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On the Consumer Value of Environmental Diversity

by

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Abstract: This paper develops a methodology for the valuation of the taste for diversity. The concerns about the contribution of diversity in the valuation of consumer goods typically arise when it is believed that the total value is greater than the value of its parts.
The methodology we propose infers the economic value of diversity through fish market price by using a system of inverse demands to model the nature of this particular commodity. We develop our analysis of the consumer value of diversity using Luenberger's benefit function (Luenberger, 1992). In this context, we show that the benefit function provides a conceptual framework to conduct a welfare analysis of the value of diversity in a system framework.

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1 Introduction

The question about how to measure biodiversity value has been widely discussed in the literature. One concern has been represented by which method to use to design the biodiversity index. Some researchers have approached the problem using a diversity function that considers the genetic distance as a measure of the difference between species. Others have proposed indexes describing abundance, richness, and evenness intended respectively as number and distribution of species (Shannon or Simpson index).

Brock and Xepapadeas (2003) developed a measure which is not based on genetic distance, but on the value of the services that biodiversity provides or enhance, such as ecosystem productivity, insurance, knowledge, or ecosystem services. Their analysis stems from the principle that "the economic value of the […] system with one of the species extinct is less than the economic value of the […] system with both species present."

In the same spirit, we are interested in valuing the services that environmental diversity provides to consumers. Measuring the value of resources based on consumers' willingness to pay is standard in economic and welfare analysis. What is not clear is how to apply such measurements to the valuation of diversity. This paper develops a methodology for such a measurement. Intuitively, the value of diversity arises when the willingness to pay for a set of goods is "greater than the sum of its parts". This means that the value of diversity goes beyond the valuation of each good. It must involve some complementarity relationships across goods. This paper develops a methodology for such a measurement to show that the value of diversity goes beyond the valuation of each good by analyzing some complementarity relationships across goods. In this paper, we develop a general approach to the valuation of these complementarities. And we illustrate the approach in an application to the consumer value of diversity with respect to fish.

As a starting point, the methodology we propose is based on a standard welfare investigation of marginal willingness to pay. The main challenge to value diversity is that we need to know more than just the value of particular goods. Indeed, to evaluate complementarity relationships, we need to know how the marginal value of a good can be influenced by other goods. Obtaining this information requires a joint evaluation of willingness to pay across goods. This creates three specific challenges. First, the scope of analysis requires a system approach to consumer valuation. Second, evaluating possible complementarities across goods in a system requires assessing the value of the "sum of the parts". This suggests relying on welfare measures that can be easily aggregated. Third, the approach must be empirical tractable.

The objective of this paper is to address these three challenges to the consumer value of diversity. The methodology we propose infers the economic value of diversity through fish market price. The value of environmental diversity is endogenously determined. This approach follows Gorman's statement, reinforced later in Barten and Bettendorf (1989), that price of fish depends on the shadow price of fish characteristics. This suggests a system of inverse demands as a natural way to model the nature of this particular commodity. This is the case when prices adjust to the quantity of the good on the market. Given the perishable nature of the commodity, in the short run supply is inelastic, prices are adjusted to clear the market, and producers are typically price takers (Barten and Bettendorf, 1989). Note that using a system approach to value marginal willingness to pay has been in the literature for decades. It can be based in the distance function first proposed by Shephard and analyzed by Deaton in the context of evaluating consumer welfare. The distance function also provides a convenient framework to conduct empirical analysis. Following the early work of Barten and Bettendorf (1989), it has been applied by Eales and Unnevehr (1994), Holt and Bishop (2002), Moro and Sckokai (2002), and Wong and McLaren (2005). This provides a framework to analyze empirically cosnumer's marginal willingness to pay for particular commodities in a way that is consistent with consumer theory. However, Shephard distance function is based on a proportional rescaling of quantities consumed. While it is convenient to evaluate index numbers (see Deaton), the Shephard distance function does <u>not</u> have "nice" aggregation properties (e.g., it is not meaningful to add proportions across scenarios when the evaluation point changes). Yet, the evaluation of diversity of a system requires the evaluation of the "sum of its parts." This suggests that the Shephard distance function is not well suited to this task. What is needed is a welfare measure that has "nice" aggregation properties so that it can provide a direct evaluation of the "sum of the parts". A welfare measure with this property is Luenberger's benefit function (Luenberger, 1992). On that basis, we develop our analysis of the consumer value of diversity using Luenberger's benefit function. The benefit function has the convenient feature of providing a measure of willingness to pay for goods, starting from a utility level U. Furthermore, the benefit function approach appears superior over the distance function because it aggregates easily across consumers and across scenarios. This makes it particularly attractive in the analysis of consumption activities for heterogeneous consumers, since the distance function approach is only applicable to a single representative consumer (Deaton, Barten, and Bettendorf). In this context, we show that the benefit function provides a conceptual framework to conduct a welfare analysis of the value of diversity in a system framework. And to show that it is empirically tractable and to illustrate its usefulness, we present an econometric application to fish consumption.

The paper is organized as follows. Section 2 presents a brief introduction of the benefit function, and its linkages with welfare analysis in a system framework. Section 3 presents the results of an application for the Italian fishing markets. The theoretical development of the welfare measure for environmental diversity, from the consumer perspective, is presented in section 4 together with the estimated welfare measures. Finally, section 5 presents concluding remarks.

2 The Model

In this section, we present an adaptation to the household level of the model we introduced in chapter 2. Consider a set of N households facing a vector of M goods. The i-th household faces $\mathbf{x}_i = (x_{i1}, \ldots, x_{iM})^T \in R_+^M$, where the superscript T denotes the transpose, and has preferences represented by the utility function $u_i(\mathbf{x}_i)$, i = 1, …, N. We assume that the utility function $u_i(\mathbf{x}_i)$ is continuous, i = 1, …, N. Let $\mathbf{g} = (g_1, \ldots, g_M)^T \in R_+^M$ be some reference bundle satisfying $\mathbf{g} \geq 0$ and $\mathbf{g} \neq 0$. Following Luenberger (1992), define the benefit function for the i-th household by

$$b_i(\mathbf{x}_i, U_i, \mathbf{g}) = \max_\beta \left\{\beta : u_i(\mathbf{x}_i - \beta\mathbf{g}) \geq U_i, (\mathbf{x}_i - \beta\mathbf{g}) \in R_+^M\right\}, \quad (1.1)$$

if there is a β satisfying $u_i(\mathbf{x}_i - \beta\mathbf{g}) \geq U_i$ and $(\mathbf{x}_i - \beta\mathbf{g}) \in R_+^M$,

$= -\infty$ otherwise.

i = 1, …, N. The benefit function $b_i(\mathbf{x}_i, U_i)$ in (1) measures the largest number of units of the bundle $\mathbf{g}$ the i-th household is willing to give up to move from the utility level U_i to the point $\mathbf{x}_i$. In the case where the bundle $\mathbf{g}$ has a unit price, this provides a measure of household <u>willingness-to-pay</u> for $\mathbf{x}_i$. And when $b_i(\mathbf{x}_i, U_i)$ is differentiable in $\mathbf{x}_i$, it follows that the marginal benefit $\partial b_i(\mathbf{x}_i, U_i)/\partial\mathbf{x}_i$ is a measure of the <u>marginal willingness to pay</u> for $\mathbf{x}_i$..

The properties of the benefit functions have been investigated by Luenberger (1992). They are briefly summarized. First, if preferences satisfy $u_i(\mathbf{x}_i + \alpha\, \mathbf{g}) > u(\mathbf{x}_i)$ for all $\mathbf{x}_i \in R_+^M$ for some $\alpha > 0$, then $u_i(\mathbf{x}_i) = U_i$ implies $b_i(\mathbf{x}_i, U_i) = 0$. Second, if $\mathbf{x}_i \in \text{int}(X)$, then $b_i(\mathbf{x}_i, U_i) = 0$ implies $u_i(\mathbf{x}_i) = U_i$. This shows that $b_i(\mathbf{x}_i, U_i) = 0$ is an implicit representation of the i-th household's preferences where $U_i = u_i(\mathbf{x}_i)$, i = 1, …, N. Third, $b_i(\mathbf{x}_i, U_i)$ is non-increasing in

U_i. Fourth, $b_i(\mathbf{x}_i + \alpha\, \mathbf{g}, U_i) = \alpha + b_i(\mathbf{x}_i, U_i)$. When $b_i(\mathbf{x}_i, U_i)$ is differentiable in $\mathbf{x}_i$, this implies $(\partial b_i/\partial \mathbf{x}_i)\, \mathbf{g} = 1$. Finally, if $u_i(\mathbf{x}_i)$ is quasi-concave in $\mathbf{x}_i$, then $b_i(\mathbf{x}_i, U_i)$ is concave in $\mathbf{x}_i$. In the case where $b_i(\mathbf{x}_i, U_i)$ is twice-continuously differentiable in $\mathbf{x}_i$, this implies that $(\partial^2 b_i/\partial \mathbf{x}_i^2)$ is a symmetric, negative semi-definite matrix which satisfies $(\partial^2 b_i/\partial \mathbf{x}_i^2)\, \mathbf{g} = 0$.

