\[
CV_2 = S^0 - (\pi_2^*/\pi_2^0)\lambda_2 \cdot S^0 \approx S^0 - (w^*/w^0) \cdot 74548(\lambda_2^0) \cdot S^0. \quad (5.37)
\]

The absolute value of \(CV_1 + CV_2\) for a change in \(w\) from \(w^0\) to \(w^*\) is shown in Table 6. This sum is less than total \(|CV|\) (from Table 5), because the total CV accounts for the effects of a shadow price.
change in one commodity market on the compensated commodity demand curve in the other market. If the change in \( \pi_1 \) is the first price change considered, then for those anglers with a positive fish catch the extra area that is not included in \( CV_1 + CV_2 \) corresponds to the cross-hatched area in Figure 8. Although the difference is quite small in this example, this is not assumed to be the general case.

Table 6. Compensating Variation Estimates in Each Commodity Market for a Representative Angler (1977 dollars).

| Opportunity Cost of Time (w) | Mean \( |CV_1 + CV_2| \) | Mean \( |CV_1| \) per Trip | Mean \( |CV_2| \) per Fish Caught |
|------------------------------|----------------------------|--------------------------|-------------------------------|
| \( \frac{1}{4} \) hourly income | $81.55 | $5.76 | $21.66 |
| \( \frac{1}{2} \) hourly income | 144.80 | 10.48 | 38.11 |

Even though \( |CV_1 + CV_2| \) generally gives an underestimate of total \( |CV| \), the individual measures are useful in that they can be used to estimate mean values per trip and per fish caught (See Table 6). The value per trip measures an angler's willingness to pay for accessibility to a fishing site. For anglers with a zero fish catch, the CV per trip represents the net benefits of a fishing experience, because fish catch is the only on-site service that is recognized as a utility-yielding commodity in this study.

The absolute values of EV estimates per quarter and per visit for a representative angler are presented in Table 7. As were the values shown in Table 5, these welfare impacts were measured for an
increase in \( w \) from \( \bar{w}^0 \) to \( w^* \). As one would expect, the estimates of EV are slightly smaller in absolute value terms than the CV estimates for the same price increases. For an increase in prices, EV is bounded by \( S^0 \), because the negative of EV measures the maximum amount of money that an angler is willing to pay to avoid the higher price. In contrast, CV is unbounded for a price rise.

Table 7. Equivalent Variation Estimates per Quarter and per Visit for a Representative Angler (1977 dollars).

| Opportunity Cost of Time (w) | Mean |EV| per Quarter | Mean |EV| per Visit |
|-----------------------------|------|----------------|------|----------------|
| \( \frac{1}{2} \) hourly income | $80.50 | $21.30 |
| \( \frac{1}{4} \) hourly income | 142.16 | 37.61 |

The absolute values of \( EV_1 + EV_2 \) for a representative angler are presented in Table 8. By comparing the values in the first columns of Tables 7 and 8, one finds that \( |EV_1 + EV_2| \) for price increases which were evaluated separately in each market is only slightly greater than the total \( |EV| \) for price increases which were evaluated simultaneously. These relationships are illustrated graphically in Figure 9 with linear demand curves. Since the EV for a price rise is equal to the negative of the CV for a corresponding price fall, measuring the EV for a shadow price change from \((\pi^0_1, \pi^0_2)\) to \((\pi^*_1, \pi^*_2)\) is equivalent in absolute terms to measuring the CV for the change from \((\pi^*_1, \pi^*_2)\) to \((\pi^0_1, \pi^0_2)\), as is illustrated in
Figure 9. If the price changes are evaluated sequentially, and if the change in $\pi_1$ is considered first, then the total CV for the fall in both prices is represented by the sum of the cross-hatched areas. If the price changes are evaluated independently of one another, on the other hand, then $CV_1 + CV_2$ is represented by the sum of the cross-hatched areas plus the dotted area. This implies that $|CV_1 + CV_2|$ is greater than total $|CV|$ for price decreases, and hence, $|EV_1 + EV_2|$ is greater than total $|EV|$ for price increases. Although the differences are extremely small in this example, this is not assumed to be the general case. \textsuperscript{43}

Table 8. Equivalent Variation Estimates in Each Commodity Market for a Representative Angler (1977 dollars).

| Opportunity Cost of Time (w) | Mean $|EV_1 + EV_2|$ | Mean $|EV_1|$ per Trip | Mean $|EV_2|$ per Fish Caught |
|-----------------------------|------------------|-----------------|-----------------|
| $\frac{1}{2}$ hourly income | $80.76$          | $5.73$          | $21.41$         |
| $\frac{1}{2}$ hourly income | $142.81$         | $10.42$         | $37.47$         |

The annual net value to Oregon anglers of steelhead fishing at the 29 rivers covered in this study is estimated by multiplying the mean value per visit (fishing experience) from Table 5 or Table 7 by the estimated number of steelhead fishing trips taken by Oregon anglers in a given year. Based on the sample, it is estimated that Oregon households took approximately 528,949 steelhead fishing trips.
Four different estimates for the annual net value of Oregon Steelhead fishing are presented in Table 9, corresponding to the two different definitions for \( w \) and the two welfare measures. Note that the CV and EV estimates are fairly similar in magnitude.

<table>
<thead>
<tr>
<th>Opportunity Cost</th>
<th>CV Measure</th>
<th>EV Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{1}{4} ) hourly income</td>
<td>$11.45</td>
<td>$11.27</td>
</tr>
<tr>
<td>( \frac{1}{2} ) hourly income</td>
<td>20.89</td>
<td>19.89</td>
</tr>
</tbody>
</table>

Figure 9. Graphical Representation of Compensating Variation for Price Decreases in Commodity Markets.
The results presented in Tables 5 through 9 indicate that recreation benefit estimates are quite sensitive to changes in the definition of the opportunity cost of time spent traveling and fishing. Also, the results suggest that when the value of fish caught per trip is considered along with the value of the fishing trip itself, benefits derived from the fishing experience can be approximately four times the benefits derived from the trip.

Since qualitative variables (such as fish catch) are not explicitly considered in the traditional travel cost methodology, it is difficult to compare these results to the results of previously conducted recreation studies. The empirical results presented indicate that the household production function methodology can be a useful technique for valuing fishing trips and sport-caught fish. Moreover, the conceptual framework can be easily expanded to include estimation of benefits resulting from changes in exogenous quality variables. The inclusion of quality characteristics of fishing sites as public inputs to fish catch is considered in the next chapter.
CHAPTER VI
INCLUSION OF EXOGENOUS WATER QUALITY VARIABLES IN THE HOUSEHOLD PRODUCTION MODEL

One of the objectives of this study is to determine the effects of selected stream quality parameters on fish catch rates. This was to be accomplished by adding water quality indicators to the set of explanatory variables in the $z_2$ production function, and then by re-estimating the technology parameters. Since water quality conditions are exogenously determined, the inclusion of water quality variables in the model gives $z_2$ more exogenous characteristics than it had in the specification used earlier as in equation (5.2). Additionally, the model becomes more useful for policy analysis if it includes policy-controlled or -influenced quality variables. Since one of the goals of this study is to develop a model that could eventually be linked to a forest planning model and used in forest policy analysis, the interest is in selecting water quality elements of anadromous fish habitat that may be influenced by timber harvesting.

