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An Empirical Test for Costs Subadditivity in the Fishery Sector

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Abstract

The seminal work by Baumol et al. (1982) has highlighted the importance of analyzing firms' costs structure. This allows to design proper policy measures and to understand the impacts of those policies in markets. The note presents an original method and an application for testing costs subadditivity in the fishery sector, by using a system of supply functions under strict conditions and assumptions. The method is practical, though robust, and can be applied in the absence of detailed data on costs structures. Under stringent hypothesis (that delimit the application) they can be inferred from the supply functions. Subadditivity in costs, in fact, is a more proper economic definition (and methodological approach) than traditional economies of scale in fishery. The latter, in fact, does not depend from the vessel technology, but on the degree of quantity and variety of fish species in the ocean. (JeL Code: C01, C30, D24, Q22)

Keywords: costs subadditivity, vessel, fishery, simultaneous equations model, 2SLS

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1. Introduction

Fishery vessels are multiproduct firms. The multiproduct firm's structures of costs and technology are important determinants of multiproduct industry structure. The seminal work by Baumol Panzar, and Willig (1982) has established theoretical conditions for the existence of multiproduct cost advantages that can be achieved by specialized or diversified firms according to the scale and scope of their production. The concept of cost subadditivity provides an additional measure by which to characterize the multiproduct cost structure. Costs subadditivity is a property that characterize production costs. It implies that production from only one firm is socially less expensive (in terms of average costs) than production of a fraction of the original quantity by an equal number of firms. Investigating the existence of costs subadditivity (or super-additivity) is not (only) an academic exercise but can provide important hints for policy guidance. In fact, a vessel with super-additive costs can save money by braking itself into two or more divisions. Most probably, unless there are factors that preclude such decentralization, we would not expect to observe profit-maximizing firms operating at super-additive costs. In that case, subsidies could be awarded in order to minimize the vessel losses, when the “main” problems should be diagnosed at the cost function level, and the “consequential” measure be taken at that level. On the contrary, a firm with subadditive costs, may enjoy cost advantage that (1) either make subsidies inefficient or improper, (2) or render any kind of antitrust policy absolutely not apt, if the firm enjoys dominant positions due to efficient production that is represented by costs subadditivity. Such analysis can also apply to tackle the effects of policies that impact costs of production inputs, including labour, as in the case of the landing obligation (see Onofri and Maynou 2017).

It is also important to highlight that subadditivity in costs is a more proper economic definition (and methodological approach) than traditional economies of scale in fishery. The latter, in fact, does not depend from the vessel (firm) technology, but on the degree of quantity and variety of fish species in the ocean.

Formally, a cost function is said to be subadditive at an output vector, say q, if and only if it is cheaper for a single firm to produce q than to split it among more than one firm in any fashion. In formal terms:

- the function c(q) is subadditive at the output level $\overline{q}$ if and only if c($\overline{q}$) $<$ $\sum_{i=1}^{n} c(\overline{q}^{i})$, where non-negative $\overline{q}^{i}$ are that $\sum_{i=1}^{n}(\overline{q}^{i})$ = $\overline{q}$.

In the case of fishery, for instance the possibility to fish different species with the same device mostly depends on the sea productivity and variety of species. This allows, a "savings" in the costs, e.g. costs subadditivity. According to Baumol et al. (1982), in the theory of contestable markets, costs subadditivity might favor a market structure characterized by few firms operating in the sector (natural oligopoly and natural monopoly).

This means that the current technology allows multi-production (e.g. simultaneously fishing different species with the same net or trawl) at a lower cost than separate production of each output that is multi-produced. In this perspective, total costs are lower than in the case the vessel had to use a different device for every type of species. Economies of scope exist if the costs of producing each product separately exceed the costs of producing all products jointly. Economies of scope and declining average incremental cost for each product are sufficient conditions for subadditivity. The presence of cost subadditivity would suggest that some form of fishermen's monopoly is appropriate on private efficiency grounds. The monopoly could be private, or could entail complete government ownership and control, or could include extensive government coordination and regulation as is found in north, or could consist of a set of single-product firms contracting among themselves (Squires, 1987).

The note presents an original method for testing costs subadditivity in the fishery sector, by using a system of supply functions under strict conditions and assumptions. The method is practical, though robust, and can be applied in the absence of detailed data on costs structures. Under stringent hypothesis (that delimit the application) they can be inferred from the supply functions.