The benefit function complements the standard expenditure function $E_i(\mathbf{p}, U_i) = \min_x\{ \mathbf{p}^T \mathbf{x}: u_i(\mathbf{x}) \geq U_i, \mathbf{x} \in R^M_+\}$, where $\mathbf{p} = (p_1, \ldots, p_M) \in R^M_{++}$ is the vector of prices for $\mathbf{x}$. Luenberger (19920 has shown that the functions $E_i(\mathbf{p}_i, U_i)$ and $b_i(\mathbf{x}_i, U_i)$ are closely related. First, when $\mathbf{p}_i^T\, \mathbf{g} > 0$, the expenditure function $E_i(\mathbf{p}_i, U_i)$ can be alternatively written as

$$E_i(\mathbf{p}_i, U_i) = \min_{x_i} \left\{ \mathbf{p}_i^T \mathbf{x}_i - b_i(\mathbf{x}_i, U_i)(\mathbf{p}_i^T \mathbf{g}) : \mathbf{x}_i \in R^M_+ \right\}, \tag{1.2}$$

Second, define the *hyper-benefit* function

$$\bar{b}_i(\mathbf{x}_i, U_i) = \min_{\mathbf{p}_i} \left\{ \left[\mathbf{p}_i^T \mathbf{x}_i - E_i(\mathbf{p}_i, U_i) \right] / (\mathbf{p}_i^T \mathbf{g}) : \mathbf{p}_i \in R^M_+ \right\} \tag{1.3}$$

When the utility function $u_i(\mathbf{x}_i)$ is quasi-concave, Luenberger (1992) has shown that $\bar{b}_i(\mathbf{x}_i, U_i) = b_i(\mathbf{x}_i, U_i)$. This establishes that, under quasi-concave preferences, the benefit function $b_i(\mathbf{x}_i, U_i)$ and the expenditure function $E_i(\mathbf{p}_i, U_i)$ are dual to each other. Since the expenditure function $E_i(\mathbf{p}_i, U_i)$ is commonly used in welfare analysis involving price changes, this means that the benefit function $b_i(\mathbf{x}_i, U_i)$ provides a convenient basis for conducting welfare analysis involving quantity changes (see Luenberger, 1996). To exploit the duality, let $\mathbf{x}_i^c(\mathbf{p}_i, U_i) \in \text{argmin}_{x_i} \{\mathbf{p}_i^T\, \mathbf{x}_i - b_i(\mathbf{x}_i, U_i): \mathbf{x}_i \in X\}$ be the quantity-dependent Hicksian demands obtained as a solution to the expenditure minimization problem in (1.2). Similarly, let $p_i^c(\mathbf{x}, U_i) \in \text{argmin}_p \{[\mathbf{p}^T\, \mathbf{x}_i - b_i(\mathbf{x}_i, U_i)]/(\mathbf{p}^T\, \mathbf{g})\}$ be a price-dependent Hicksian demands obtained as a solution of the minimization problem in (1.3). If $E_i(\mathbf{p}_i, U_i)$ is differentiable in $\mathbf{p}_i$, then the envelope theorem applied to (1.3) gives Shephard's lemma:

$$\partial E_i(\mathbf{p}_i, U_i)/\partial \mathbf{p}_i = \mathbf{x}_i^c(\mathbf{p}, U_i). \tag{1.4}$$

Similarly, if $\bar{b}_i(\mathbf{x}_i, U_i)$ is differentiable in $\mathbf{x}_i$, then applying the envelope theorem to (1.3) gives

$$\partial\bar{b}_i(\mathbf{x}_i, U_i)/\partial\mathbf{x}_i = \left[\mathbf{p}_i^c(\mathbf{x}_i, U_i)\right]/\left(\mathbf{p}_i^T\mathbf{g}\right). \qquad (1.5)$$

When prices are normalized such that $\mathbf{p}_i^T\,\mathbf{g} = 1$, equation (1.5) becomes $\partial\bar{b}_i/\partial\mathbf{x}_i = \mathbf{p}_i^c(\mathbf{x}_i, U_i)$. In addition, when preferences are quasi-concave, then $\bar{b}_i(\mathbf{x}_i, U_i) = b_i(\mathbf{x}_i, U_i)$, implying that the price dependent Hicksian demands $\mathbf{p}_i^c(\mathbf{x}_i, U_i)$ can be interpreted as the i-th household's marginal <u>willingness-to-pay</u> for $\mathbf{x}$, i = 1, …, N. Finally, the associated price-dependent Marshallian demands are defined as follows: $p_i^*(\mathbf{x}) = p_i^c(\mathbf{x}_i, u_i(\mathbf{x}_i))$, i = 1, …, N (recall corollary 1 and proposition 2 from chapter 2).

We take the reference bundle $\mathbf{g}$ to be private goods. Then, as long as the reference bundle $\mathbf{g}$ remains constant, the benefit function $b_i(\mathbf{x}_i, U_i)$ in (1.1) can be conveniently added across households. The aggregate benefit function is defined as

$$B(\mathbf{x}, \mathbf{U}) = \sum_{i=1}^{N} b_i(\mathbf{x}_i, U_i) \qquad (1.6)$$

where $\mathbf{x} = (\mathbf{x}_1, \ldots, \mathbf{x}_N) \in X^N$ and $\mathbf{U} = (U_1, \ldots, U_N) \in R^N$. The aggregate benefit $B(\mathbf{x}, \mathbf{U})$ in (1.6) measures the largest number of units of the fix bundle $\mathbf{g}$ the N households are willing to give up to move from the utility levels U to point $\mathbf{x}$. It provides a convenient aggregate welfare measure in the quantity space (see Luenberger, 1995, 1996).

3 The Consumer Value of Environmental Diversity

Denote by I = {1, …, n} the index set of n goods. Consider the partitions $I = \{I_A, I_B\}$ where I_A is the index set of environmental goods facing the N households, and I_B is the set of other goods. Also, consider partitioning the set I_A into K subsets: $I_A = \{I_{A1}, \ldots, I_{AK}\}$, where I_{Ak} denotes the k-th subset of environmental goods, k = 1, …, K. We are interested in measuring the value of environmental services.

Consider the i-th household facing $\mathbf{x}_i = (\mathbf{x}_{iA}, \mathbf{x}_{iB})$, where $\mathbf{x}_{iA} = \{x_{ij}: j \in I_A\}$ denotes the environmental goods and $\mathbf{x}_{iB} = \{x_{ij}: j \in I_B\}$ are the other goods. For simplicity, assume that $\mathbf{p}^T\mathbf{g}=1$. Given some reference utility U_i, the i-th household <u>total value</u> for the environmental goods $\mathbf{x}_{iA}$ is

$$V_{iA}\left(\mathbf{x}_i, U_i\right) = b_i\left(\mathbf{x}_{iA}, \mathbf{x}_{iB}, U_i\right) - b_i\left(0, \mathbf{x}_{iB}, U_i\right). \tag{1.7}$$

The value $V_{iA}(\mathbf{x}_i, U_i)$ in (1.7) provides a welfare measure of the total value of the goods $\mathbf{x}_{iA}$. However, it can be useful to try to decompose this total value into some of its components. One of its components is the value of diversity associated with the goods in $\mathbf{x}_{iA}$. To investigate this issue, let $\mathbf{x}_{i,Ak} = \{x_{ij}: j \in I_{Ak}\}$ denote the environmental goods in the subset I_{Ak}, k = 1, …, K. And let $\mathbf{x}_{i,A\text{-}Ak} = \{(y_{i1}, \ldots, y_{in}): y_{ij} = x_{ij} \text{ if } j \in I_A\text{-}I_{Ak};\ y_{ij} = 0 \text{ if } j \in I_{Ak}\}$. Given some reference utility U_i, the i-th household <u>incremental value</u> for the environmental goods $\mathbf{x}_{i,Ak}$ is defined as

$$V_{i,Ak}\left(\mathbf{x}_i, U_i\right) = b_i\left(\mathbf{x}_{iA}, \mathbf{x}_{iB}, U_i\right) - b_i\left(\mathbf{x}_{i,A\text{-}Ak}, \mathbf{x}_{iB}, U_i\right). \tag{1.8}$$

k = 1, …, K. Of special interest is the sum of the incremental values across the K sets of environmental goods: $\sum_{k=1}^{K} V_{i,Ak}(\mathbf{x}_i, U_i)$. In general, this sum will not be the same as the total value $V_{iA}(\mathbf{x}_i, U_i)$ in (1.7). The reason that (1.8) values the environmental goods one group at a time, while (1.7) values them jointly. This suggests defining the i-th household's <u>value of environmental diversity</u> as

$$W_i\left(\mathbf{x}_i, U_i\right) = \sum_{k=1}^{K} V_{i,Ak}\left(\mathbf{x}_i, U_i\right) - V_{i,A}\left(\mathbf{x}_i, U_i\right). \tag{1.9}$$

In general, $W_i(\mathbf{x}_i, U_i)$ in (1.9) can be positive, zero, or negative. It can be zero if the value of the environmental goods in each group is independent of environmental goods in other groups. It is positive when the consumer values environmental diversity.