Description of Water Quality Data

From Department of Environmental Quality (D.E.Q.) data files and Oregon Water Resources Department reports, data were acquired on five physical water quality parameters for 25 of the 29 rivers covered in the 1977 angler survey. These four quality parameters were selected for inclusion in the model: streamflow (cubic feet per
second), water temperature (degrees centigrade), turbidity (JTU and FTU), and total nonfilterable residue (milligrams per liter). Research has indicated that these water quality parameters can influence fish habitat quality and fish survival rates. Changes in stream quality conditions can influence adult populations of anadromous fish during periods of fish migration back upstream. Any significant changes in adult steelhead abundance are likely to have immediate impacts on fish catch rates. Wild anadromous fish also spend the early part of their lives being reared in fresh-water streams. Any significant changes in fry emergence and survival rates caused by alterations in stream quality can influence adult returns in later years; so stream quality changes may have delayed as well as immediate effects on catch rates. Thus, it would be desirable to have lagged quality variables in the model; however, both time and data limitations have prevented the incorporation of a lag distribution into the model. The main concentration of this study is on the immediate impacts of physical water quality conditions on fish catch rates. Quality data for 1977 are required for the empirical analysis.

The streamflow data were recorded by both sources on a daily basis, whereas the other quality data were recorded by the D.E.Q. on a monthly basis, where one sample was taken per month. It was necessary to adjust all of the quality data to a quarterly basis so that they would be consistent with the fish catch data from the angler survey. Thus, the water quality data were averaged over the days or months of each quarter. Some of the rivers had only one location at which water samples were taken, while others had more than one sample


point. For the rivers with multiple sample points the quality data were averaged over the sample points in the same county. This averaging process was necessary because the fish catch data were not site specific. That is, the angler questionnaire only provided information on the rivers and counties in which respondents fished, not on the exact locations of fishing sites.

In addition to physical quality parameters, the quality data set used in this study also includes data on numbers of smolts released from hatcheries into nine of the coastal rivers. These data were obtained from the Oregon Department of Fish and Wildlife (O.D.F.W.). The smolt releases data were used to construct a variable to indicate fish abundance in the nine rivers. Although a better variable would have been total adult fish stocks (hatchery and wild), data on fish populations are generally not available. Nonetheless, it can be argued that hatchery releases serve as good indicators of fish abundance in these nine rivers, because according to the O.D.F.W., the fish in these rivers are primarily hatchery fish (over 70 percent hatchery fish in most cases).

The relevant number of smolt releases to include in the model varies for a given river from quarter to quarter. Both winter and summer species of steelhead are released during the month of April in any given year, but the two species generally return to the coastal rivers at different times of the year. Approximately 90 percent of the winter releases will return during the four-month period from December of the following year through March. The remaining 10 percent will return during the same four-month period a year later. As
for summer steelhead releases, they will return after two years during the months of May through November. The hatchery steelhead that returned in 1977 were thus released in both 1975 and 1976. Assuming that the steelhead returns are evenly distributed across the various months in each period, portions of the 1975 releases and 1976 releases are apportioned to the four quarters of 1977 in the manner described in Table 10.

Table 10. Distribution of 1975 and 1976 Summer and Winter Steelhead Smolt Releases Among the Four Quarters of 1977.

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Definition of Smolt Releases (Rel) Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75% of stw 1975</td>
</tr>
<tr>
<td>2</td>
<td>28% of sts 1975</td>
</tr>
<tr>
<td>3</td>
<td>43% of sts 1975</td>
</tr>
<tr>
<td>4</td>
<td>29% of sts 1975 plus 25% of stw 1976</td>
</tr>
</tbody>
</table>

a stw denotes winter steelhead.
b sts denotes summer steelhead.

Since the hatchery fish that returned in 1977 were released in April of 1975 and 1976, daily streamflow data for each of these two months were added to the quality data set for use in constructing a lagged streamflow variable. As is indicated in
Table 10, the hatchery returns in the first three quarters of 1977 were winter and summer steelhead released in 1975. Accordingly, for the first three quarters the lagged streamflow variable is defined as the average daily streamflow in April 1975. For the rivers with no summer steelhead runs, hatchery fish that returned in the fourth quarter of 1977 were released in 1976. In these cases the lagged variable for the fourth quarter is defined as the average daily streamflow in April 1976. For the three rivers with both summer and winter runs, the fourth quarter lagged variable is defined as the average daily streamflow in April of both 1975 and 1976.

Since the nine coastal rivers for which smolt releases data were obtained have similar fish migration patterns, it is hypothesized that their stream quality — fish catch relationships are also similar. If this is the case, then these technical relationships can be explained by the same model for all of the nine rivers. Given the assumption of homogeneity across the rivers, such a model is developed in this study to estimate the effects of water quality changes on numbers of sport-caught steelhead for these rivers.

Influences of Selected Water Quality Variables on Fish Catch

The first attempt toward modeling the stream quality — fish catch relationships involved the inclusion of all of the six quality variables (including smolt releases and lagged streamflow) in the fish catch per quarter ($z_2$) production function. In Cobb-Douglas form this production function is specified as
\[ z_2 = e^{y_1 x_2 + \alpha_{21} t_2 + \alpha_{22} x_2 + \beta_{21} \text{Rel} + \theta_1 \text{Temp} + \theta_2 \text{Sf} + \theta_3 \text{Lsf} + \theta_4 \text{Turb} + \theta_5 \text{Res}} \]  

(6.1)

where the exogenous quality variables are lagged smolt releases (Rel), water temperature (Temp), streamflow (Sf), lagged streamflow (Lsf), turbidity (Turb) and total nonfilterable residue (Res).

After this function was estimated it was immediately seen that adding all of the quality variables to the model at the same time could lead to problems, because there were symptoms of multicollinearity (such as low t ratios coupled with a high F statistic) in the model.

With these symptoms the set of explanatory variables does not influence the dependent variable, but the separate effects of each of the individual explanatory variables cannot be determined. [Intrilligator (1978), p. 153].

In the presence of a multicollinearity problem the parameter estimates can be both imprecise and unstable. These undesirable conditions may be exhibited by the model specification in (6.1), since high intercorrelations among the six quality variables are evidenced by the high partial correlation coefficients in Table 11. The only variables which do not have partial correlations greater than the \( R^2 \) (= .58) for the multiple regression with at least two of the other five quality variables are turbidity and residue; but the correlation between turbidity and residue of .96 is the highest one in the matrix.46 The second highest correlation of .93 is between the lagged streamflow and streamflow variables. Because of these two extremely high correlations, it would be prudent to use neither turbidity and residue at the same time nor lagged streamflow and streamflow at the same time as explanatory variables. Because lagged streamflow and residue
have higher partial correlations with the other variables than do streamflow and turbidity, respectively, it was decided that lagged streamflow and residue should be dropped from the model.

Table 11. Correlation Matrix for Exogenous Quality Variables.

<table>
<thead>
<tr>
<th></th>
<th>Streamflow</th>
<th>Water temperature</th>
<th>Turbidity</th>
<th>Residue</th>
<th>Hatchery releases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagged streamflow</td>
<td>.93</td>
<td>-.77</td>
<td>.17</td>
<td>.36</td>
<td>.60</td>
</tr>
<tr>
<td>Streamflow</td>
<td></td>
<td>-.62</td>
<td>.13</td>
<td>.34</td>
<td>.48</td>
</tr>
<tr>
<td>Water temperature</td>
<td></td>
<td></td>
<td>-.19</td>
<td>-.25</td>
<td>-.62</td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td></td>
<td>.96</td>
<td>.08</td>
</tr>
<tr>
<td>Residue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.20</td>
</tr>
</tbody>
</table>

The \( z_2 \) production function was then reestimated with these four quality variables included: Rel, Sf, Temp, and Turb. Although the coefficient to Rel had the correct sign and was significantly different than zero, this was not true of the coefficients to the other three quality variables. Thus, these four quality variables do not seem to work well as a group in the \( z_2 \) production model, apparently because of high correlations that still exist between some of these variables. One possible remedy for this
problem is to use a quality index which would be defined as some combination (such as a weighted average) of all of the different but related quality parameters; however, the construction of a quality index is beyond the scope of this study. It would also require more research on the relative importance of each quality parameter in influencing fish abundance and fish catch rates.