The note is organized as follows: section 2 presents a survey of the (scarce) economic and econometric literature that has produced test for subadditivity in industries. Section 3 presents an original methodology, by developing testable implications and testable empirical specifications, under stringent conditions.

2. Tests of Cost subadditivity: a Survey of the Literature

Tests of cost subadditivity are difficult to devise, since one of the requirements is global knowledge of the cost function[1], while local knowledge in the neighborhood of the point of approximation is usually the best that can be achieved. Acceptance of local subadditivity then

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[1] The first preliminary step for testing costs subadditivity implies the definition of an empirical costs specification and the econometric estimation of the costs function of a multi-product firm. The economic literature has focused on the analysis of proper empirical specifications of the cost functions that allow to further test for subadditivity, given available data. The seminal model by Caves et al (1980) defines a Generalized Translog (GT) supply function/costs specification as follows:

$$(1)\quad \ln C = \alpha_0 + \sum \alpha_i q_i^{(\pi)} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} q_i^{(\pi)} c_j^{(\pi)} + \frac{1}{2}\sum_i \sum_r \delta_{ir} q_i^{(\pi)} \ln w_r + \sum_r \beta_r \ln w_r \ + \frac{1}{2}\sum_r \sum_l \beta_{rl} \ln w_r \ln w_l$$

Where where C is the cost (supply) function, qi and qj are the quantities of output i and j (where I and j = 1,…, n) , wr indicates factor prices (in our three-input case r, $l = L, K, F$), and the superscripts in parentheses π represent Box-Cox transformations of outputs. Under certain conditions the specification can become the nested *Standard Translog* (ST) *Specification*, assuming the usual logarithmic (lnc) form[1]. We can the estimate a system of GT.

provides a sufficient condition for global cost subadditivity (Evans and Heckman, 1984). Although Baumol et al. (1982) provide both necessary and sufficient conditions for cost subadditivity, the long-run multiproduct cost function allows only local sufficient conditions. Failure to establish cost subadditivity will then not preclude its existence. Tests of cost subadditivity specify all factors of production to be in full static equilibrium and outputs as exogenously fixed. In general, cost subadditivity requires economies from proportional expansion of the product vector along an output ray and economies arising from product combinations along a cross-sectional hyperplane (Baumol, et al., 1982).

The Evans-Heckman (1984) test for subadditivity implies a two-product industry where all firms have access to the same technology. The cost function $C(q_1, q_2)$ is locally subadditive at $\bar{q} = (\bar{q}_1, \bar{q}_2)$ if and only if for nonnegative $\bar{q}_1, \bar{q}_2$:

$$(1)\ \sum_i C(a_i\, \bar{q}_1, b_i\, \bar{q}_2) > C(\bar{q}_1, \bar{q}_2)$$

With i = 1,....n.

$$(2) \sum a_i = 1,\ \sum b_i = 1,\ a_i \geq 0, b_i \geq 0$$

For at least two a_i and b_i not equal to zero. The test computes (2) for an admissible range of outputs and allows for local subadditivity. The degree of subadditivity can be measures as:

$$(3)\ Sub_t\,(\varphi,\omega) = [\ \check{C}_t - \check{C}_t^A(\varphi,\omega) - \check{C}_t^B(\varphi,\omega)]/\ \check{C}_t$$

Where φ and ω are parameters that satisfy $0 \leq \varphi \leq 1$ and $0 \leq \omega \leq 1$. If $Sub_t\,(\varphi, \omega)$ is less than zero, the cost function is subadditive with respect to the industry configuration at the selected time t. If $Sub_t(\varphi,\omega)$ equals zero the cost function is additive; if it is larger than zero the cost function is superadditive.

Another (indirect) way to test for subadditivity, is looking at the existence of economies of scope in the industry. Scope economies (diseconomies) are reflected into cost savings (cost disadvantages) associated with the joint production of many outputs. Economies of scope exist if the costs of producing each product separately exceed the costs of producing all product jointly. Economies of scope and declining average incremental cost for each product are sufficient conditions for subadditivity. The average incremental cost of output *i*, when the total output vector is $\tilde{q}$, is the cost of producing out vector $\tilde{q}$, minus the cost of producing all of $\tilde{q}$ excluding product *i*, divided by the output of i, $\tilde{q}_i$. (Evans and Heckman, pag 616).

