Development of a Computable General Equilibrium (CGE) Model for Fisheries*

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Abstract

This paper gives an introduction to Computable General Equilibrium (CGE) modelling, and presents an application of the technique to fisheries using data from Salerno, Italy. First, this study explains the data requirements for CGE model of the type employed. Second, we explain the process that can be used to develop and employ an applied static CGE model. Then we use the model for policy analysis.
The main purpose of this paper is to contribute to and facilitate the use of general equilibrium models for policy and decision-making by looking at the relationship between economics and biology. To the best of our knowledge, this is the first application of a CGE model applied to fishing industry.
Our model offers some interesting conclusions that help us to better understand the modelling and dynamics of fisheries (and in particular the link between economy-biology) when considered as a whole sector in interaction with the rest of the economy.

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I. INTRODUCTION

General equilibrium (GE) theory suggests that real-world markets are interdependent where changes in supply or demand conditions usually have repercussions on supply and demand conditions. Since the beginning of the 1980s GE models have become popular to analyse and describe economy, because they provide quantitative results in policy analysis. General equilibrium models are increasingly being used for many problems (see Harberger, 1962; Shoven and Whalley, 1992). They may be applied to any large economic change. Computable general equilibrium (CGE) model is a policy model where the main goal is to formulate a model of simultaneous equilibrium[1].

In this paper, we focus on a static CGE model. We give a brief introduction to CGE modelling, and we provide a simple basic structure that can be used for the development of a CGE model for fisheries. The main goal of this study is to develop a CGE model for the evaluation of the socio-economic contributions of the fishing activities. From fishery management point of view, it is necessary to employ a regional economic model and estimate the regional economic impacts attributable to fishery policies. For our simple example we consider real data from Salerno, Italy. Our regional model is the first CGE model applied to fisheries, where the link between economics and biology is presented.

The paper is organised as follows: Section II provides the data (SAM) from Salerno-Italy, while Section III presents the general structure of a CGE model. Section IV presents the CGE model statement, while in Section V we discuss the application of a CGE model to fisheries. Section VI presents the main empirical results for Salerno obtained using GAMS[2] software package (www.gams.com). Finally, Section VII concludes the paper and proposes future research.

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[1] The simplest form of general equilibrium model is the input-output model developed by Leontief.

[2] GAMS (*G*eneral *A*lgebraic *M*odelling *S*ystem) is an optimisation software. Other software package similar to GAMS is GEMPACK.

II. THE SOCIAL ACCOUNTING MATRIX

CGE modelling takes the following steps: (i) database construction, (ii) model estimation and calibration, (iii) base run solutions and (iv) simulations, i.e. solving the model under different scenarios (for CGE steps see Appendix 3).

First, a CGE model is usually based on a Social Accounting Matrix (SAM) database, which is an extension of the I-O matrix. A SAM is a matrix of balanced expenditure and income accounts. In the SAM, the column entries represent expenditures to payments made by economic agents, while the row entries represent receipts of income to agents. All receipts are equal to all expenditures, in the form that the matrix gives a record of interrelationships in an economy at the level of individual production sectors and factors, as well as private, public and foreign institutions.

Our SAM distinguishes the following accounts: activities, commodities, factors, households, savings, taxes and the rest of the world. Activity column entries indicate expenditures incurred during the production process and include purchases of intermediate inputs and payments to the factors of production. The total supply of commodities, value at market prices, is given as domestic marketed production, imports of goods and non-factor services, indirect taxes as well as export taxes. The commodity row gives the total demand for marketed commodities and includes household and government consumption. The intersection between the commodity column and government row gives the indirect taxes paid. Furthermore, factors include labour and capital. The factor account pays factor taxes to the government and factor payments to the RoW. Household column indicates the allocation of total household income among income taxes and savings.

In addition, the savings-investment column gives the total investment expenditure in the economy, while the RoW column shows the exports of goods and services. Purchases of imports and receipts of factor payments are specified in the row.