Even though these four quality variables could not be used in the same model, perhaps including only a subset of these variables would provide acceptable results. First, to determine which of the quality variables have a significant influence on fish catch rates, the separate effect of each variable on $z_2$ (given $x_2$ and $t_2$) was estimated. This was done by estimating a different $z_2$ production function for each of the four quality variables. The pertinent regression results are presented in Table 12. In each Cobb-Douglas production function the inputs $x_2$ and $t_2$ are included. The capital goods variable $k_2$ is excluded for lack of explanatory power. All of the F statistics are significant at the .001 level. Of the exogenous quality variables only Rel has a highly significant coefficient at the .005 level, but Temp and Sf also have significant coefficients at the .05 and .10 levels, respectively. The coefficient to Turb is neither significantly different than zero nor does it have the hypothesized negative sign. It may be that there was not enough variability in mean turbidity levels in the sample to estimate a significant coefficient. A possible explanation for the positive sign is that none of the mean turbidity levels were high enough to have detrimental effects on catch rates.
Table 12. Regression Results for Fish Catch Production Functions in Which Exogenous Quality Variables are Included.

<table>
<thead>
<tr>
<th>Quality Variable Included ($s_j$)</th>
<th>Exogenous Quality Variable</th>
<th>Other Explanatory Variables</th>
<th>Constant term</th>
<th>$F^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smolt Releases (Rel) n=34</td>
<td>$\ln(s_j)$</td>
<td>$\ln(x_2)$</td>
<td>$\ln(t_2)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.31158^b</td>
<td>.27631^a</td>
<td>.69580^a</td>
<td>-4.8056^a</td>
</tr>
<tr>
<td>Water temperature (Temp) n=31</td>
<td>-1.0954^c</td>
<td>.28292^b</td>
<td>.64761^a</td>
<td>1.0390</td>
</tr>
<tr>
<td>Streamflow (Sf) n=34</td>
<td>.25207^d</td>
<td>.25465^b</td>
<td>.64972^a</td>
<td>-2.9804</td>
</tr>
<tr>
<td>Turbidity (Turb) n=31</td>
<td>.14164</td>
<td>.30334^a</td>
<td>.65713^a</td>
<td>-1.6286^b</td>
</tr>
</tbody>
</table>

$a(b)$ Denotes significance at the .005(.01) level.
$c(d)$ Denotes significance at the .05(.10) level.
Numbers in parentheses are standard errors.

The results presented in Table 12 indicate that the quality variables with significant explanatory power in this example are Rel, Temp, and Sf. Although the separate effect of each of these three variables is significant, as a group these variables do not seem to influence the quantity of fish caught per quarter. That is, when all three variables were included in the model, neither Temp nor Sf had a coefficient that was significantly different than zero.
Also, in the complete model the sign on the coefficient to Sf was contrary to the sign on the estimated coefficient to Sf in Table 12.

Since Rel, Temp, and Sf do not seem to work well together, the three possible combinations of these three variables were tested. Each combination of two variables worked fairly well in that the signs on all of the coefficients were consistent with the signs in Table 12. In each case, however, only one of the two quality variables had a coefficient that was significantly different than zero even at the 10 percent level. When Sf and Temp were included in the same model, for example, Temp had a highly significant coefficient, but Sf had very little explanatory power. When Rel was included with either Sf or Temp, on the other hand, Rel always dominated in explanatory power.

In fact, the smolt releases variable consistently had a significant coefficient with the correct positive sign in all of the regressions discussed above. When any of the other quality variables were added to the production function along with Rel, however, these variables did not have significant influences on fish catch rates. Thus, smolt releases seems to work best as the only exogenous quality variable in the model. Such a model can be useful for policy analysis, because policy decisions regarding smolt releases will generally not influence physical water quality parameters. In some cases, therefore, policies regarding smolt releases can be evaluated independently of policies concerning water quality.

Like Rel, both Temp and Sf have more explanatory power when they are included separately in the z₂ production function than when they
are included together. For some policy analysis, however, it may be useful to use these two variables jointly. Research has shown that both water temperature and streamflow can be influenced by timber harvesting (Chamberlin, 1982). If both $S_f$ and $Temp$ are included in the $z_2$ production model, then it is possible to measure the impact of logging-induced changes in $Temp$ and $S_f$ on angler benefits. The production model in which both $Temp$ and $S_f$ are included is written in logarithmic form as

$$\ln(z_2) = .2724 \ln(x_2) + .6647 \ln(t_2) - .9287 \ln(Temp) + .0195 \ln(S_f)$$

(6.2)

The constant term was dropped for lack of statistical significance. The coefficients for both of the input variables are highly significant, and the coefficient to $\ln(Temp)$ is significant at the .025 level. The coefficient to $\ln(S_f)$ is also significant, but only at the .25 level. For reasons that will be discussed in the next section, it is necessary to use the technology parameter estimates from (6.2) rather than those from Table 12 for measuring the welfare implications of changes in both water temperature and streamflow.

**Measuring Welfare Impacts of Exogenous Quality Changes**

The first equation in Table 12 provides technology parameter estimates which can be used to measure the welfare impacts of changes in the number of smolts released from hatcheries. In order to evaluate welfare implications of quality changes, however, one needs to have estimates of taste parameters as well as technology parameters.
The taste parameter estimates for $\lambda_1$ and $\lambda_2$ from Table 4 can be used here if the production function for $z_2$ defined on $x_2, t_2$, and Rel is found to be homogeneous of degree one in inputs. The results in Table 12 suggest that this production model is homogeneous in $x_2$ and $t_2$ of degree .972, which is not significantly different than 1 at the .001 level of significance. With the assumption of constant returns to scale (CRS), this production function in logarithmic form becomes

$$\ln(z_2) = -4.9482 + .28274 \ln(x_2) + .71726 \ln(t_2) + .31658 \ln\text{Rel}$$

(6.3)

The estimated input coefficients in this model are only slightly different than the estimates shown in Table 2 for the original production model. It should be mentioned that estimates for the input coefficients remained fairly stable throughout this analysis. Thus, including different sets of explanatory variables does not seem to considerably influence the input elasticities.

There are several approaches for determining the effects on angler benefits of a change in releases from Rel$^0$ to Rel$^1$. One approach is to derive the compensated inverse demand function for releases, and then measure the area under the demand curve between Rel$^0$ and Rel$^1$. Maler (1974) states that the inverse compensated demand function for a quality characteristic can be obtained by partially differentiating the expenditure function with respect to the quality characteristic. In this example the expenditure function that is associated with the Cobb-Douglas indirect utility function in (5.28) is of the form
\[
e = \frac{1}{(U/A)} \left[ \frac{1}{\gamma_1 + \gamma_2 + \gamma_3} \right]^{\lambda_1} \left[ \frac{1}{\pi_1(w,d)} \right]^{\lambda_2} \left[ \frac{1}{\pi_2(w,Rel)} \right]^{\lambda_3}
\]

where \( \lambda_i = \frac{\gamma_i}{\gamma_1 + \gamma_2 + \gamma_3} \) and \( \Lambda = (\lambda_1) \gamma_1 (\lambda_2) \gamma_2 (\lambda_3) \gamma_3 \). The inverse compensated demand function for Rel is written as

\[
p_1^* = \frac{\partial e}{\partial Rel} = \frac{1}{(U/A)} \left[ \frac{1}{\gamma_1 + \gamma_2 + \gamma_3} \right]^{\lambda_1} \left[ \frac{1}{\pi_1(w,d)} \right]^{\lambda_2} \left[ \frac{1}{\pi_2(w,Rel)} \right]^{\lambda_3} \frac{\partial \pi_2(w,Rel)}{\partial Rel}
\]

where \( p_1^* \) denotes the compensated demand price for Rel. Since we only have estimates for \( \lambda_1 \) and \( \lambda_2 \), however, we cannot empirically specify (6.5), and hence we cannot calculate welfare changes by measuring areas under the inverse compensated demand curve for Rel.