Scope economies are a necessary (but not sufficient condition) for costs subadditivity.

Suppose that the multi-product cost function is represented by C = C (q; w) where $q = (q_1, q_2, q_3)$ is the quantity of three different outputs and $w = (w_L, w_k, w_F)$ are respectively the prices of labor, capital and other inputs. Local measures of global and product-specific scale and scope economies can be easily defined. The measure of global or aggregate scope economies for our three-output case can be computed as:

$$(4)\ SA\,(q, w) = \frac{[C(q_1;w)+C(0,q_2,0;w)+C(0,0,q_3;w)-C(q;w)]}{C(q;w)}$$

with $SC_A > 0$ (< 0) denoting global economies (diseconomies) of scope.

Product-specific economies of scope for output i are

$$(5) S_{PS}\,(q, w) = \frac{[C(q_i;w)+C(q_{-i};,w)-C(q;w)]}{C(q;w)}$$

where *C(qi; w)* is the cost of producing only output i, and Si > 0 (< 0) indicates a cost disadvantage (advantage) in the “stand-alone” production of output i.

3. Vessels as Multiproduct firms: a Tentative Test for Subadditivity in Fishery Production

Vessels can be considered as multi-product firms because they can fish a variety of species (given the sea productivity) with the use of the same technology and capacity. This allows in saving on costs, and might imply costs subadditivity. The individual vessel multi-product supply curve is:

$$(6)\ \sum_n q_n = f(p_n), \qquad with \frac{dq_n}{dpn} > 0.$$

where q_n, is the quantity of n species caught and sold by the vessel; c_n, are the vessel’s production costs and on p_n, the market price for *n* types of caught species. Vessels are price-takers and price at marginal cost. Therefore, the supply function is also the cost function $\sum_n c_n = f(q_n)$ with (ususally) $\frac{dcn}{dqn} > 0$.

Given, *$c(q_n) = p(q_n)$ the supply function i the supply function is* $\Rightarrow$ $\boxed{\sum_n q_n = f(c_n)}$

The assumption of marginal cost pricing is required to fully exogenize prices and costs[2] and keep multi-product quantities as only control variable. Such assumption is grounded on the evidence that fish prices are determined by the market (no collusion among firms) and are

[2] See Varian (2000)

pretty similar among all vessels. Given the above assumptions, our exercise implies two steps.

Step 1. We empirically estimate a system of supply functions (which are also the costs functions) for n different products. Required data are produced quantity for each n species and related price for each species. (see Onofri and Maynou, 2017).

Step 2. Recalling that a cost function *c(q)* is subadditive at the output level $\overline{q}$ if and only if c$(\overline{q}) < \sum_{i=1}^{n} c\left(\overline{q}^{i}\right)$, *where non-negative* $\overline{q}^{i}$ *are that* $\sum_{i=1}^{n}\left(\overline{q}^{i}\right) = \overline{q}$) then there is costs subadditivity at the output level $\overline{q}$, where a perfect competition market-defined price if and only if q$(\overline{p}) < \sum_{i=1}^{n} q\left(\overline{p}^{i}\right)$. As necessary condition, when estimated parameter for quantity/quantities present negative estimated sign then we can assume costs subadditivity (see Maddala) at certain output level. An increase in prices/costs might generate a corresponding decrease in output quantities, in the relationship described by the supply function, which usually imply a positive relationship price/cost/produced quantity. This can be interpreted as a symptom of costs subadditivity[3]. If detailed data on costs are available the usual Evans-Heckman test can be applied.

4. An Application

We have used a dataset, with 3,964 observations gathered in 2014. The dataset gathers observations of weekly transactions (that imply price of the fish and traded quantity), made by the 88 vessels (the fleet of Sant Carles de la Rapita in southern Catalonia), in the period

[3] See Onofri and Maynou (2017) for a preliminary application in Appendix.