To illustrate, consider the simple case where environmental goods are partitioned into two groups: K = 2. Then, for the i-th household, $\mathbf{x}_i = (\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB})$, and equations (1.7), (1.8) and (1.9) take the form

$$V_{iA}(\mathbf{x}_i, U_i) = b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i) - b_i(0, 0, \mathbf{x}_{iB}, U_i), \tag{1.7'}$$

$$V_{i,A1}(\mathbf{x}_i, U_i) = b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i) - b_i(0, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i), \tag{1.8a'}$$

$$V_{i,A2}(\mathbf{x}_i, U_i) = b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i) - b_i(\mathbf{x}_{i,A1}, 0, \mathbf{x}_{iB}, U_i), \tag{1.8b'}$$

and

$$\begin{aligned} W_i(\mathbf{x}_i, U_i) &= V_{i,A1}(\mathbf{x}_i, U_i) + V_{i,A2}(\mathbf{x}_i, U_i) - V_{i,A}(\mathbf{x}_i, U_i) \\ &= b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i) - b_i(0, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i) - b_i(\mathbf{x}_{i,A1}, 0, \mathbf{x}_{iB}, U_i) + b_i(0, 0, \mathbf{x}_{iB}, U_i). \end{aligned} \tag{1.9'}$$

In the case where $b_i(\mathbf{x}_{iA}, \mathbf{x}_{iB}, U_i)$ is twice differentiable in $\mathbf{x}_{iA}$, this gives

$$W_i(\mathbf{x}_i, U_i) = \int_0^{\mathbf{x}_{i,A2}} \int_0^{\mathbf{x}_{i,A1}} \left[\partial^2 b_i(a_1, a_2, \mathbf{x}_{iB}, U_i) / \partial a_1 \partial a_2\right] da_1\, da_2. \tag{1.9''}$$

This generates the following results.

<u>Proposition 1</u>: Let $\mathbf{x}_{iA} = (\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}) \geq 0$ where $\mathbf{x}_{iA} \neq 0$ and $\mathbf{x}_{iB} \neq 0$. Assume that the i-th household benefit function $b_i(\mathbf{x}_{iA}, \mathbf{x}_{iB}, U_i)$ is twice differentiable in $(\mathbf{x}_{iA}, \mathbf{x}_{iB})$. The i-th household value of environmental diversity $W_i(\mathbf{x}_i, U_i)$ satisfies

a) $W_i(\mathbf{x}_i, U_i) = 0$ if $\partial^2 b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i)/\partial \mathbf{x}_{i,A1} \partial \mathbf{x}_{i,A2} = 0$ for all $(\mathbf{x}_{iA}, \mathbf{x}_{iB}) \geq 0$,

b) $W_i(\mathbf{x}_i, U_i) < 0$ if $\partial^2 b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i)/\partial \mathbf{x}_{i,A1} \partial \mathbf{x}_{i,A2} < 0$ for all $(\mathbf{x}_{iA}, \mathbf{x}_{iB}) \geq 0$,

c) $W_i(\mathbf{x}_i, U_i) > 0$ if $\partial^2 b_i(\mathbf{x}_{i,A1}, \mathbf{x}_{i,A2}, \mathbf{x}_{iB}, U_i)/\partial \mathbf{x}_{i,A1} \partial \mathbf{x}_{i,A2} > 0$ for all $(\mathbf{x}_{iA}, \mathbf{x}_{iB}) \geq 0$,

The proposition shows how the sign of the value of environmental diversity $W_i(\mathbf{x}_i, U_i)$ is determined. From a), a sufficient condition for a zero value of W_i is that the marginal benefit of $\mathbf{x}_{i,A1}$ is independent of $\mathbf{x}_{i,A2}$. From b), a sufficient condition for $W_i < 0$ is that the marginal benefit of $\mathbf{x}_{i,A1}$ decreases with $\mathbf{x}_{i,A2}$. In this case, the incremental benefit of $\mathbf{x}_{i,A1}$ is smaller when $\mathbf{x}_{i,A2}$ is positive (compared to $\mathbf{x}_{i,A2} = 0$). This means that the environment goods behave as <u>substitutes</u> across groups. Finally, from c), a sufficient condition for $W_i > 0$ is that the marginal benefit of $\mathbf{x}_{i,A1}$ increases with $\mathbf{x}_{i,A2}$. Then, the incremental benefit of $\mathbf{x}_{i,A1}$ is higher when $\mathbf{x}_{i,A2}$ is positive. This identifies the presence of synergy or complementarity across environmental groups, yielding a positive consumer value for environmental diversity.

4 Empirical Specification

For the analysis in this paper, we consider the following specification for the benefit function developed in Chapter 2 for the i-th household

$$b_i(\mathbf{x}_i, U_i) = \alpha_i(\mathbf{x}_i) - [U_i\beta_i(\mathbf{x}_i)]/[1 - U_i\gamma_i(\mathbf{x}_i)], \tag{1.10}$$

where $\beta_i(\mathbf{x}_i) > 0$, $[1 - U_i\, \gamma_i(\mathbf{x}_i)] > 0$. We have seen that $(\partial b_i/\partial \mathbf{x}_i)\, \mathbf{g} = 1$ holds for all $\mathbf{x}_i$ and U_i. This implies $(\partial\alpha_i/\partial\mathbf{x}_i)\, \mathbf{g} = 1$, $(\partial\beta_i/\partial\mathbf{x}_i)\, \mathbf{g} = 0$, and $(\partial\gamma_i/\partial\mathbf{x}_i)\, \mathbf{g} = 0$. From (1.10), assuming that $(\mathbf{p}_i^T\, \mathbf{g}) = 1$, the i-th household's price-dependent Hicksian demands are

$$p_i^c(\mathbf{x}_i, U_i) = \partial\alpha_i/\partial\mathbf{x}_i - \partial\beta_i/\partial\mathbf{x}_i\left[U_i/(1 - U_i\gamma_i(\mathbf{x}_i))\right] - (\partial\gamma_i/\partial\mathbf{x}_i)\beta_i(\mathbf{x}_i)U_i^2/(1 - U_i\gamma_i(\mathbf{x}_i))^2,$$

$i = 1, \ldots, N$.

Solving $b_i(\mathbf{x}_i, U_i) = 0$ yields $U_i = u_i(\mathbf{x}_i)$. Thus, $U_i/[1 - U_i\, \gamma_i(\mathbf{x}_i)] = \alpha_i(\mathbf{x}_i)/\beta_i(\mathbf{x}_i)$. Using $p_i^*(\mathbf{x}_i) \equiv p_i^c(\mathbf{x}_i, u_i(\mathbf{x}_i))$, we obtain the price-dependent Marshallian demands

$$p_i^*(\mathbf{x}_i) = \partial\alpha_i/\partial\mathbf{x}_i - \partial\beta_i/\partial\mathbf{x}_i\left[\alpha_i(\mathbf{x}_i)/\beta_i(\mathbf{x}_i)\right] - (\partial\gamma_i/\partial\mathbf{x}_i)\left[\alpha_i(\mathbf{x}_i)^2/\beta_i(\mathbf{x}_i)\right].$$

Let

$\alpha_i(\mathbf{x}_i) = \alpha_0 + \sum_{j=1}^{M} \alpha_j\, x_{ij} + \sum_{j=1}^{M}\sum_{k=1}^{M} \frac{1}{2}\, \alpha_{jk}\, x_{ij}\, x_{ik}$, with $\alpha_{jk} = \alpha_{j'k'}$ for all $j \neq j'$ and $k \neq k'$,

$\beta_i(\mathbf{x}_i) = \exp(\beta_0 + \sum_{j=1}^{M} \beta_j\, x_{ij})$,

$\gamma_i(\mathbf{x}_i) = \sum_{j=1}^{M} \gamma_j\, x_{ij}$,

with

$$\alpha_{jk} = \alpha_{j'k'}, \text{ for all } j \neq j' \text{ and } k \neq k', \tag{1.11}$$

as symmetry restrictions. Then, with $(\partial\alpha_i/\partial\mathbf{x}_i)\ \mathbf{g} = 1$, $(\partial\beta_i/\partial\mathbf{x}_i)\ \mathbf{g} = 0$, and $(\partial\gamma_i/\partial\mathbf{x}_i)\ \mathbf{g} = 0$ holding for all $\mathbf{x}_i$ imply the additional restrictions

$$\sum_{j=1}^{M} \alpha_j\, g_j = 1, \tag{1.12}$$

$$\sum_{j=1}^{M} \alpha_{jk}\, g_j = 0,\ k = 1, ..., M, \text{ (using the symmetry restrictions)}, \tag{1.13}$$

$$\sum_{j=1}^{M} \beta_j\, g_j = 0, \tag{1.14}$$

and

$$\sum_{j=1}^{M} \gamma_j\, g_j = 0. \tag{1.15}$$

It follows that the i-th household's price-dependent Marshallian demands for the j-th good is

$$p_{ij}^{*}(\mathbf{x}_i) = \alpha_j + \sum_{k=1}^{M} \alpha_{jk} x_{ik} - \beta_j\, \alpha_i(\mathbf{x}_i) - \gamma_j \left[\alpha_i(\mathbf{x}_i)^2 \big/ \beta_i(\mathbf{x}_i) \right], \tag{1.16}$$

$j = 1, \ldots, M$, $k = 1, \ldots, M$, and $i = 1, \ldots, N$.