An alternative approach to measuring welfare impacts of changes in Rel is to use the equation for CV or EV defined on Rel. Letting \( \pi_2^0 = \pi_2(w,Rel^0) \) and \( \pi_2^1 = \pi_2(w,Rel^1) \), the equation for the CV of a change in \( \pi_2 \) from \( \pi_2^0 \) to \( \pi_2^1 \) is written as

\[
CV = S^0 - (\frac{1}{\pi_2^0/\pi_2^1})^{\lambda_2} \cdot S^0.
\]

Given the empirically specified implicit price equation for \( \pi_2 \):

\[
\hat{\pi}_2 = 255.7545(w) \cdot 71726(\text{Rel})^{-0.31658},
\]

equation (6.6) can be written as

\[
CV = S^0 - (\text{Rel}^1/\text{Rel}^0)^{-0.31658(\lambda_2)} \cdot S^0.
\]

Depending on whether the opportunity cost of time \( w \) is valued at one-fourth or one-half of the angler's hourly income, the
appropriate parameter estimate for $\lambda_2$ from Table 4 can be used in (6.8). The value of $S^0$ will also depend on the definition of $w$.

The same approach can be used to estimate the welfare impacts on anglers of changes in water temperature (Temp) and/or streamflow (Sf). Since the input coefficients from (6.2) sum to .937, which is not significantly different than 1, the assumption of a CRS technology can be adopted for the production function in which Temp and Sf are included. The estimated CRS production function is written as

$$\ln(z_2) = .2892\ln(x_2) + .7108\ln(t_2) - .9797\ln(\text{Temp}) + .0822\ln(\text{Sf})$$

and the implicit price equation for $\pi_2$ is empirically specified as

$$\hat{\pi}_2 = 1.8247(w) \cdot .7108(\text{Temp}) \cdot .9797(\text{Sf})^{-.0822}.$$  

(6.9)

(6.10)

Using equation (6.10) one finds that the equation for the CV of an exogenous quality change from $(\text{Temp}^0, \text{Sf}^0)$ to $(\text{Temp}^1, \text{Sf}^1)$ is written as

$$\text{CV} = S^0 - [(\text{Temp}^1 / \text{Temp}^0) \cdot .9797(\text{Sf}^1 / \text{Sf}^0)^{-0.0822}]^{\lambda_2} \cdot S^0.$$  

(6.11)

Again, the parameter estimate for $\lambda_2$ can be taken from Table 4.

The CV for a change in both temperature and streamflow can also be determined by calculating areas under the inverse compensated demand curves $p^*_2 = \partial e/\partial \text{Temp}$ and $p^*_3 = \partial e/\partial \text{Sf}$, where $e$ is the expenditure function conditioned on Temp and Sf. If the changes in Temp and Sf are calculated independently of one another, then the sum of CV in each quality "market" will in general misstate the total CV that is calculated by a sequential procedure or by (6.11), because the inverse compensated demand function for one quality characteristic will in general depend on the other quality characteristic. It is important to account for such interrelationships between quality "markets" when
one evaluates changes in both characteristics. For this reason it is better to use the technology parameter estimates from (6.2) or (6.9) for welfare analysis rather than those from Table 12, where each quality variable was separately included in the production function.

The equations in (6.8) and (6.11) will give estimates of CV per quarter for exogenous quality changes. Rather than determining changes in quarterly benefits, it may be more interesting for policy analysis to determine changes in the value of a fishing experience. In addition, since a change in site quality characteristics influences the marginal cost (implicit price) of catching a fish, the demand for fish catch is also responsive to exogenous water quality changes. The fishing trips (ordinary) demand function of the Cobb-Douglas type is not dependent on \( \pi_2 \); hence, because of the restrictions placed on the model, the number of trips taken per quarter is not influenced by changes in the site quality variables Rel, Temp, and Sf. One can determine the influence of a quality change on the value of a fishing experience by estimating the quarterly CV or EV for the quality change, and then dividing this benefit estimate by the constant number of trips taken \( z_1^0 \).

For estimating the change in \( z_2 \) with respect to a change in Rel or (Temp,Sf), one can use the "quasi" ordinary demand function for \( z_2 \) defined on \( w \) and the exogenous quality variable(s). These "quasi" demand functions are found by substituting the equations for \( \hat{\pi}_2 \) from (6.7) and (6.10) into the ordinary demand equation \( \hat{z}_2 = \lambda_2(\mu/\hat{\pi}_2) \), yielding
\[ \hat{z}_2 = \lambda_2 (.00391)(S)(w)^{-0.71726}(Rel)^{0.31658} \]

and

\[ \hat{z}_2 = \lambda_2 (.54803)(S)(w)^{-0.7108}(Temp)^{-0.9797}(Sf)^{0.0822}. \]

Using the results in Chapter III, we can also show that the welfare effects of exogenous quality changes can be measured by using the compensated commodity demand curves that are conditioned on the quality variables (as long as the cost function is homogeneous in commodities). In the commodity markets, quality changes induce shifts in marginal cost curves. Since input demand curves also shift in response to exogenous quality changes, an alternative procedure is to sum the changes in areas under all of the compensated (general equilibrium) input demand curves that are conditioned on the quality variables. If there exists a necessary input, then the total welfare change can be evaluated in the necessary input market. This result follows from Chapter III, but it is also demonstrated by Bockstael and McConnell (1983). In this application the parameter estimates required for specifying compensated demand equations are not known, so neither of these procedures can be used. As long as specifications of the indirect utility function and the cost function are known — as is the case in this study — the simplest of all of the procedures for measuring welfare changes is to use the equations for compensating and equivalent variations derived from the indirect utility function.
CHAPTER VII
CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

This study provides an empirical test of the household production function framework for evaluating wildlife recreation. The results suggest that for steelhead sport fishing in Oregon, the HPF methodology may provide a valid recreation valuation technique; however, limitations in the data used to estimate the model could lead to a serious bias in the parameter estimates. The major data limitation in this application is the absence of independent data on input quantities. In spite of deficiencies in the data, the results are theoretically plausible; but future research should be directed toward obtaining results that are not subject to the same biases by acquiring and using independent data on input quantities.