2013-2015. In the selected location, fish is landed and sold at the Dutch auction daily. The buyers are mostly wholesalers that sell the product to retailer (fish mongers), who sell to the final consumer. The data relate to first sale prices. The dataset includes 12 major categories of catches, which will be denoted by the FAO 3-alpha code (MON: monkfish; EOI: white octopus; HKE: European hake; JAX: horse mackerel; MTS: mantis shrimp; MUT: red mullet; SQM: squid; BOY: purple murex; CTC: cuttlefish; OCC: common octopus; SBG: golden seabream; SOL: European sole) and two main fishing technologies (OTB: semi-industrial otter bottom trawl and AM: small scale set fishing gear, mainly trammel nets). In addition, the dataset includes information on fuel prices and boat engine power. Table 1 reports some descriptive statistics of the selected variables.

Table 1. Descriptive Statistics of the Dataset

Variable	Mean	Standard Deviation	Min	Max
MON Value in Euro	155.45	299.47	0	2630.53
BOY Value in Euro	124.41	213.29	0	3617.15
CTC Value in Euro	134.79	280.69	0	4596.31
EOI Value in Euro	130.40	229.45	0	2185.08
HKE Value in Euro	311.48	617.45	0	6811
JAX Value in Euro	33.52	75.95	0	1516.02
MTS Value in Euro	267.60	396.84	0	3261.89
MUT Value in Euro	205.29	395.27	0	5954.45
OCC Value in Euro	182.91	391.56	0	9291.62
SBG Value in Euro	228.30	660.95	0	12066.88
SOL Value in Euro	160.315	354.82	0	5080.11
SQM Value in Euro	62.82	151.24	0	2378.76
Fishing techinque AM	Dummy Variable, taking the value of 1 if the fishing technique is AM and zero otherwise			
Fishing Technique OTB	Dummy Variable taking the value of 1 if the fishing technique is OTB and zero otherwise			

MON Quantity in Kilograms	30.93	61.59	0	541.45
BOY Quantity in Kilograms	21.98	43.87	0	639.1
CTC Quantity in Kilograms	17.49	38.11	0	724.55
EOI Quantity in Kilograms	51.94	93.53	0	688.05
HKE Quantity in Kilograms	50.61	110.86	0	1739.6
JAX Quantity in Kilograms	29.74	67.26	0	1496.95
MTS Quantity in Kilograms	70.68	115.29	0	995.95
MUT Quantity in Kilograms	46.33	103.34	0	1429.85
OCC Quantity in Kilograms	34.49	68.91	0	1524.35
SBG Quantity in Kilograms	32.49	72.69	0	1093.55
SOL Quantity in Kilograms	10.56	24.37	0	396.85
Fuel Price in Euro	556.48	54.82	0	617.14
Engine Power (HP)	143.53	127.45	19	500
MON Price Euro per kilo	2.12	2.95	0	25.7
BOY Price Euro per kilo	4.76	4.2	0	24.55
CTC Price Euro per kilo	4.65	4.25	0	19.2
EOI Price Euro per kilo	1.09	1.52	0	14.6
HKE Price Euro per kilo	3.21	3.23	0	13.6
JAX Price Euro per kilo	0.56	0.68	0	4.4.
MTS Price Euro per kilo	3.19	2.68	0	10.7
MUT Price Euro per kilo	3.03	3.16	0	15.55
OCC Price Euro per kilo	4.12	2.24	0	10.4
SBG Price Euro per kilo	3.64	5.04	0	26.1
SOL Price Euro per kilo	10.76	8.08	0	32.6

FAO 3-alpha code (MON: monkfish; EOI: white octopus; HKE: European hake; JAX: horse mackerel; MTS: mantis shrimp; MUT: red mullet; SQM: squid; BOY: purple murex; CTC: cuttlefish; OCC: common octopus; SAN: sand eel; SBG: golden seabream; SOL: European sole).

Given the multiproduct nature of the vessels, we model a system of simultaneous supply functions equations, where (logged) supplied quantity is a function of (logged) price (for each fish category). Price is determined in the market and exogenous. Dummies for fishing techniques are added in the model. The model also includes constants and error terms for each considered category (or supply side segment). Equation (4) shows the system of supply functions estimated with a 3SLS routine.