Further considerations on Heterogeneity and Extension to a Panel Data Analysis

The benefit function is measured in terms of the number of units of the reference bundle **g** the consumer is willing to give up starting from utility U to obtain goods **x**. In our analysis, we consider the case where **g** involves market goods. For aggregation purpose, we want **g** to be the same for all consumers (Ch. 2). However, if the "law of one price" does not hold (because of transaction costs, etc.), each consumer can face different prices. This means that, even if the reference bundle **g** is constant, its unit value at a particular point of time can vary across consumers. In the application that follows, only aggregate consumption data is available. To address this issue, we group consumers into R regions. We define the regions such that all consumers in each region face the same prices at a given time.

In the r-th region at a given time, let the observed prices for **x** be $\mathbf{p}_r$, $r = 1, \ldots, R$. This implies that the unit value of **g** can vary across regions, i.e. that $\mathbf{p}_r^T\, \mathbf{g} = k_r$, where k_r is the unit value of $\mathbf{g}$ in region r. Below, we make the assumption that actual prices are proportional to the marginal willingness to pay for $\mathbf{x}$, i.e., that $\mathbf{p}_r^T = k_r\ (\partial b_i/\partial \mathbf{x}_i)$. We know that the benefit function satisfies $(\partial b_i/\partial \mathbf{x}_i)\ \mathbf{g} = 1$. This implies that $\mathbf{p}_r^T\ \mathbf{g} = \mathbf{k}_r\ (\partial b_i/\partial \mathbf{x}_i)\ \mathbf{g} = k_r$, r = 1, …, R, as expected.

Consider the hypothetical case where prices had been normalized in the r-th region such that $\mathbf{p}_r^T\ \mathbf{g} = 1$. In this case, assume that the marginal benefit obtained by the i-th household in the r-th region takes the form $\partial b_i/\partial \mathbf{x}_i = f_{ik}(\theta, \mathbf{x}_{i,}\ .)^T$, where $f_{ik}(\theta, \mathbf{x}_{i,}\ .)\ \mathbf{g} = 1$. Given $\mathbf{p}_r^T\ \mathbf{g} = k_r$, it follows that the price-dependent equations for the i-th household in the r-th region become

$$\mathbf{p}_{i,r} = k_r\, f\left(\theta, \mathbf{x}_i, \cdot\right) \tag{1.17}$$

where k_r can vary across regions. This implies a need to allow for different parameters k's across regions. We treat the parameters k's as additional parameters that need to be estimated.

To account for heterogeneous regional preferences, we also introduce regional dummy variables in the model. Let $D_{ir} = 1$ if the i-th household is in the r-th region, and 0 otherwise. The dummy variables D's are introduced to allow the parameters α_j to vary across regions, with α_j becoming $[\alpha_j + \sum_{r=1}^{R-1} \delta_{rj}\, D_{ir}]$. As a result, the dummy variables D's appear as intercept shifter in equation (1.16). Since the α_j's must satisfy the theoretical restrictions (1.12), it follows that (1.12) becomes

$$\sum_{j=1}^{M}\left[\alpha_j + \sum_{r=1}^{R\text{-}1} \delta_{r,j} D_{i,r}\right]\, g_j = 1 \tag{1.18}$$

for all r, implying that $\sum_{j=1}^{M}\ \alpha_j\, g_j = 1$ and $\sum_{j=1}^{M}\ (\alpha_j + \delta_{rj})\, g_j = 1$, r = 1, …, R-1.

One important issue that remains to be discussed is the choice of the reference bundle $\mathbf{g}$. As discussed above, to obtain nice aggregation properties, we want to choose $\mathbf{g}$ so that it remains constant for all consumers and includes only private goods. In our application, $\mathbf{g}$ is chosen to be $\mathbf{g} = \bar{\mathbf{x}}/(\bar{\mathbf{x}}^T\ \bar{\mathbf{p}})$, where $\bar{\mathbf{x}}$ and $\bar{\mathbf{p}}$ are the sample means. This means that the reference bundle **g** is the sample average consumption bundle rescaled to have unit value on average.

5 An Application

In this paper the model is applied to estimate a system of price-dependent demands for fish landed at Italian regional ports. The main underlining assumption is that fish commodities are weakly separable from all other commodities.

Description of the Database

The raw data was obtained from available publication of the Italian Institute of Statistics (ISTAT) and from the Istituto Ricerche Economiche per la Pesca e l'Acquacoltura (IREPA onlus)[2]. It consists of annual landing and average prices of 47 marine species, population, and tonnage of fishing vessels for 12 Italian regions[3]. The sample period covers 1974 through 2003, for a total of 360 observations.

Given the large number of species, to make the analysis manageable, we aggregated the species into five
of species reported in the Italian statistics[4].

Landings have been rescaled accordingly to regional population (demand side) and fleet tonnage (production capacity, supply side) to proxy regional consumption of fish species. The rescaling is done for each category as follows: $X = RL\,[1 - (1 - RP/TP)\,(RTSL/TTSL)]$, where RL is regional landing, RP is regional population, TP is total Italian population, RTSL is regional tonnage of fishing fleet, and TTSL is total tonnage of the Italian fleet. This also accounts for the unobservable transfers between regions; the fish that is landed is also

[2] We thank Ms. Gambino (IREPA) for making available part of the data on tonnage (elaborations on data from the Italian Ministry for Agricultural and Forestry Policies-Mipaf).

[3] The dataset includes only Italian regions facing the sea: 1-Abruzzi, 2-Calabria, 3-Campania, 4-Emilia Romagna, 5-Friuli V. Giulia, 6-Liguria, 7-Marche, 8-Puglia, 9-Sardegna, 10-Sicilia, 11-Toscana, 12-Veneto. Nevertheless, some regions are excluded because no availability of price data, Lazio and Basilicata, or because of the large presence of missing values, Molise.

[4] Similar but broader categories were analyzed in Moro and Sckokai (2002).

consumed in the regions that do not have direct access to the sea. Adjusting landings for the shares of population and fleet tonnage allows our data to be as if for regional markets. A region with large population is likely to consume the largest part of its landings, exporting the remaining to other regions. It is easy to check that, *ceteris paribus*, if RP increases also X increases. On the other side, a region with high production capacity will export more, relatively to other regions. Everything else being equal, when RTSL increases X decreases. Finally, quantities are then expressed in *per capita*[5] terms (kg/person) by dividing by regional population, and prices for each category are derived by dividing total value of landing (calculated before the adjustment), expressed in 2004 euros, by total landing. Descriptive statistics are presented in table 1.

Table 1 ABOUT HERE

Estimation and Empirical Results

Given the availability of aggregated consumption data, the econometric specification is written as a system of M regressions where the j-th good is obtained by combining equations (1.16) and (1.18), and adding an error term:

$$p_{rtj}^{*}(\mathbf{x}_{rt}) = k_r \left[\alpha_j + \sum_{r=1}^{R-1} \delta_{rj} D_r + \sum_{k=1}^{M} \alpha_{jk} x_{rtk} - \beta_j \alpha_{rt}(\mathbf{x}_{rt}) - \gamma_j \left[\alpha_{rt}(\mathbf{x}_{rt})^2 / \beta_{rt}(\mathbf{x}_{rt})\right]\right] + \varepsilon_{rtj} \quad (1.19)$$

where $\mathbf{x}_{rt}$ represents per capita fish consumption in the r-th region at year t, r = 1, …, R-1 (R=12), t = 1974, …, 2003 (T=30), and j and k represent respectively the j-th and k-th category/species, j,k = 1, …, M (M=5).

[5] In the case presented in this paper, only data on aggregated consumption are available. It is important to note that this does not undermine the applicability of the theoretical framework developed in chapter 2 to the Italian fishery case. This is so because even with aggregate data, the marginal benefit of a private good is just the marginal benefit associated with the consumer that consumes it, suggesting that the analysis should be done on a *per capita* basis.