The major advantage of using the HPF approach for analyzing recreation demand is that it determines implicit prices for non-market recreation commodities. These implicit prices are dependent on market prices for inputs, opportunity costs of time used in the production of recreational experiences, and technology variables and parameters. One of the disadvantages of the HPF approach is that it can be extremely data dependent. This study has shown that even with a lack of price data for market inputs, however, it is possible to obtain estimates of the technology parameters and implicit prices.
The HPF approach also has the advantage of providing a theoretically-based framework for modeling the relationship between an endogenous quality variable (such as fish catch rates) and the demand for fishing trips. The Cobb-Douglas functional form that was used in this study imposes the condition that for the two commodities—fishing trips and fish catch per quarter—the demand function for one commodity is not dependent on the shadow price for the other commodity. Consequently, changes in the implicit price of a sport-caught fish influence the demand for sport-caught fish but not the demand for fishing trips. A more flexible functional form might specify ordinary commodity demands as functions of substitute prices, but it may not be amenable to welfare analysis. An advantage of the Cobb-Douglas functional form is that it is amenable to welfare analysis. In this study it was necessary to compromise flexibility of functional forms for their amenability to welfare analysis so that recreation benefits could be determined.

The value of a fishing experience (i.e., visit) includes the value of the fishing trip itself and the value of the fish caught. The HPF framework enables the separate calculation of per unit values in each commodity market; but in calculating the total value of fishing experience, these values must be simultaneously or sequentially calculated in order to account for market interrelationships. In most previous studies fish catch has not been included as an endogenous variable for which the angler has an effective demand. Thus, it is difficult to compare the benefit
estimates from this study to those from other studies. The results of this study suggest that the benefits derived from catching a fish are greater than the benefits derived from traveling to and from the fishing site.

Another advantage of the HPF approach is that it provides a means for explicitly considering the role of time in the recreationist's decision making process and for including the value of time in the recreation benefit measure. The inclusion of travel time in the traditional travel cost model has been found to cause multicollinearity problems. Although multicollinearity is present in the HPF model that was estimated in this study, it does not seem to be a serious problem. In this study both travel time and fishing time are found to have significant influences on the production of fishing experiences. One problem with including time as a labor input is that there seems to be no theoretical basis for selecting appropriate values for the opportunity costs of time used in the production of recreational experiences. The results presented above suggest that recreation benefits are sensitive to the value placed on time. More research is thus needed in the area of determining the opportunity costs of leisure time and travel time.

Still another advantage of the HPF approach is that it can be used to model the effects of exogenous quality changes on recreation demand and benefits. Exogenous quality characteristics can be included as technology variables in the production functions. The original goal in this study was to include a fish stock variable
in the production function for fish catch; however, there is a
general lack of reasonably good fish population data for Oregon
rivers. The numbers of smolts released from hatcheries in 1975
and 1976 were used as indicators of the total numbers of smolts
that contributed to the 1977 catch. Five selected water quality
parameters were used to indicate the quality of the fish habitat
for returning adults in 1977. One problem associated with using
all of the site quality variables together is that these variables
were found to be highly intercorrelated among themselves. Thus,
it may be more useful to include a general habitat quality index
rather than each different quality variable in the fish catch
production model. More research should be directed toward obtaining
better fish population data and developing habitat quality indices.

Each of the different quality variables were separately tested
for inclusion in the fish catch production model. The lagged
smolt releases variable was found to have the most significant
influence on fish catch. The production model in which lagged smolt
releases is included might be useful for policy analysis. Firstly,
the welfare effects of changes in numbers of smolts released from
hatcheries can be evaluated with this model. Secondly, if
hatchery smolt releases can be assumed to be synonymous with smolts
produced in natural fish habitats— as far as their effects on fish
catch are concerned— then this model could be used to analyze the
welfare effects of changes in smolt stocks. Such changes might be
caused by forest management practices or habitat enhancement
projects. It might be possible, therefore, to link this production model to a forest planning model, provided that the effects of forest management on smolt production were estimable.

One limitation of the model developed in this study is that it is based on the concept of a "representative river". This means that all of the production relationships are assumed to be homogeneous across rivers. That is, the effects of both fishing inputs and water quality on fish catch are assumed to be the same for all of the 29 rivers included in the study. This representative river concept also imposes the condition that anglers cannot substitute visits to one river for visits to another. A multiple site model would have the advantage of describing substitute relationships between fishing sites, and it would also permit variations in production relationships across sites.

Another extensive survey of Oregon steelhead anglers would be needed to obtain data that would be more useful for an application of the HPF approach in a multiple site context. For example, input, fish catch, and site location data could be obtained for each and every fishing trip. To avoid potential memory biases, respondents could be asked to keep a record of their per trip expenditures over a period of time. In order to help determine the appropriate opportunity costs of time, the respondents could be asked to indicate whether their visits occurred on weekdays or weekends, and they could note what their alternative activities would have been (e.g., working or other recreational activities) had they
not gone fishing. It would also be useful to know the specific location of fishing sites, because this would alleviate the need to average the water quality data over different sampling points. Perhaps a map could be enclosed with the questionnaire, on which sections of each river would be designated. The sections could coincide with locations of water quality sampling sites. Anglers would not have to reveal the exact location of the fishing sites they visited; they could be instructed to indicate only the section in which the site was located. It might also be useful for the questionnaire to inquire about the angler's subjective evaluations of certain site quality characteristics and about their previous fishing experience.

Until another extensive survey of Oregon anglers can be made, the estimated values of steelhead fishing experiences from this study might be useful for determining the benefits of steelhead fishing experiences in Oregon as a whole or on a per river basis. Given estimates of the total number of steelhead fishing trips taken during any given time period to any given river, total benefits can be estimated by multiplying the estimated number of trips by the mean value per fishing experience (i.e., visit). Since the mean values in this study are presented in 1977 dollars, it may be necessary to adjust them to current dollars.

This study has shown that in the HPF framework, welfare changes can be evaluated in either the input markets or in the commodity markets. When the technology is constant returns to scale, welfare measurement in commodity markets is performed in the same manner as
it is in the traditional neoclassical framework. In the case of nonconstant returns to scale, however, welfare measures are not easily interpreted in commodities space unless the cost function is homogeneous in commodities.
Endnotes

1. For summaries of the literature relating logging activities to anadromous fish habitat, see Brown (1980), Chamberlin (1982), Crow, et al. (1976), and Reiser and Bjorn (1979).

2. Recreation benefits are roughly defined as the amount of money recreationists are willing to pay over and above what they actually do pay for the opportunity to participate a given number of times in a recreational activity. This net economic value approximates the potential net value of a resource to a hypothetical owner who could charge each recreationist his willingness to pay value for permission to participate. Net benefits to participating recreationists do not reflect any option or existence values for nonusers. Option value is usually defined as the amount that an individual is willing to pay to preserve the option to visit a site at some time in the future. Exis-
tence value is defined as the benefits derived from the sheer knowledge that the recreation area is preserved in its natural state.

3. With the contingent valuation technique, benefit estimates are derived from surveys in which consumers are asked to state the maximum amounts they are willing to pay for a hypothetical change in quality, or the minimum amounts they are willing to accept in the absence of a hypothetical change.

4. Utility is an unobservable measure of the level of satisfaction an individual derives from consuming a bundle of final goods (both market and nonmarket). In the direct utility function utility is specified as a function of quantities of final goods consumed by the individual. The parameters of the utility function are called "taste parameters".

5. Two final goods are perfect complements if their elasticity of substitution is zero. Elasticity of substitution is a pure measure of the rate at which one good can be substituted for another good while maintaining a constant level of utility. The demand curve for a nonmarket good that is complementary to a market good is a decreasing function of the market good's price up to a certain price (Maler, 1974). Thus, given the assumption of complementarity between a nonpriced recreational activity and transportation goods, a negatively sloping demand curve for the services of a recreation site can be constructed by using the cost of transportation as a proxy for price per visit.

6. Recreation benefits are commonly estimated by the consumer surplus associated with the travel cost demand curve. Consumer surplus is represented by the area under the ordinary demand
curve and above the price line. The usefulness of consumer surplus as a money measure of consumer welfare is discussed in Chapter III.