Eq. (4)

$$
\begin{aligned}
&(a)\ LogQ_{1,n} = \alpha_0 + \beta_1 Price_{1,n} + \beta_2 FishingTechnique_{1,n} + \varepsilon \\
&(b)\ LogQ_{2,n} = \alpha_0 + \beta_1 Price_{2,n} + \beta_2 FishingTechnique_{2,n} + \varepsilon \\
&(c)\ LogQ_{3,n} = \alpha_0 + \beta_1 Price_{3,n} + \beta_2 FishingTechnique_{3,n} + \varepsilon \\
&(d)\ LogQ_{4,n} = \alpha_0 + \beta_1 Price_{4,n} + \beta_2 FishingTechnique_{4,n} + \varepsilon \\
&(e)\ LogQ_{5,n} = \alpha_0 + \beta_1 Price_{5,n} + \beta_2 FishingTechnique_{5,n} + \varepsilon \\
&(f)\ LogQ_{6,n} = \alpha_0 + \beta_1 Price_{6,n} + \beta_2 FishingTechnique_{6,n} + \varepsilon \\
&(g)\ LogQ_{7,n} = \alpha_0 + \beta_1 Price_{7,n} + \beta_2 FishingTechnique_{7,n} + \varepsilon \\
&(h)\ LogQ_{8,n} = \alpha_0 + \beta_1 Price_{8,n} + \beta_2 FishingTechnique_{8,n} + \varepsilon \\
&(i)\ LogQ_{9,n} = \alpha_0 + \beta_1 Price_{9,n} + \beta_2 FishingTechnique_{9,n} + \varepsilon \\
&(j)\ LogQ_{10,n} = \alpha_0 + \beta_1 Price_{10,n} + \beta_2 FishingTechnique_{10,n} + \varepsilon \\
&(k)\ LogQ_{11,n} = \alpha_0 + \beta_1 Price_{11,n} + \beta_2 FishingTechnique_{11,n} + \varepsilon \\
&(l)\ LogQ_{12,n} = \alpha_0 + \beta_1\ Price_{12,n} + \beta_2\ FishingTechnique_{12,n} + \varepsilon
\end{aligned}
$$

Table 2 reports estimation results. The sign of the estimated coefficients is both positive (as prescribed by microeconomic theory) and negative. In the latter case, highlighted in orange in Table 2, the structural equation estimates for the supply function imply negative responses of quantity supplied to price of the product. Following Merrill and Fox (1970) and Maddala (1992), we interpret the results as depending on costs subadditivity.

Table 2. Estimation Results.

Supply Functions Estimation Results	
Variables	**Estimated Coefficients**
(Log) MON Quantity	
(Log) MON Price	0.67 *
Fishing Technique OTB	0.88
Constant	2.93***
(Log) BOY Quantity	

(Log) BOY Price	-0.41***
Fishing Technique AM	0.67***
Constant	3.35***
(Log) CTC Quantity	
(Log) CTC Price	-1.03***
Fishing Technique OTB	0.04
Constant	4.95***
(Log) EOI Quantity	
(Log) EOI Price	-1.02***
Fishing Technique OTB	-1.53***
Constant	5.07***
(Log) HKE Quantity	
(Log) HKE Price	-0.77***
Fishing Technique AM	-0.83***
Constant	5.59***
(Log) JAX Quantity	
(Log) JAX Price	-0.38***
Fishing Technique OTB	1.04***
Constant	3.97***
(Log) MTS Quantity	
(Log) MTS Price	-0.17*
Fishing Technique OTB	0.57*
Constant	5.72***
(Log) MUT Quantity	
(Log) MUT Price	-1.27***
Fishing Technique OTB	1.21***
Constant	6.28***
(Log) OCC Quantity	
(Log) OCC Price	0.03
Fishing Technique AM	0.45

Constant	3.21***
(Log) SBG Quantity	
(Log) SBG Price	-0.21*
Fishing Technique AM	-1.49*
Constant	3.50
(Log) SOL Quantity	
(Log) SOL Price	-0.23
Fishing Technique AM	0.02
Constant	1.96

*= 10% statistically significant; **= 5% statistically significant; ***= 1% statistically significant.

5. Conclusions

The note presents an original method for testing costs subadditivity in the fishery sector, by using a system of supply functions under strict conditions and assumptions, in . The method is practical, though robust, and can be applied in the absence of detailed data on costs structures. Under stringent hypothesis (that delimit the application) they can be inferred from the supply functions. The method can have important policy implications. Analyzing the structure of the firms' costs allows to design proper policy measures and to understand the impacts of those policies in markets.

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