Before the estimation, it is important to consider the stochastic properties of the system demands. Let $\mathbf{p}_{rt}^{*} = (p_{rt1}, \ldots, p_{rtM})$ be the (1×M) vector of independent variables and $f(\theta, \mathbf{z}_{rt})$ be the (1×M) vector of quantity variables that represent the right hand side of the demand system. Note that $\mathbf{z}_{rt}$ contains consumption as well as the regional dummies. We can express the whole system of demands derived from (1.19) as

$$\mathbf{p}_{rt}^{*} = f\left(\theta, \mathbf{z}_{rt}\right) + \boldsymbol{\varepsilon}_{rt}, \qquad r = 1, \ldots, R, \text{ and } t = 1, \ldots, T, \tag{1.20}$$

where the error term $\boldsymbol{\varepsilon}_{rt}$ is a (1×M) vector and it satisfies $E[\boldsymbol{\varepsilon}_{rt}]=0$, $E[\boldsymbol{\varepsilon}_{rt}\ \boldsymbol{\varepsilon}_{rt}^{T}] = \boldsymbol{\Sigma}$, where $\boldsymbol{\Sigma}$ denotes the contemporaneous covariance matrix. Note that the $\boldsymbol{\Sigma}$ matrix is in general non-singular (since the dependent variable is represented by price and not expenditure shares). As a result, we can proceed with estimating the full set of M equations. Since (1.20) is non-linear in the parameters, it requires using nonlinear estimation methods. The system, together with restrictions (1.11), (1.13)-(1.15) and (1.18) can be estimated by an Iterative Seemingly Unrelated Regression (ITSUR) procedure, allowing for correlation between equations.

Since we have panel data, there is a need to explore the time series properties of the model. Here, we focus on the serialcorrelation of $\boldsymbol{\varepsilon}_{rt}$, possibly reflecting the presence of individual specific effects. Neglecting serial correlation would likely bring inefficiency in the parameter estimates (Hsiao, 2003). There are several ways to handle serial correlation. We follow the suggestions by Hsiao (p. 57) applying them to the multiple equation case. Assume that $\boldsymbol{\varepsilon}_{rt}$ follows an AR(1) process $\boldsymbol{\varepsilon}_{rt} = \boldsymbol{\varepsilon}_{r,t-1}\ R^{M} + \mathbf{u}_{rt}$, where R^{M} is a diagonal M×M matrix reflecting serial correlation, and $\mathbf{u}_{rt}$ is a (1×M) vector of white noise error terms. Given R^{M}, we could transform the model (1.20) into

$$\mathbf{p}_{rt}^{*} = f\left(\theta, \mathbf{z}_{rt}\right) + \left[\mathbf{p}_{r,t-1}^{*} - f\left(\theta, \mathbf{z}_{r,t-1}\right)\right] R^{M} + \mathbf{u}_{rt}, \tag{1.21}$$

and estimate it and obtain efficient estimates of the parameters. Estimate of R^{M} matrix is obtained by using the residuals from estimating the model

$$\mathbf{p}_{rt}^* - \overline{\mathbf{p}}_r^* = f\left(\theta, \mathbf{z}_{rt} - \overline{\mathbf{z}}_r\right) + \left(\boldsymbol{\varepsilon}_{rt} - \overline{\boldsymbol{\varepsilon}}_r\right), \tag{1.22}$$

where $\overline{\mathbf{p}}_r^*$, $\overline{\mathbf{z}}_r$, and $\overline{\boldsymbol{\varepsilon}}_r$, are the individual means from (1.20) that are subtracted to eliminate the individual effects. The estimation of the AR process revealed significant serial correlation at lag one in the residuals of (1.20): $\rho_{1,1} = 0.6142$, $\rho_{2,2} = 0.5847$, $\rho_{3,3} = 0.5401$, $\rho_{4,4} = 0.5165$, $\rho_{5,5} = 0.3657$.

Estimation of (1.21) requires a new set of restrictions implied by the presence of serial correlation. The new restrictions are

$$\left[\begin{pmatrix}\alpha_1+\delta_{r,1} & \cdots & \alpha_M+\delta_{r,5}\end{pmatrix} - \begin{pmatrix}\alpha_1+\delta_{r,1} & \cdots & \alpha_5+\delta_{r,5}\end{pmatrix}\begin{pmatrix}\rho_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_{55}\end{pmatrix}\right]\begin{pmatrix}g_1 \\ \cdots \\ g_5\end{pmatrix} = k_r \tag{1.23}$$

for the r-th region, and

$$\left[\begin{pmatrix}\alpha_1 & \cdots & \alpha_5\end{pmatrix} - \begin{pmatrix}\alpha_1 & \cdots & \alpha_5\end{pmatrix}\begin{pmatrix}\rho_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_{55}\end{pmatrix}\right]\begin{pmatrix}g_1 \\ \cdots \\ g_5\end{pmatrix} = k_{12} \tag{1.24}$$

for the 12th region. Moreover, we have

$$\left[\begin{pmatrix}\alpha_{k1} & \cdots & \alpha_{k5}\end{pmatrix} - \begin{pmatrix}\alpha_{k1} & \cdots & \alpha_{k5}\end{pmatrix}\begin{pmatrix}\rho_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_{55}\end{pmatrix}\right]\begin{pmatrix}g_1 \\ \vdots \\ g_5\end{pmatrix} = 0, \text{ for k=1,..., 5,} \tag{1.25}$$

$$\left[\begin{pmatrix}\beta_1 & \cdots & \beta_5\end{pmatrix} - \begin{pmatrix}\beta_1 & \cdots & \beta_5\end{pmatrix}\begin{pmatrix}\rho_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_{55}\end{pmatrix}\right]\begin{pmatrix}g_1 \\ \vdots \\ g_5\end{pmatrix} = 0, \text{ and} \tag{1.26}$$

$$\left[\begin{pmatrix}\gamma_1 & \cdots & \gamma_5\end{pmatrix} - \begin{pmatrix}\gamma_1 & \cdots & \gamma_5\end{pmatrix}\begin{pmatrix}\rho_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_{55}\end{pmatrix}\right]\begin{pmatrix}g_1 \\ \vdots \\ g_5\end{pmatrix} = 0. \tag{1.27}$$

Equation (1.21) was estimated by ITSUR with restrictions (1.11), and (1.23)-(1.27) imposed. Estimates are consistent and asymptotically efficient. Overall, the model presents a good fit, as shown by the single-equation R^2 presented in the first part of table 2. The estimated parameters are presented in Appendix B.

Table 2 ABOUT HERE

Testing the Theory

The estimated model was used to investigate the concavity property of the benefit function. For the entire sample period, the benefit function was found to be globally concave and well behaved. Inspection of the "Luenberger matrix", defined as the Hessian of the benefit function (Ch. 2), and the corresponding eigenvalues calculated at the sample means (table 4), reveals that, as expected, the "Luenberger matrix" is singular (Ch. 2). Further interpretation of the 'Luenberger matrix' follows in the next section.

Formulae for the price flexibilities are derived in Appendix A. The estimates for "Luenberger" (compensated) and uncompensated quantity flexibilities evaluated at the sample means are presented in table 5. They express by how much the price of commodity j must change due to a marginal change in *per capita* consumption of commodity j, maintaining the same utility level. Own-quantity flexibilities are all negative as expected by the curvature property of the benefit function, meaning that the inverse demand functions are downward sloping. Their small magnitude[6] (in absolute value) is not surprising and it is consistent with other findings in the literature (Barten and Bettendorf, 1989; Beach and Holt, 2001; Holt and Bishop, 2002). However, our estimates are less consistent with those obtained by Moro and Sckokai (2002) using annual fish landing in Italy. The largest own-quantity compensated flexibility is for category 2 (*other fish*), while the smallest for category 5 (*crustaceans*). Most of the fish categories are net *q*-complements. The largest cross-quantity

[6] Since we are dealing with a price-dependent demand system, small quantity flexibilities correspond to high price elasticities.

compensated flexibility is for category 3 (*cephalopod*s) with respect to category 2 (*other fish*), the largest (net) *q*-complements. The opposite case is represented by anchovies, mackerels, and sardines with respect to other fish, with which are (net) *q*-substitutes. Uncompensated quantity flexibilities are in general smaller in absolute term. This is a sign that the substitution effect, measured by f_{jk}^{c} dominates the income/utility effect. Price-dependent uncompensated demands are rather price inflexible, i.e. $f_{jj}^{*}>-1$, implying that direct demands are price elastic. Scale flexibilities, which measure the response of each commodity price to an increase in quantity of commodities, are also presented in table 5. They Scale flexibilities for categories 1 and 3 are positive, suggesting that for these categories the complementarity effect dominates, while the remaining three are negative. To take one example, scale flexibility for category 3 (*cephalopods*) is 0.2263, indicating that a 1 percent increase in the quantity of all commodities will increase the price (or marginal benefit for consumers) of cephalopods by 0.2263 percent. Overall, these results are inconsistent with findings of the literature (Barten and Bettendorf, 1989; Holt and Bishop, 2002; Beach and Holt, 2001; Wong and McLaren, 2005).