In general, the SAM provides a snapshot of the economy at a single point in time and each cell records the value of each transaction (i.e. the product of prices and quantities).

Appendix 1 shows an example of a SAM structure used in a general CGE model.

III. OVERVIEW OF THE STATIC CGE MODEL

- *CGE General Structure*

In this section we present the general structure of a static CGE model. The main characteristic of static CGE models is that data for modelling are either I-O tables and/or national accounts for a single year.

In general equilibrium theory we formulate a model of simultaneous equilibrium in competitive markets for all commodities. The model explains all payments based on the SAM. In the standard CGE models, one first distinguishes between different producers, goods and factors. According to the theory, producers maximise profits, while consumers maximise utility. In this type of model, equilibrium is then characterised by a set of prices and levels of production (i.e. market demand equals supply for all commodities). The model is based on a system of simultaneous equations, in which factors are fully utilized (see Dervis, de Melo and Robinson, 1982; Robinson, 1990 for more details). Prices are set so that equilibrium profits of firms are zero. Factor incomes are divided among households (total household income is used to pay taxes, save and consume), while government revenue comes from direct and indirect taxes. Household incomes equal household expenditures (equilibrium condition). Household goods consumption is determined by assumptions about consumer behaviour. Consumers are generally assumed to maximize utility, where the assumed form of the utility is a CES, a Linear expenditure system or a Translog function. Furthermore, government tax revenues equal government expenditures including subsidy payments. The Rest of the World supplies imports and demands export goods. This section gives an overview of the basic CGE model by explaining all the payments that are recorded in our SAM.

CGE models are based on the Walrasian general equilibrium structure (Walras, 1954). Accordingly, "*for any price vector, the value of the excess demand is identically zero*". For production, we have two types: Cobb-Douglas (CD) and Constant Elasticity of substitution (CES). If the production function has no constant returns of scale, we can calculate the different supply functions. The model satisfies Walras law in that the set of commodity market equilibrium conditions is functionally dependent.

In most CGE models, imports are determined by an import demand function. CGE models employ the "*Armington assumption*" that products produced in different regions are different from each other in quality (Armington, 1969). Armington has three advantages: (i) it accounts for the large amount of cross-hauling present in the data (imports and exports), (ii) it explains the empirical observation clear, and (iii) it allows for differing degrees of substitution among different products and goods. Furthermore, exports of a good depend on the ratio of the domestic price of the good and the export price of the good. There is a distinction between domestically supplied goods and exported goods according to a constant elasticity of transformation (CET) function.

To run a CGE model, we estimate a number of parameters from the model, so that the equilibrium solution satisfies all our equations under the method of "calibration". Because CGE models contain so many parameters to be estimated, the only way is to use the estimation method called calibration. Calibration for CGE models can be used in order to estimate parameters in, for example, Cobb-Douglas, CES and CET functions. In addition, we need information of prices, quantities and values in the initial equilibrium for model estimation. For instance, we can set all the prices at unity at the initial equilibrium condition (homogeneity of degree zero). Figure 1 presents the structure of a production technology when specified by a CES. Figure 2 shows the structure of a simple model of one country, 2 producing sectors and 3 goods (imports, M; domestic production, D; and exports, E). For general CGE steps see Appendix 3.