7. The assumption of weak separability permits the specification of a subutility function for any subset of commodities. If weak separability exists, then the marginal rate of substitution between any two commodities of the same group is only a function of the variables in that group. The marginal rate of substitution for two commodities is equal to the ratio of their marginal utilities (i.e., the ratio of the partial derivatives of the utility function with respect to each commodity).

8. Freeman (1979) defines the demand price or marginal value of \( q_1 \) as the negative of the partial derivative of the individual's expenditure function with respect to \( q_1 \). An expenditure function determines the minimum amount of money that must be spent to consume the bundle of commodities which will achieve a given level of utility at a given set of prices. If the quantity demanded of a commodity is dependent on \( q_1 \), then \( q_1 \) will appear in the expenditure function, and thus the marginal value of \( q_1 \) can be determined in this manner.

9. Throughout this thesis, "commodities" (or final nonmarket goods) will denote output of the household production process, and "goods" will denote inputs (or intermediate market goods) used to produce commodities.

10. Constant returns to scale (CRS) exists when, if the quantities of goods purchased are doubled, then the quantity of quality characteristics consumed are doubled. A CRS technology leads to an implicit price for each characteristic that is not dependent on the quantity of that characteristic consumed. Nonjointness exists when each good contains only one characteristic, or when each good can be divided into separate parts, each of which contains only one characteristic. A sufficient condition for nonjointness is that the implicit price of any characteristic is not dependent on the quantities of any other characteristics. A homothetic utility function is a monotone increasing function of a function that is linearly homogeneous in characteristics. "Preferences are said to be homothetic if, for some normalization of the utility function, doubling quantities of characteristics consumed doubles utility." [Deaton and Meullbauer (1980), p. 142].

11. A nonlinear hedonic price equation generates implicit price functions that are conditioned on characteristic quantities. Each characteristic demand equation is estimated with observations on observed quantities of characteristics consumed by individuals and the estimated implicit prices \( p_z \). If implicit prices are dependent on characteristics, and if each individual consumes a
different bundle of characteristics, then characteristic prices as well as quantities will vary across individual observations, and hence a demand equation for each characteristic can be estimated.

12. Nonjoint production exists when each good is used to produce only one commodity, or when each good can be divided into separate parts, each of which is used to produce only one commodity.

13. A concave transformation frontier follows from a cost function that is regular strictly quasi-convex in commodities (Henderson and Quandt, 1980).

14. A necessary and sufficient condition for the ratio of marginal costs to be independent of \( z_1 \) and \( z_2 \) is that the cost function have the form \( C = C(\delta_1 z_1 + \delta_2 z_2, p) \), where \( \delta_1 \) is only dependent on \( p \) (Meullbauer, 1974).

15. The convexity of the indifference curve follows from a quasi-concave direct utility function (Henderson and Quandt, 1980).

16. Barnett (1977) specifies the commodity demand system in implicit notation as \( G(z, \pi, \mu) = 0 \). Although in some cases a closed-form solution for \( G \) may not exist, we are using explicit notation in this discussion for the purpose of simplifying the notation.

17. Meullbauer (1974) shows that under total jointness, \( K * \pi \) equals \( \pi^* z \) when the joint production function \( J(z, x) = 0 \) is homogeneous in \( z \) and \( x \) of degree \( 1/K \). Under total nonjointness, on the other hand, the individual production functions must all be homogeneous of the same degree \( 1/K \) in their respective inputs.

18. Decreasing (increasing) returns to scale means that if inputs are increased by a factor of say two, then output is increased by a factor less than (greater than) two. If a joint production function is homogeneous of degree \( 1/K \) in \( x \) and \( z \), then the technology is decreasing returns to scale if \( K > 1 \) and increasing returns to scale if \( K < 1 \). A nonjoint production function that is homogeneous of degree \( 1/K \) in \( x \) exhibits decreasing returns to scale if \( K > 1 \) and increasing returns to scale if \( K < 1 \).

19. The sufficient conditions for a cost function are that it be a nondecreasing, linearly homogeneous, concave, continuous function of input prices (Varian, 1978).

20. The sufficient conditions for an indirect utility function coincide with the properties of an indirect utility function (See Appendix A).
21. Simultaneous equations bias arises from the application of ordinary least squares to a single equation belonging to a system of simultaneous equations, or from the estimation of an incomplete system of equations. It originates from violation of the assumption that explanatory variables in an equation are independent of the error term.

22. The two conditions for establishing identification from the structural form of the model are called the rank and order conditions. The rank condition refers to the rank of the matrix of coefficients of excluded variables. The order condition is based on a counting rule for the included and excluded variables in each equation.

23. A household's allocation of time among commodity production processes can be viewed as a two-stage budgeting problem. If \( z \) is assumed to be a weakly separable commodity group, then \( T \) would be determined in the first stage. In the second stage \( T \) would be allocated optimally among the individual \( z_i \)'s.

24. This will be true only if some assumptions are made. First, it is assumed that any time in addition to the initial allocation \( T^0 \) that is subsequently used to produce \( z \) is taken away from time that was spent earning \( w \) per unit of time and that any portion of \( T^0 \) that is not subsequently used to produce \( z \) is used to earn \( w \) per unit of time. It must also be assumed that the earnings gained (lost) by changes in time allocations are subsequently added to (subtracted from) the initial amount of money available for \( z \) (\( M^0 \)).

25. In this discussion welfare changes are defined in terms of CV. They can be easily converted into definitions of EV. The implicit definition of EV for a price change from \( p^0 \) to \( p^1 \) is written as \( V(p^0, u^1 + EV) = V(p^1, u^1) \).

26. Hiett and Worrall (1977) have found that although sport fishermen may estimate total numbers of fishing trips with reasonable accuracy, they tend to overestimate the degree of effort expended on fishing trips and to overestimate total catch. As long as the errors in estimating effort and catch are in the same direction and of similar magnitudes, estimates of the relationship between catch and effort in the fish catch production function may not be significantly influenced by any measurement errors.

27. Bockstael and McConnell (1980) state that there is no compelling reason for using a catch rate (such as catch per trip) rather than the total catch (such as annual or quarterly catch) to represent the endogenous quality commodity in the HPF model. The use of a catch per trip variable would unnecessarily complicate the model, however, because in order to calculate total costs it would be necessary to multiply mean expenditures on fishing inputs per trip by the total number of trips taken during the
quarter or year. As a result, there would be a multiplicative relationship between catch and trips in the cost function, which in turn would result in an implicit price for each commodity that is dependent on the other commodity. The model would thus resemble one with joint production.

28. The capital stock variables are comprised of only those items that the respondent used on salmon and steelhead fishing trips. Each capital good in \( k_1 \) and \( k_2 \) is valued at its purchase price. This procedure is based on the assumption that over the relevant years prior to and including 1977, mean depreciation rates were not only equivalent across all capital goods, but were also equal to mean annual inflation rates.