Table 4 ABOUT HERE

Table 5 ABOUT HERE

Substitutability, Complementarity, and Value of Environmental Diversity

The curvature property of the benefit function is important not just for the consistency with the theory, but also for the derivation of the welfare measures[7], and therefore for the applicability of measures of the value of environmental diversity developed here. The benefit

[7] Welfare measures obtained by using the benefit function are discussed in Luenberger (1996), and in Paragraph 2.4.

function estimated through the inverse demand system measures the household willingness-to-pay to reach consumption level **x** starting from utility level U. Using the empirical results we can analyze the relations, in terms of environmental diversity, between fish categories and derive the willingness to pay for the expressions (1.7')-(1.9').

As shown in proposition 1, the sign of the off-diagonal terms of the "Luenberger matrix" is sufficient to establish the sign of the value that consumers assign to environmental diversity. By inspecting table 4, we note that *small pelagic* behave as substitutes only for *other fish*, while they show a complementarity relationship with all the remaining categories of species. This means that the i-th household values environmental diversity, intended as (1.9), negatively for (x_1, x_2), while positively for the pairs (x_1, x_3), (x_1, x_4), and (x_1, x_5). The category *other fishes* instead yields positive values to the household when associated only with the category *cephalopods*, through their synergic relationship. The category *cephalopods* have a synergic relationship with all the other categories. Finally, *other mussels* and *crustaceans* yield positive values when associated with *small pelagic* and *cephalopods*, and negative values when associated with *other fish*; though, they behave as substitutes, yielding negative consumer value for environmental diversity.

Table 6 presents the results obtained by applying (1.7')-(1.9') to the Italian fishery data. The base utility level is chosen to be U = $u(\mathbf{x}^a)$, and it is defined implicitly from solving $b(\mathbf{x}^a, u(\mathbf{x}^a))=0$. Concavity of the benefit function is checked to hold at any evaluation point. Some relationships are more interesting than others, so we choose to report only results for five pairs of goods. While s*mall pelagic* and *crustaceans* behave as complements, *other fish* and *crustaceans* behave as substitutes. This relation appears to be induced by the substitutability between s*mall pelagic* and *other fish*. Similar example is provided by the pair *other fish-other mussels* which appear to be substitutes and *cephalopods-other mussels* which interestingly behave as complements.

The top part of the table reports the *per capita* regional total value for selected pairs of goods averaged over entire time span, as calculated in (1.7'). Those figures represent consumer's benefit for the consumption of two single species one at the time: euros that each household, for each region, is willing to pay for its annual consumption of those two species. The bottom part of the table reports instead the value of environmental diversity as calculated by using (1.9'). The results confirm the theory in the sense that the values of diversity are of the signs predicted by proposition 1. The pairs *other fish-crustaceans* and *other fish- other mussels* have negative signs. This means that the i-th household[8] values environmental diversity, intended as consumption of one additional species, negatively. Hence, for example, the incremental benefit of consumption of *other fish* is smaller when consumption of *crustaceans* (*other mussels*) is positive (-0.16 euros for Sardegna region), compared to when consumption of *crustaceans* (*other mussels*) is zero. Opposite interpretation is for the other three pairs of groups of specie, for which the diversity value is positive. The results of table 6 show that the amount of euros that consumers are willing to pay for environmental diversity varies considerably between regions. For example, we can see that the household willingness to pay for environmental diversity referred to *other fish* and *cephalopods* goes from a minimum of 0.10 euros for Campania region to 6.74 euros for Marche region. This highlights the strong degree of complementarity that households from Marche region attribute to those two species relatively to households from Campania region.

We can express the results in aggregate terms by multiplying the regional per capita welfare measures just discussed by the population of each region. This gives the aggregated benefit for each region. The top panel of table 7 reports the average (over time) total value for the selected pairs of fish categories. The bottom panel reports the measure for the value of environmental diversity relatively to the aggregate regional consumer surplus. It is obtained

[8] Again, given data limitation, we assume that consumers are identical within each region, while they are different between regions.

by multiplying the per capita measures for population and then dividing by the aggregate consumer surplus. For the most part, we can notice that the environmental diversity component related to consumption represents a small percentage of the total value of the consumption of the species. Marche and Sicilia are the regions where that component is more relevant for the most of the reported species (x_1, x_5), (x_2, x_5), (x_2, x_3), while Abruzzi is the region with the highest value of diversity for (x_3, x_3) and (x_3, x_4). Campania and Toscana region denote the regions with the lowest appreciation for diversity. Finally, the benefit results for the whole group of Italian regions are reported. Table 7 shows the value of diversity, as a percentage of consumer value, for the aggregate group of regions.

Table 6 ABOUT HERE

Table 7 ABOUT HERE

6 Concluding Remarks

The paper addresses the question of how consumers value fish diversity. The question is answered by looking at the difference between the benefits of having the availability of a more diverse offer of fish species than having a more specialized one. Results are obtained from an application to the Italian fishery using a panel data for 12 regions in 30 years.

The analysis is based on the benefit function developed by Luenberger (1992). The benefit function provides a powerful way of conducting welfare analysis, with a special focus on the value of fish diversity as perceived by consumers. The framework is general and can address questions on the wider concept of biodiversity[9]. The model presented in this paper is

[9] The **x**'s will include not only quantity of biomass, but also other variables explaining the effect of biodiversity on the productivity of the ecosystem.

proposed as an alternative to the Inverse AIDS models that are more common in the literature.

This analysis could be extended to address the interest of policy makers facing a situation of scarcity of a natural resource which has market value. One example is given by managers considering the introduction of a moratorium on particular species. Obtaining a value for fish biodiversity is also valuable for cases in which optimal harvesting policies are considered. For example, when the fish stock is negatively affected by pollution, the value of diversity may be considered in a social welfare problem so to provide incentives for controlling pollution, even in the case when there are no incentives at all, i.e. the case of open access, when the shadow value of the stock is zero.

Appendix A

Price Flexibilities

When $u(\mathbf{x})$ is quasi-concave and strictly increasing in $\mathbf{x}$, we have that $u(\mathbf{x}) = U$ which implies $b(\mathbf{x}, U) = 0$, thus we can write $p^*(\mathbf{x}) \equiv p^c(\mathbf{x}, u(\mathbf{x}))$. We can derive price flexibilities deriving the latter identity for the j-th commodity with respect to $\mathbf{x}_k$ which yields

$$\partial p_j^*(\mathbf{x})/\partial \mathbf{x}_k \equiv \partial p_j^c(\mathbf{x}, u(\mathbf{x}))/\partial \mathbf{x}_k + \partial p_j^c(\mathbf{x}, u(\mathbf{x}))/\partial U \;\partial u(\mathbf{x})/\partial \mathbf{x}_k \tag{A1}$$

where the last term can be derived by differentiating $b(\mathbf{x}, u(\mathbf{x})) = 0$ with respect to $\mathbf{x}_k$, yielding $\partial u(\mathbf{x})/\partial \mathbf{x}_k = - \partial b(\mathbf{x}, u(\mathbf{x}))/\partial \mathbf{x}_k\, [\partial b(\mathbf{x}, u(\mathbf{x}))/\partial U]^{-1}$. Rearranging and multiplying by $\mathbf{x}_k/p_j$ gives[10] $\partial \log(p_j^*(\mathbf{x}))/\partial \log(\mathbf{x}_k) \equiv \partial \log(p_j^c(\mathbf{x}, u(\mathbf{x})))/\partial \log(\mathbf{x}_k) - \partial \log(p_j^c(\mathbf{x}, u(\mathbf{x})))/\partial U \;\; p_k^*(\mathbf{x})\, \mathbf{x}_k \;\; [\partial b(\mathbf{x}, u(\mathbf{x}))/\partial U]^{-1}$, which represents the j-th uncompensated price flexibility equation.

Let f_{jk}^c denotes the compensated price flexibility for commodity j with respect to $\mathbf{x}_k$, f_{jk}^* the compensated price flexibility for commodity j with respect to $\mathbf{x}_k$, and s_j the scale flexibility of commodity j, so to have

$$f_{jk}^c = \partial \log(p_j^c(\mathbf{x}, u(\mathbf{x})))/\partial \log(\mathbf{x}_k),$$

$$f_{jk}^* = f_{jk}^c - \partial \log(p_j^c(\mathbf{x}, u(\mathbf{x})))/\partial U \;\; p_k^*(\mathbf{x})\, \mathbf{x}_k \;\; [\partial b(\mathbf{x}, u(\mathbf{x}))/\partial U]^{-1},$$

$$s_j = \sum_{k=1}^{K} f_{jk}^*.$$

Given the specification of the benefit function (1.10), it is possible to derive explicit formulae for the flexibilities. Let $Ut = U/(1 - U\,\gamma(\mathbf{x}))$. The derivative of the price-dependent Hicksian demand for the j-th good with respect to the k-th good and U are given by

$\partial p_j^c(\mathbf{x}, U)/\partial \mathbf{x}_k = \partial^2\alpha/\partial \mathbf{x}_k^2 - [\partial^2\beta/\partial \mathbf{x}_k^2\; Ut + \partial\beta/\partial \mathbf{x}_k\; \partial Ut/\partial \mathbf{x}_k] - \partial\gamma/\partial \mathbf{x}_k\; [\partial\beta/\partial \mathbf{x}_k\; Ut^2 + \beta(\mathbf{x})\; \partial(Ut^2)/\partial \mathbf{x}_k]$, and

$\partial p_j^c(\mathbf{x}, U)/\partial U = - \partial\beta/\partial \mathbf{x}_k\, \partial Ut/\partial \mathbf{x}_k - \partial\gamma/\partial \mathbf{x}_k\; \beta(\mathbf{x})\; \partial(Ut^2)/\partial \mathbf{x}_k$.