Figure 1. Production technology

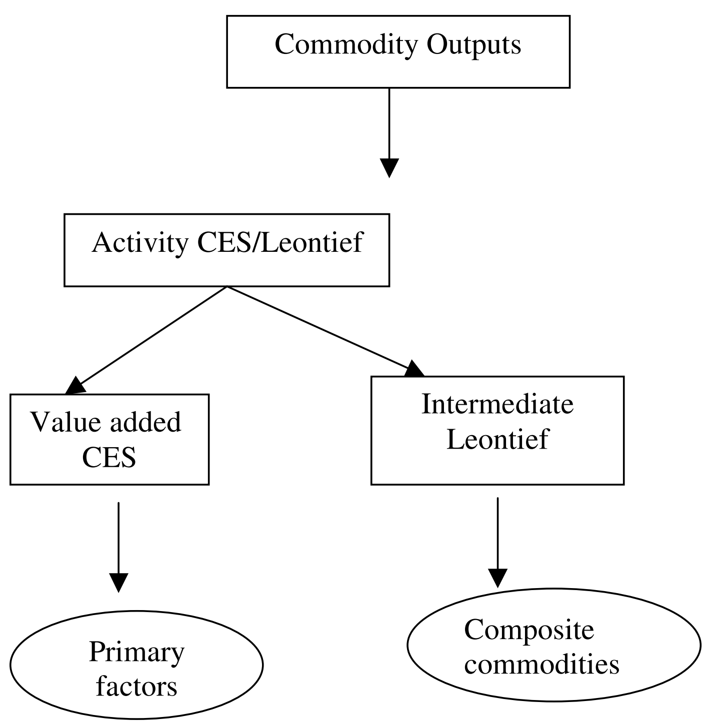
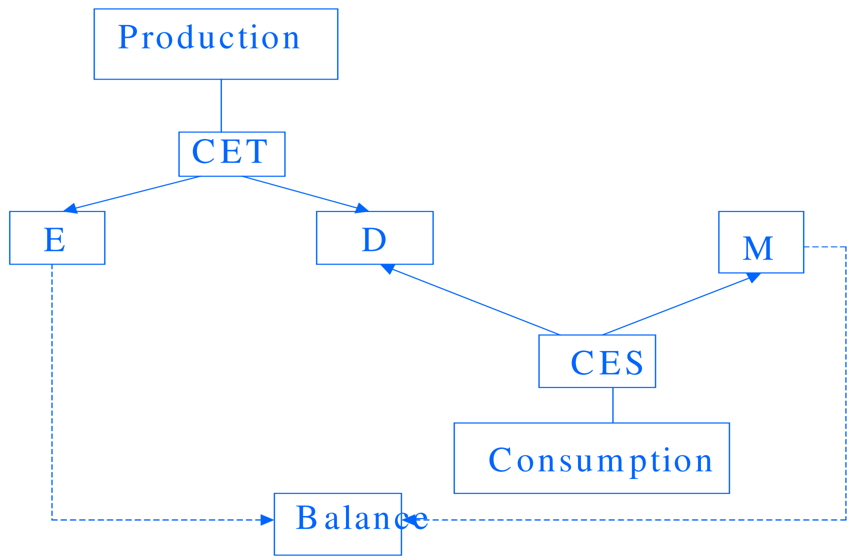


Figure 2. Structure of a simple (basic) model



- **A Static Model for Fisheries**

Following Hartwick and Olewiler (1986), the equilibrium in fisheries may have a number of assumptions. One can use most common forms of markets in economic analysis: perfect competition (open access) and monopoly. In open access, time value in the form of the discount rate is set to infinity. This is done regarding the fact that a fisherman on the open sea has no reason to leave anything to the future. He harvests as much as he is able to catch. When we do care about the steady state, we mean that harvest = natural growth. This comes from the stock of fish, which maximises the total economic surplus. Furthermore, the stock changes the profit prospects of the fishermen. In equilibrium, the marginal value of changing the fish stock should be equal to what can be earned from the royalty on the capital market. A stable income over time obviously presumes a stable fish stock.

On the other hand, we also need information about the growth of the species. For most fish species we assume that the growth rate of the stock depends on its size or biomass. As the biomass or stock size increases, the growth rate will decline. Graphically, each point on the growth curve represents a sustainable yield of fish for a given stock of fish. We define a biological equilibrium as the value of the fish stock for which there is no growth in the fish population or biomass

IV. CGE MODEL STATEMENT

In this section we present the variables and equations for a static CGE model (Lofgren *et al.*, 2001). A static CGE model does not deal with issues of next periods. The variables are divided into four parts: prices, production, institutions and system constraints (see Table 1). The equations (mathematical statement of the model) are presented in more details in Appendix 4.