29. It would be preferable to include a single distance variable \( \text{Dis} \) (defined as one-way distance to river) rather than the three dummy variables. A distance variable cannot be used in this application, however, because of the way in which the variable \( t_1 \) was constructed. Since independent data were not available on travel time, the \( t_1 \) variable was computed by multiplying round-trip distance by \( z_1 \), and then by dividing this product by a constant miles per hour (MPH) figure for the given mode of transportation. Since \( t_1 = (2 \cdot \text{Dis} \cdot z_1) / \text{MPH} \), including \( \text{Dis} \) in the \( z_1 \) model as another explanatory variable would likely cause estimation problems that would not arise if independent data were available on \( t_1 \). Optimally, one would like to have independent data on quarterly quantities of all of the inputs. Unfortunately, since independent input data are not available for this study, all of the quarterly input variables were constructed by multiplying average per trip input quantities (or expenditures in the case of \( x_1 \) and \( x_2 \)) by \( z_1 \). Since \( z_1 \) is the dependent variable in the first production function, this procedure clearly leads to a violation of the assumption that the error term of the equation is uncorrelated with any errors in the explanatory variables. In some cases this can lead to a serious bias in the parameter estimates. This estimation problem may also arise in the \( z_2 \) production function, since \( z_2 \) is calculated by multiplying average per trip fish catch by \( z_1 \), and thus errors in the variables \( x_2 \) and \( t_2 \) may be correlated with errors in \( z_2 \).

30. In previous studies foregone hourly income has generally been used as a proxy for the opportunity cost of travel time [Keith and Workman (1977), and Sorhus (1980)].

31. We are assuming two-stage budgeting, and that one commodity group is composed of \( z_1 \) and \( z_2 \). Thus, \( \mu \) is a predetermined variable in this model, which means that the instrumental variable \( \tilde{I} \) can be treated as an exogenous variable.
32. Note that the quality vector \( s \) is not included in the \( z_2 \) production function. In this section the production relationships are estimated without inclusion of water quality variables, because water quality data could not be obtained for all of the 29 rivers in the study. In the following chapter the production relationships are reestimated with a subset of the observations for which water quality data were available.

33. Note that \( \sigma_i \) will always be nonnegative for substitute inputs, because the denominator in the middle expression of (5.4) is the reciprocal of the price ratio associated with the input ratio in the numerator.

34. This is not a completely acceptable condition for the \( z_1 \) production function. That is, it is not necessary that \( x_1 \) be greater than zero, because over relatively small distances it is possible for anglers to walk to and from fishing sites without making any expenditures on food and lodging. In order to estimate the Cobb-Douglas production function, any observations for which \( x_1 = 0 \) are omitted. Since there are only 29 observations out of a total of 404 for which \( x_1 = 0 \), omitting them from the model should not have an appreciable effect on the parameter estimates.

35. Of course, in these results the high \( t \) statistics may be partly due to the way in which the input variables were constructed. Errors in these explanatory variables may well be correlated with errors in the dependent variable, and consequently with the error term of the equation. If so, then the \( t \) statistics may be biased upward.

36. Perhaps this can be explained by the fact that all of the rivers have winter steelhead runs, but only a few have summer steelhead runs. Also, the winter runs are generally more substantial than the summer runs. Thus, fish are generally more abundant in the first and fourth quarters than in the second and third quarters, which could cause anglers to be more efficient in the first and fourth quarters, as these empirical results suggest. Another explanation for these results is that rivers with summer steelhead runs might attract more anglers that go fishing only occasionally, and thus have less experience than the year-round anglers.

37. In this application if we assume that \( w_1 = w_2 \), then we are in effect assuming that the angler is indifferent between time spent traveling and time spent fishing, and that the allocation of time reflects only production considerations. If we were to define \( w_1 \) differently than \( w_2 \), then we could account for differences between the marginal utilities of \( t_1 \) and \( t_2 \); but these differences should be determined by including \( t_1 \) and \( t_2 \) in the direct utility function. Pollak and Wachter contend that
household time spent in different production activities is a direct source of utility or disutility. They argue that time inputs should be treated as arguments along with commodities in the utility function. The result of specifying the utility function in such a manner would be joint production.

38. This constraint is similar to Becker's (1965) full income constraint, except that in Becker's constraint V denotes exogenous unearned income and T denotes total time available for work and for producing commodities. Regular labor time is not fixed in Becker's model.

39. It is assumed that the maximum number of hours that a person can work each day is twelve. The remaining hours are assumed to be spent in leisure activities that have a zero opportunity cost. The amount of time available for producing commodities in any quarter is equal to the total time available for work (i.e., 12 multiplied by the total number of days) minus the number of hours that are spent earning the regular wage.

40. The 292 observations that were used to estimate \( \lambda_1 \) and \( \lambda_2 \) are those for which \( w \neq 0 \). For the other 112 observations, \( w = 0 \), and hence \( \pi_1, \pi_2 = 0 \). Nonzero input and commodity prices are required in this model, since \( \pi_1 \) and \( \pi_2 \) are denominators in the commodity demand equations.

41. The only errors in CV would result from random errors in estimating \( \lambda_1 \) and \( \lambda_2 \). The same is true of EV as well.

42. In the case where shutdown prices are infinite values — as they are in this application — a necessary input is defined as one for which positive usage is necessary for producing a positive output.

43. There are two possible reasons for the extremely small differences between \( CV_1 + CV_2 \) and total CV and between \( EV_1 + EV_2 \) and total EV. First, since the estimated values of the parameters \( \lambda_1 \) and \( \lambda_2 \) are very small, it can be shown that the effect of a change in \( \pi_i \) on the compensated demand for \( z_j \) is also likely to be very small. This means that a change in \( \pi_i \) induces a minor shift in the compensated demand curve for \( z_j \). The second possible reason is that the same \( \pi^* \) (or \( w^* \)) was used to calculate total welfare both separately in each market and simultaneously in both markets. In actuality, once a demand curve shifts, the shutdown price for that commodity (or good) changes. But since the demand curves are asymptotic in this study, it is not possible to determine the subsequent shutdown prices.
44. Data were obtained from Oregon Water Resources Dept. Water Resources Data for Oregon. Water years 1975-1978.

45. Smolts are defined as fish weighing 10 fish to the pound or more. These are two-salt migratory smolts (i.e., two years in salt water).

46. L.R. Klein states that collinearity is harmful if the partial correlations between sets of any two explanatory variables are greater than the overall (multiple) correlation $R^2$ (Koutsoyianis, 1977, p. 237).

47. The observations over these nine rivers comprise approximately one-third of the 94 observations that were used to estimate the original $z_2$ production function in (5.2). Apparently, this portion of the sample is not completely representative of the sample of 94 observations, as far as the $k_2$ variable is concerned. Nevertheless, this subsample is still used, because according to the results in Table 12, the two input coefficients remained fairly stable. Also, the coefficient to the $k_2$ variable did not change considerably, and it was not highly significant in the earlier regression estimated with the complete data set.
REFERENCES


APPENDIX A

I. Consumer Demand Functions

A. The consumer demand functions presented in Chapter II are called Marshallian (ordinary) demand functions. They are conditioned on prices and income, which are observable variables. Most of the neoclassical properties of a demand system concern the Hicksian (compensated) demand functions, which are conditioned on prices and utility. Since utility is not observable, Hicksian demand functions are not observable. They are derived from the expenditure function \( E(\pi, U) \); by Shepherd's lemma, the Hickian demand system is \( \partial E(\pi, U) / \partial \pi = H(\pi, U) \). The Hicksian demand functions are constructed by varying prices and income so as to keep the consumer at a fixed level of utility. "Thus, the income changes are arranged so as to "compensate" for the price changes" [Varian, 1978, p. 92].

B. Neoclassical Properties of a Demand System

1. The matrix of substitution terms (\( \partial H_i(\pi, U) / \partial \pi_j\)) is negative semi-definite and thus, has nonpositive diagonal terms.