Then the derivative of the benefit function with respect to the utility level U is

[10] Where $p_j \equiv p_j^*(\mathbf{x}) \equiv p_j^c(\mathbf{x}, u(\mathbf{x}))$, and $\partial b(\mathbf{x}, u(\mathbf{x}))/\partial \mathbf{x}_k = p_k^*(\mathbf{x})$.

$\partial b(\mathbf{x}, u(\mathbf{x}))/\partial U = -\beta(\mathbf{x})\, \partial Ut/\partial\, \mathbf{x}_k$.

Therefore, the explicit expressions for the compensated and uncompensated flexibilities are as follows:

$f_{jk}^{c} = \{\alpha_{jk} - \beta_j^2\, \beta(\mathbf{x})\, Ut - \beta_j\, \beta(\mathbf{x})\, Ut^2 - \gamma_j\, [\beta_j\, \beta(\mathbf{x})\, Ut^2 + \beta(\mathbf{x})\, 2Ut^3\, \gamma_j]\}\ (\mathbf{x}_k / p_j^{c})$,

(A2)

$f_{jk}^{*} = f_{jk}^{c} - \{\beta_j\, [1/(1 - U\, \gamma(\mathbf{x}))^2] + \gamma_j\, \beta(\mathbf{x})\, [2U/(1 - U\, \gamma(\mathbf{x}))^3]\}\ p_j^{*}\ [\beta(\mathbf{x})/(1 - U\, \gamma(\mathbf{x}))^2\,]\ \ (\mathbf{x}_k / \ p_j^{c})$.

(A3)

Appendix B

Parameter Estimates and Standard Errors of the Demand System

Parameter	Coeff.		SE	Parameter	Coeff.		SE	Parameter	Coeff.		SE
α_0	11.1546		11.8288	k_5	1.9903	**	0.1225	$\delta_{5,4}$	0.6813		0.6627
α_1	0.8499	**	0.2366	k_6	3.7880	**	0.1227	$\delta_{6,1}$	2.0466	**	0.2641
α_2	3.7806	**	0.5406	k_7	1.9953	**	0.1181	$\delta_{6,2}$	1.8546	**	0.4752
α_3	6.9550	**	1.1382	k_8	2.3989	**	0.123	$\delta_{6,3}$	4.8517	**	0.6146
α_4	2.8297	**	0.4876	k_9	2.8360	**	0.1225	$\delta_{6,4}$	1.6998	*	0.6658
$\alpha_{1,1}$	-0.0288		0.0155	k_{10}	2.1945	**	0.1228	$\delta_{7,1}$	0.3477		0.2986
$\alpha_{1,2}$	-0.0262		0.0182	k_{11}	3.2266	**	0.1232	$\delta_{7,2}$	0.0432		0.5128
$\alpha_{1,3}$	0.0531		0.0368	k_{12}	1.8153	**	0.1232	$\delta_{7,3}$	2.1967	**	0.6876
$\alpha_{1,4}$	0.0027		0.0134	$\delta_{1,1}$	0.8754	**	0.2594	$\delta_{7,4}$	-0.3101		0.7212
$\alpha_{2,2}$	-0.1831	**	0.0435	$\delta_{1,2}$	-0.5785		0.4496	$\delta_{8,1}$	0.6338	*	0.2638
$\alpha_{2,3}$	0.3309	**	0.0555	$\delta_{1,3}$	0.1502		0.6043	$\delta_{8,2}$	0.0494		0.46
$\alpha_{2,4}$	-0.0387		0.0261	$\delta_{1,4}$	-0.1558		0.6418	$\delta_{8,3}$	1.9745	**	0.6282
$\alpha_{3,3}$	-0.9593	**	0.2052	$\delta_{2,1}$	0.7956	**	0.2585	$\delta_{8,4}$	0.5306		0.6626
$\alpha_{3,4}$	0.1331	**	0.0445	$\delta_{2,2}$	0.1637		0.4563	$\delta_{9,1}$	1.0456	**	0.2628
$\alpha_{4,4}$	-0.0575		0.0333	$\delta_{2,3}$	1.0130		0.5821	$\delta_{9,2}$	0.8094		0.4561
β_1	0.0084	**	0.00565	$\delta_{2,4}$	0.0102		0.6486	$\delta_{9,3}$	2.2844	**	0.6128
β_2	0.0652	**	0.011	$\delta_{3,1}$	0.5392	*	0.258	$\delta_{9,4}$	0.3950		0.6564
β_3	-0.1290		0.0129	$\delta_{3,2}$	0.4910		0.4603	$\delta_{10,1}$	0.7636	**	0.2743
β_4	0.0081		0.00862	$\delta_{3,3}$	1.0121		0.5783	$\delta_{10,2}$	-0.2950		0.4654
γ_1	-0.00003		0.00005	$\delta_{3,4}$	2.2302	**	0.6481	$\delta_{10,3}$	0.7600		0.6768
γ_2	-0.0004	*	0.0002	$\delta_{4,1}$	-0.1012		0.2645	$\delta_{10,4}$	0.6940		0.6715
γ_3	0.0011	**	0.0003	$\delta_{4,2}$	-1.0495	*	0.4613	$\delta_{11,1}$	0.3943		0.2566
γ_4	-0.0001		0.00012	$\delta_{4,3}$	0.6065		0.6695	$\delta_{11,2}$	0.9274	*	0.455
k_1	2.1328	**	0.1212	$\delta_{4,4}$	-0.9736		0.6445	$\delta_{11,3}$	1.4541	*	0.5769
k_2	2.2173	**	0.1232	$\delta_{5,1}$	0.2431		0.2608	$\delta_{11,4}$	3.3209	**	0.6483
k_3	2.5654	**	0.1233	$\delta_{5,2}$	-0.5355		0.4726				
k_4	1.5965	**	0.1209	$\delta_{5,3}$	0.4850		0.608				

Note: * indicates significance at the 5% level and ** indicates significance at the 1% level.

Table 1– Descriptive Statistics for Fish "Consumption" in the Italian Regions.

	Per capita "Consumption" (kg/person)					Prices (euros/kg)			
Fish Category	Mean	Deviation	Min	Max	Fish Price	Mean	Deviation	Min	Max
x_1	2.19	2.36	0.06	15.64	p_1	1.67	0.77	0.40	5.08
x_2	3.52	3.20	0.70	17.5	p_2	5.27	1.45	0.98	11.46
x_3	0.66	0.69	0.06	5.42	p_3	5.69	1.61	2.26	11.64
x_4	2.28	2.79	0.01	21.88	p_4	3.40	1.94	0.21	13.71
x_5	0.50	0.55	0.04	3.33	p_5	10.33	5.78	2.76	61.56

(Note: x_1=*small pelagic*, x_2=*other fishes*, x_3=*cephalopods*, x_4=*other mussels*, and x_5=*crustaceans*)

Table 2– Measure of fit and autocorrelation diagnostic.

Single Equation R^2		
p_1		0.7678
p_2		0.7248
p_3		0.6880
p_4		0.6231
p_5		0.7908
Parameters Estimated		79
Objective Value		4.7729
N. of observations		348
Violation of concavity		0
AR(2) coefficients		
$\rho_{1,1}$		0.0302
$\rho_{2,2}$		0.1183
$\rho_{3,3}$		0.0590
$\rho_{4,4}$		0.0516
$\rho_{5,5}$		0.1292

Table 3– Covariance matrix of the system of equations.

	p_1	p_2	p_3	p_4	p_5
p_1	0.1469	0.0579	0.0673	0.0405	0.1321
p_2	0.0579	0.6096	0.2168	0.1511	0.4921
p_3	0.0673	0.2168	0.8435	0.1814	0.4913
p_4	0.0405	0.1511	0.1814	1.4260	0.3914
p_5	0.1321	0.4921	0.4913	0.3914	5.8082

Table 4 – Analytical "Luenberger matrix" evaluated at the sample means.