Table 1. CGE Variables and Equations

VARIABLES	EQUATIONS
Import price	= tariff adjustment*exchange rate*import price
Export price	= tariff adjustment * exchange rate * export price
Absorption	=(domestic sales price*domestic sales quantity)+(import price*import quantity)*(sales tax adjustment)
Domestic Output Value	(producer price*domestic output quantity) = (domestic sales price*domestic sales quantity) + (export price*export quantity)
Activity Price	= (producer prices) * yields
Value-added Price	= (activity price) – (input cost per activity unit)
Activity Production Funct.	= f (factor inputs)
Factor Demand	(Marginal cost of factor f in activity a) = (marginal revenue product of factor f in activity a)
Intermediate demand	= f (activity level)
Output function	Domestic output = f (activity level)
Armington Function	Composite supply = f (import quantity, domestic use of domestic output)
Import-Domestic Demand Ratio	= f (domestic-import price ratio)
Composite supply for nonimported commodities	= domestic use of domestic output
CET Function	Domestic output = f (export quantity, domestic use of domestic output)

Export-Domestic Supply Ratio	= f (export-domestic price ratio)
Output Transformation for NonexportedCommodities	Domestic Output = domestic sales of domestic output
Factor Income	Household factor income = (income share to household h)* (factor income)
Household income	= (factor incomes) + (transfers from government) *ROW
Household Consumption Demand for commodity c	= f (household income, composite price)
Investment Demand for commodity c	= (base-year investment) * (adjustment factor)
Government Revenue	= (direct taxes) + (transfers from ROW)+ (sales tax) + (import tariffs) + (export taxes)
Government Expenditures	(Government spending) = (household transfers) + (government consumption)
Factor Markets	(Demand for factor f) = (supply of factor f)
Composite Commodity Markets	(Composite supply) = (composite demand, sum of intermediate, household, government, investment demand)
Savings-Investment Balance	(Household savings) +(government savings)+(foreign savings)=(investment spending)+(WALRAS dummy variable)

V. CGE MODEL FOR FISHERIES

Applied literature focusing on general equilibrium effect on fisheries is small. However, many previous studies of regional economic impacts of fishery used Input-Output (I-O) models. We have three main categories in the literature: commercial fishing, sport fishing and those that deals with both. Studies in the first category include King and Shellhammer (1981) and Butcher et al. (1981). Furthermore, Martin (1987) and Hammel *et al*. (2002) explain sport fishing, while Hushak *et al*. (1986) and Carter and Radtke (1986) show the impact of fishery dealing with the third category.

Computable General Equilibrium (CGE) Models for Fisheries is not a widely area of research. With an applied CGE model we can take into account the fish population dynamics. To our knowledge, only one CGE model of this type exists, the recent study of Houston *et al*. (1997). They develop a regional CGE model to evaluate the impacts associated with reduced marine harvests for a coastal Oregon region. They use five fishing sectors or vessel types, groundfish trawlers, crabbers, shrimp and scallop draggers, whiting midwater trawlers and small boats. The Oregon model has five processing sectors, 24 aggregated industry and commodity sectors, household income categories, two government expenditures, three factor income accounts and an investment expenditure account. Appendix 2 shows an example of a SAM structure for fisheries used in and proposed by Houshak *et al*. (1997).

Houston *et al*. (1997) present three scenarios for Oregon CGE model. According to the first scenario, there is a 20% reduction in groundfish catch because the fishery has become less productive and/or more restrictive. Under this scenario, boats catch less per unit fishing effort. Under the second scenario, there is a $6 million buyback of 16 trawl boats. It is assumed that this money comes from the federal government, or some other source outside the local economy. Finally, the third scenario assumes a removal of 16 trawl boats. Under the three policy scenarios, Houston *et al*. (1997) estimate changes in numbers of jobs (i.e. employment impacts of reduced groundfish harvests). The results show a bigger change (effect) on scenario 1.