2. The matrix of substitution terms is symmetric:

\[
\begin{align*}
\frac{\partial H_i(\pi, U)}{\partial \pi_j} &= \frac{\partial H_j(\pi, U)}{\partial \pi_i} \\
\end{align*}
\]

3. The "compensated own price effect" is nonpositive, which means that the Hicksian demand curves slope downward:

\[
\frac{\partial H_i(\pi, U)}{\partial \pi_i} \leq 0
\]

II. The Expenditure Function

A. The expenditure function is analogous to the cost function. It can be found by inverting the indirect utility function \( V = V(\pi, \mu) \) with respect to \( \mu \). It is formally defined as

\[
E(\pi, U) = \min \{ \pi'z \mid U = U(z) \}
\]

and gives the minimum costs of achieving a given level of
utility at given prices.

B. The properties of \( E(\pi, U) \) are that it is nondecreasing, continuous, concave, and homogeneous of degree one in \( \pi \).

III. The Indirect Utility Function

A. \( V(\pi, \mu) \) gives the maximum utility that can be attained at a given set of prices and income.

B. Properties of \( V(\pi, \mu) \)

1. continuous in all \( \pi > 0 \) and \( \mu > 0 \)
2. nonincreasing in \( \pi \) and nondecreasing in \( \mu \)
3. quasi-convex in \( \pi \)
4. homogeneous of degree zero in \( \pi \) and \( \mu \).
OREGON FISHING ACTIVITIES QUESTIONNAIRE

1. Did you, yourself, go fishing in Oregon any time during the last 3 months (January-March 1977), or not?
   Yes, fished. (Go to Question 2) No, did not fish. (Go to Question 5)

2. How many times did you go fishing from January through March 1977? Number.

3. Of these trips, how many were intended primarily as fishing trips, as contrasted to trips taken mainly for other reasons (but where some fishing was done)? Number.

4. Of all your fishing trips, how many were primarily for steelhead? Number.
   How many were primarily for salmon fishing? Number.
   How many for resident trout? Number.
   How many for any other species? (Please specify) Number.

5. What type of fishing license(s) did you, yourself, purchase for 1977? (Check all that apply.)
   - Resident Combination
   - Resident Combination with bow
   - Resident Angler
   - Juvenile Angler
   - Nonresident Angler
   - 10-day Angler
   - 1-day Angler
   - 2-day Angler
   - 3-day Angler
   - Pioneer Angler
   - Disabled Vet Angler
   - Senior Citizen Angler
   - 10-day Angler
   - 1-day Angler
   - 2-day Angler
   - 3-day Angler
   - Pioneer Angler
   - Disabled Vet Angler
   - Senior Citizen Angler

6. In addition, did you purchase a salmon-steelhead tag? Yes No

7. What is your approximate age?
   - Under 21
   - 21-29
   - 30-39
   - 40-49
   - 50-59
   - 60-69
   - 70 years or over

8. How many people, including yourself, are in your household and living at home at the present time? Number.

9. Please indicate the average number of hours, if any, you were working for pay during the last three months. Please check if you are retired or are a student.
   Number of hours worked per week.
   Retired.
   Student.

10. Which of the following categories most closely corresponds to the combined yearly income, before taxes, for all members of your household for 1976?
    - Under $3,000
    - $3,000-$ 4,999
    - $ 5,000-$ 7,999
    - $ 8,000-$11,999
    - $12,000-$14,999
    - $15,000-$17,999
    - $18,000-$ 24,999
    - $25,000-$ 34,999
    - $35,000-$ 49,999
    - $50,000-$100,000
    - Over $100,000

(PLEASE TURN TO PAGE 2 IF YOU FISHED IN JANUARY-MARCH 1977; PLEASE TURN TO PAGE 4 IF YOU DID NOT)
Please answer the following questions (11-21) about your last 3 Oregon fishing trips during the period January through March 1977. If you took less than 3 trips, please fill in only the questions referring to the number of trips you took.

11. Write name of river, stream, or name of lake (or ocean) where this fishing trip took place ..........................................................

12. In what county was this port, river, lake, or stream where you fished? (See map on back of introductory letter) ..........................................................

13. How many miles did you travel, one way, on your fishing trip? ...........................................................................

14. Did you make this trip in an automobile or a pickup without a camper? Circle YES or NO ..........................................................

15. Did you make this trip in a motor home, auto with camper, or a pickup camper? Circle YES or NO ..........................................................

16. How many hours (or days) did you spend at your destination? ...........................................................................

17. When you were developing your plans for this trip, what was the shortest length of time you would have considered staying at destination, in hours (or days)? ..........................................................

18. How many hours did you actually fish? (If for more than one species, divide the time among species):

   STEELHEAD ..........................................................................................................................
   SALMON ..........................................................................................................................
   RESIDENT TROUT .............................................................................................................
   SEA-RUN CUTTHROAT ....................................................................................................
   WARM WATER GAME FISH ..........................................................................................
   OTHER ............................................................................................................................

19. How many fish of each species did you, yourself, catch?

   STEELHEAD ..........................................................................................................................
   SALMON ..........................................................................................................................
   RESIDENT TROUT .............................................................................................................
   SEA-RUN CUTTHROAT ....................................................................................................
   WARM WATER GAME FISH ..........................................................................................
   OTHER ............................................................................................................................

20. How many people went with you on this trip? .....................................................................................

21. Approximately how much did you and your group spend for the following items? (Just your best estimate)

   (a) Food, drink (including liquor), bought in restaurants, bars, or taverns, while traveling to and from your destination ..........................................................
   (b) Food and drink bought in restaurants, bars, and taverns while at your destination ..........................................................
   (c) Total amount spent for camping fees, lodging in motels and hotels, while traveling to and from your destination ..........................................................
   (d) Amount spent for camping fees and lodging while at your destination ..........................................................
   (e) Guide service, bait, and lures .....................................................................................
   (f) Rental of fishing tackle, equipment, boat, and/or motor ..........................................................
   (g) Boat launching fees ..................................................................................................
   (h) Gallons of gas used in your boat (do not include rental boats and motors) ..........................................................
   (i) Other rental items (Specify) .....................................................................................
   (j) Miscellaneous expenses (Specify) ............................................................................
(Answer blanks for questions 11-21)

<table>
<thead>
<tr>
<th>Trip 1</th>
<th>Trip 2</th>
<th>Trip 3</th>
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</table>

PLEASE GO ON TO NEXT PAGE
22. Listed below are items often used by fishermen. Please record your expenditures for equipment, regardless of when purchased, that you still use in your Oregon fishing activities. To see how to complete percents for the last two columns, please refer to the following example:

**EXAMPLE:** Assume you purchased a boat, and use it a total of 100 hours per year. Of this 100 hours, 50 hours were used for all angling, of which 25 hours were for salmon and steelhead angling. In this case, 50% should be allocated to all angling, and 25% should be allocated to salmon and steelhead fishing.

<table>
<thead>
<tr>
<th>Item</th>
<th>Purchase price</th>
<th>Year(s) in which purchased</th>
<th>State in which purchased was made</th>
<th>Replacement cost today</th>
<th>Percent of time boat is used for fishing</th>
<th>Percent of time boat is used for salmon and steelhead fishing</th>
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<tr>
<td>Tackle:</td>
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<tr>
<td>Rod(s)</td>
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<tr>
<td>Reel(s)</td>
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<tr>
<td>Creel(s)</td>
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<tr>
<td>Tackle box(es)</td>
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<tr>
<td>Landing net(s)</td>
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<tr>
<td>Any other tackle</td>
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<td>$</td>
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</table>

Other equipment expenditures not listed above:
(specify): $ __________ $ __________ $ __________ $ __________

Is there anything else you would like to say about fishing in Oregon? Please return questionnaire and any comments you would like to make in envelope provided.

THANK YOU FOR YOUR COOPERATION.