Fish Category	x_1	x_2	x_3	x_4	x_5	Eigen values
x_1	-0.0311	-0.0401	0.0785	0.0023	0.0597	-1.7464
x_2	-0.0401	-0.2834	0.5241	-0.0483	-0.0634	-0.5553
x_3	0.0785	0.5241	-1.3395	0.1562	0.4336	-0.0369
x_4	0.0023	-0.0483	0.1562	-0.0612	-0.0106	0.0000
x_5	0.0597	-0.0634	0.4336	-0.0106	-0.6891	-0.0657

(Note: x_1=*small pelagic*, x_2=*other fishes*, x_3=*cephalopods*, x_4=*other mussels*, and x_5=*crustaceans*)

Table 5 – Compensated, uncompensated, and scale flexibilities evaluated at the sample means (standard errors in parenthesis).

	Compensated Flexibilities					Uncompensated Flexibilities					
Fish Category	x_1	x_2	x_3	x_4	x_5	x_1	x_2	x_3	x_4	x_5	Scale
p_1	-0.0399	-0.0828	0.0307	0.0031	0.0175	-0.0241	-0.0066	0.0488	0.0349	0.0386	0.0916
	(0.0194)	(0.0515)	(0.0185)	(0.018)	(0.0168)	(0.0249)	(0.0621)	(0.0211)	(0.0236)	(0.0232)	(0.1053)
p_2	-0.0172	-0.1952	0.0685	-0.0216	-0.0062	-0.0049	-0.1362	0.0825	0.0031	0.0102	-0.0454
	(0.0106)	(0.0419)	(0.0119)	(0.0151)	(0.0124)	(0.0139)	(0.0636)	(0.0113)	(0.0211)	(0.0173)	(0.0944)
p_3	0.0269	0.2879	-0.1395	0.0555	0.0338	0.0231	0.2700	-0.1438	0.0481	0.0289	0.2263
	(0.0156)	(0.0379)	(0.0267)	(0.0231)	(0.0232)	(0.0201)	(0.0738)	(0.0309)	(0.0312)	(0.0291)	(0.1352)
p_4	0.0015	-0.0517	0.0316	-0.0423	-0.0016	-0.0136	-0.1242	0.0144	-0.0726	-0.0217	-0.2177
	(0.0089)	(0.0363)	(0.0135)	(0.0236)	(0.01)	(0.0165)	(0.0731)	(0.0182)	(0.0335)	(0.0209)	(0.1366)
p_5	0.0131	-0.0224	0.0290	-0.0024	-0.0346	0.0101	-0.0372	0.0255	-0.0086	-0.0387	-0.049
	(0.0125)	(0.0448)	(0.0205)	(0.0151)	(0.02)	(0.0125)	(0.0448)	(0.021)	(0.0151)	(0.0201)	(0.0923)

Table 6 – Mean *per capita* regional total value and value of environmental diversity for selected pairs of goods (euros/person).

Region	Abruzzi	Calabria	Campania	Emilia R.	Friuli V.G.	Liguria	Marche	Puglia	Sardegna	Sicilia	Toscana	Veneto
Total value												
x_1, x_5	6.92	2.73	2.76	7.62	4.66	10.37	10.92	9.97	5.77	11.77	4.84	3.45
x_2, x_5	18.39	9.60	7.45	16.00	8.43	23.18	47.90	32.53	31.56	41.39	12.09	9.27
x_2, x_3	16.06	9.26	7.00	15.33	9.73	22.32	55.70	31.12	30.84	35.02	10.63	10.41
x_3, x_4	11.34	2.15	2.71	9.54	19.34	15.00	18.62	12.86	11.50	10.34	2.01	6.08
x_2, x_4	23.28	8.55	7.51	21.33	23.54	30.61	49.97	32.48	32.62	32.29	10.01	11.20
Value of diversity												
x_1, x_5	0.04	0.01	0.01	0.13	0.03	0.03	0.30	0.09	0.01	0.09	0.02	0.02
x_2, x_5	-0.11	-0.02	-0.01	-0.07	-0.02	-0.05	-1.27	-0.23	-0.16	-1.07	-0.01	-0.02
x_2, x_3	0.91	0.19	0.10	0.74	0.49	0.63	6.74	2.55	2.44	4.54	0.16	0.48
x_3, x_4	0.40	0.01	0.01	0.22	0.52	0.21	0.50	0.29	0.28	0.15	0.00	0.10
x_2, x_4	-0.90	-0.02	-0.02	-0.62	-0.35	-0.44	-0.87	-0.46	-0.37	-0.24	-0.01	-0.08

Table 7 – Mean regional benefit for total value and percentage of value of environmental diversity for selected pairs of goods (euros).

Region	Abruzzi	Calabria	Campania	Emilia R.	Friuli V.G.	Liguria	Marche	Puglia	Sardegna	Sicilia	Toscana	Veneto	Aggregate
Population	1,234,011	2,054,179	5,548,866	3,928,046	1,206,717	1,717,260	1,424,111	3,941,001	1,612,159	4,935,591	3,533,298	4,372,312	35,507,551
Total Benefit													
x_1, x_5	8,534,609	5,606,267	15,339,943	29,924,687	5,622,127	17,802,472	15,553,491	39,275,956	9,295,608	58,107,364	17,084,072	15,069,873	237,216,469
x_2, x_5	22,692,369	19,713,739	41,355,257	62,851,144	10,168,042	39,807,765	68,218,174	128,206,028	50,885,069	204,283,287	42,702,132	40,548,440	731,431,445
x_2, x_3	19,819,257	19,029,696	38,817,215	60,209,458	11,745,917	38,325,783	79,320,055	122,658,206	49,712,219	172,853,873	37,570,349	45,521,242	695,583,269
x_3, x_4	13,996,672	4,410,052	15,020,361	37,462,026	23,332,131	25,765,204	26,518,029	50,672,871	18,535,000	51,026,277	7,101,789	26,572,448	300,412,860
x_2, x_4	28,727,692	17,566,578	41,691,558	83,767,470	28,400,996	52,556,955	71,162,210	127,999,622	52,587,437	159,364,893	35,354,579	48,957,477	748,137,467
Value of diversity as percentage of Total Benefit													
x_1, x_5	0.52	0.27	0.37	1.74	0.65	0.25	2.71	0.94	0.20	0.74	0.36	0.72	0.90
x_2, x_5	-0.57	-0.16	-0.12	-0.45	-0.25	-0.24	-2.65	-0.72	-0.51	-2.58	-0.12	-0.18	-1.23
x_2, x_3	5.67	2.10	1.38	4.84	4.99	2.83	12.09	8.18	7.93	12.98	1.55	4.57	7.95
x_3, x_4	3.50	0.39	0.38	2.33	2.67	1.39	2.68	2.24	2.40	1.45	0.16	1.72	1.97
x_2, x_4	-3.88	-0.19	-0.20	-2.90	-1.47	-1.43	-1.75	-1.42	-1.12	-0.76	-0.08	-0.75	-1.35

References

Banks, J., R. Blundell, and A. Lewbel. "Quadratic Engel Curves and Consumer Demand" Review of Economics and Statistics 79 (1997):527-539.

Brock W. A. and Xepapadeas A. "Valuing Biodiversity from an Economic Perspective: A Unified Economic, Ecological, and Genetic Approach." The American Economic Review 93 (2003): 1597-614.

Barten A. P. and L. Bettendorf. "Price Formation of Fish: an Application of an Inverse Demand System" European Economic Review 33 (1989): 1509-1525.

Beach R. H. and Holt M.T. "Incorporating Quadratic Scale Curves in Inverse Demand Systems." American Journal of Agricultural Economics 83 (2001): 230-45.

Deaton A. "The Distance Function and Consumer Behaviour with Applications to Index Numbers and Optimal Taxation" Review of Economic Studies 46 (1979): 391-405.

Eales J. S. and Unnevehr L. J. "The inverse almost ideal demand system." European Economic Review 38 (1994): 101-15.

Hsiao C. Analysis of Panel Data, 2nd edition. Cambridge University Press, Cambridge, 2003.

Holt M. T. and Bishop R. C. "A semiflexible normalized quadratic inverse demand system: an application to the price formation of fish." Empirical Economics 27 (2002): 23-47.

ISTAT. Statistiche della caccia e della pesca, Roma-ISTAT, 1987-2003.

ISTAT. Statistiche della caccia e della pesca e della cooperazione, Roma-ISTAT, 1985-1986.

ISTAT. Annuario statistico della zootecnia, pesca e caccia, Roma-ISTAT, 1974-1984.

ISTAT. Statistiche Demografiche, Demo-Geodemo, website: http://demo.istat.it/.

Luenberger, D.G. "Benefit Functions and Duality" Journal of Mathematical Economics 21 (1992): 461-481.

________. Microeconomic Theory. McGraw-Hill Inc., New York, 1995.

________. "Welfare from a benefit viewpoint." Economic Theory 7 (1996): 445-62.

Moro D. and Sckokai P. "Functional separability within a quadratic inverse demand system." Applied Economics 34 (2002): 285-93.

Wong K.K.G. and McLaren K. R. 2002. "Specification and Estimation of Regular Inverse Demand System: A Distance Function Approach" American Journal of Agricultural Economics 87 (2005): 823-34.