Our model is different than that of Houston *et al*. (1997) because we are looking at the linkage between biology and economics. Next we present the static CGE model for Salerno (Salerno-CGE model).

VI. THE SALERNO-CGE MODEL & RESULTS

The Computable general equilibrium model for Salerno is a static model of the Salerno economy calibrated to 2001 (for obvious reasons we can't present the full Salerno-SAM here). The structure of the Salerno CGE model is as follows: the Salerno-CGE model is disaggregated into two Households (fisheries and non-fisheries), two Factors (labor and capital), two Firms, 29 Activities, 37 Commodities, Government, 6 Taxes, Savings and the Rest-of-the-World (RoW).

Our regional model has two components: a CGE model, which represents the behaviour of economic agents (i.e. economic part), and a biology model, which is a representation of biological process affecting fisheries productivity (under the biological production functions for Salerno).

The economic part of CGE model for Salerno employs standard assumptions. The model assumes that producers maximize profits subject to production functions, while households maximize utility subject to budget constraints. Production and consumption behaviour are modelled using the constant elasticity of substitution (CES) family of functions, which includes Leontief[3], Cobb-Douglas and constant elasticity of transformation (CET) functions. Hence, substitution between regional supply and exports is given by CET, while firms smoothly substitute over primary factors through CES functions. Furthermore, factors are mobile across activities, available in fixed supplies, and demanded by producers at market-clearing prices. The model satisfies Walras' law in that the set of commodity market equilibrium conditions is functionally dependent, while the model is homogeneous of degree of zero in prices. Other main assumptions are the following two: first, the Salerno is treated as an open economy, implying that Salerno faces exogenous prices for imports and exports. Second, products are differentiated according to region and Armington assumption, so that imports and exports are different from domestically produced goods.

Regarding the Savings, its row receives payments from the household, while its column shows spending on commodities for investment. We assume that (i) household income is allocated in fixed shares to savings and consumption, (ii) the value of total investment spending is determined by the value of savings and (iii) investment spending is allocated by the commodities. Here, the set of equilibrium conditions includes the commodity market equilibrium conditions as well as the savings-investment balance (including the Walras variable). Note that if the CGE model works, then Walras should be zero. Furthermore, the government of the model earns its revenues from income and sales taxes and spends it on consumption and transfers to households. Government savings is the difference between its revenues and spending. The income tax is a fixed share of the gross income of each household.sales taxes are fixed shares of producer commodity prices. The government consumes commodity quantities, and pays market prices and taxes. The final account of our model is the rest of the world (RoW).

- Explanation for the biological production functions for the Salerno case.

Economic analysis of fishery management policies require the evaluation of economic impacts of changes in *biological* and *economic* conditions of fishery. The biological production functions are included in the Salerno-CGE Model through the equation:

$$(1) \qquad B_{t+1} = B_t + g(B_t) - Y_t\left(1 + \gamma \times \left(\frac{Y_t}{B_t}\right)^{\beta - 1}\right)$$

$$\text{with } \gamma = \frac{1-\alpha}{\alpha} \times \frac{B^{curr}}{Y_{in}^{curr}}$$

where B is the biomass of the stock, t is the time step in the model (year), g is the growth function of the stock (equation 2), Y is the yield estimated in the economic sub-module of the CGE Model, γ is a constant parameter and β is the reactivity parameter. $Y_{in,\ curr}$ represents the Salerno catch (=Y_{curr}/α).

[3] For all sectors, we assume Leontief technology, that is, that a fixed input quantity is needed per unit of output.

Growth function

For the Salerno case, the biologic functions of growth g(B) can either be in the form of a Pella and Tomlinson (generalized production model) with 3 parameters r, K, m, either in the form of a Fox model (exponential model) with only 2 parameters. In this case, the parameter value of m is one but the equation is different. All the stocks with a m value of one in table I follow a Fox model whereas the others follow a Pella and Tomlinson model.

The growth in the Fox model:

(2) $$g(B) = r \times B \times \ln\left(\frac{K}{B}\right)$$

The growth in the Pella and Tomlinson model:

(3) $$g(B) = r\ B\left(1 - \left(\frac{B}{K}\right)^{m-1}\right)$$

Values of reactivity β

Two values of β can be first tested in the Salerno case:

- β=1 corresponds to the fact that a variation in the fishing effort of the Salerno fleet (increase for instance) will be followed by the same reaction of the other fleets targeting the same stock (increase). This assumes that the biological production function of Salerno matches exactly the production function of the whole stock but only represents the relative part a of the fishing mortality (and yield).

- β=0 corresponds to the situation in which the fishing effort of other fleets applied on a given stock remain constant, whatever the variations of effort of Salerno (assumption often made in bio-economic models).

To solve equation (1) we assume that $B_{t+1} - B_t < \varepsilon$ (=0.0001). So, we get that

$$g(B_t) = (B_{t+1} - B_t) + Y_t((1 + \gamma \times \left(\frac{Y_t}{B_t}\right)^{\beta-1})$$

Table I. Population parameters estimated for the stocks selected for the Salerno case.

Scientific name	Sub-areas	r	K (Tons)	m
Aristaemorpha foliacea	G5 operational unit	-0.38	25	0.295
Aristeus antennatus	G5 operational unit	-0.30	10	0.137
Engraulis encrasicolus	Sardinia	0.84	75794	1
Merluccius merluccius	G5 operational unit	-0.70	500	0.555
Mullus barbatus	G5 operational unit	-0.38	150	0.201
Mullus surmuletus	Sardinia	0.2	2433	1
Nephrops norvegicus	Sardinia	0.18	15163	1
Octopus vulgaris	Sardinia	0.25	38441	1
Others	Sardinia	0.4	338063	1
Parapaeneus longirostris	G5 operational unit	-0.34	50	0.329
Sardina pilchardus	Sardinia	0.22	296426	1
Sepia officinalis	Sardinia	0.25	1207	1
Squilla mantis	Sardinia	1.41	1902	1
Thunnus thynnus	East Atl. & Mediterranean	0.36	297271	1

Table II. Exploitation parameters estimated for the stocks selected for the Salerno case (Y curr represents the total catch).

Scientific name	Sub-areas	F curr	Ycurr	B curr
Thunnus thynnus	G5 operational unit area	0.72	28959	40282
Sepia officinalis	G5 operational unit area	0.47	322	690
Octopus vulgaris	Sardinia	0.39	3158	8130
Aristaemorpha foliacea	G5 operational unit area	0.48	3.5	15
Aristeus antennatus	G5 operational unit area	0.66	1.9	6
Parapaeneus longirostris	Sardinia	1.02	9.2	20
Mullus barbatus	Sardinia	1.46	29.2	48
Squilla mantis	Sardinia	3.90	465	119
Engraulis encrasicolus	Sardinia	3.02	6414	2127
Merluccius merluccius	G5 operational unit area	0.93	57	131
Nephrops norvegicus	Sardinia	0.55	387	704
Sardina pilchardus	Sardinia	0.78	6575	8379
Mullus surmuletus	Sardinia	0.2	179	895
Others	East Atl. & Mediterranean	0.4	49747	124366

Table III. Relative proportion of Salerno catch in the total catch for each stock (α)

Scientific name	Sub-areas	Salerno relative part
Aristaemorpha foliacea	G5 operational unit	100%
Aristeus antennatus	G5 operational unit	100%
Engraulis encrasicolus	Sardinia	3%
Merluccius merluccius	G5 operational unit	100%
Mullus barbatus	G5 operational unit	100%
Mullus surmuletus	Sardinia	3%
Nephrops norvegicus	Sardinia	100%
Octopus vulgaris	Sardinia	6%
Others	Sardinia	5%
Parapaeneus longirostris	G5 operational unit	100%
Sardina pilchardus	Sardinia	2%
Sepia officinalis	Sardinia	24%
Squilla mantis	Sardinia	34%
Thunnus thynnus	East Atl. & Mediterranean	9%

- RESULTS FOR SALERNO CASE

We run our CGE model for Salerno using the optimisation software package GAMS (www.gams.com). A CGE model in GAMS has seven parts:

1. Sets definition
2. data input (SAM)
3. initial values from the Sam
4. calibration for estimation
5. variables and equations definitions
6. initial values and numeraire
7. Solution

The steps for the equilibrium solution between economic and biological modules are presented in Appendix 5.

Table IV and Table V show the main results from Pella-Tomlinson model and Fox model respectively. Our results based on the equations (1), (2) and (3) for the Salerno case. First, we estimate the parameters of surplus production models in the form of Pella-Tomlinson and Fox models. After, the biological production function through the yield from the CGE economic model is estimated in order to take into account for the reactivity of fleets regarding a variation in the Italian fishing effort targeting a given group. Two different scenarios of reactivity are considered, namely: beta = 1 and beta = 0.

TABLE IV. **Pella-Tomlinson model for Salerno case**

Yield	382	64	882	147
Scientific Name	Aristeus antennatus	Merluccius	Mullus barbatus	Parapaeneus longirostris
SAM name	Blue & Red shrimp	Europ. Hake	Stripped Mullet	Deepwater Rose shrimp
CGE name	gsb-c	eh-c	sm-c	drs-c
R	-0.3	-0.7	-0.38	-0.34
K	10	500	150	50
M	0.137	0.555	0.201	0.329
B	6	131	48	20
g	0.9972287	74.72757	27.09253	5.77554
Alpha	1	1	1	1
Y_{curr}	1.9	57	29.2	9.2
$Y_{in,curr}$	1.9	57	29.2	9.2
Gama	0	0	0	0
$B_{(t+1)}$	-375.00277	141.7276	-806.907	-121.224
M*F	0.09042	0.51615	0.29346	0.33558

TABLE V. **Fox model for Salerno case**

Yield	637	39	456	745	11923	68	745	172	19287
Scient. name	Engraulis	Mullus sur	Nephrops	Octopus	Others	Sardina	Sepia offic	Squilla mant	Thunnus
SAM name	Eur. Anchovy	Red mullet	Norw. Lobster	Com. Octopus	Others	Eur. Pilcharc	Com. Cuttlefi	Spottail Man	Norw. Bluefin tuna
CGE name	an-c	rm-c	nl-c	co-c	os-c	ep-c	cc-c	sms-c	bt-c
r	0.84	0.2	0.18	0.25	0.4	0.22	0.25	1.41	0.36
K	75794	2433	15163	38441	338063	296426	1207	1902	297271
m	1	1	1	1	1	1	1	1	1
B	2127	895	704	8130	124366	8379	690	119	40282
g	6384.35543	179.0101	389.0095131	3157.618169	49746.57	6573.6203	96.4622801	465.036319	28984.76
alpha	0.03	0.03	1	0.06	0.05	0.02	0.24	0.34	0.09
Y_{curr}	6414	179	387	3158	49747	6575	322	465	28959
$Y_{in,curr}$	213800	5966.667	387	52633.33333	994940	328750	1341.66667	1367.64706	321766.7
gama	0.32166978	4.85	0	2.419949335	2.374971	1.2488852	1.62857143	0.16890323	1.265811
Bt+1/beta=0	7190.164	-3305.74	637.0095	-9131.57	-133176	4420.211	-1082.25	391.9368	-1009.64
Bt+1/beta=1	7669.452	845.8601	637.0095	8739.756	133872.8	14799.7	-1171.82	382.985	25566.06
g(bt)/beta=0	704.9	984.8	456.0	5386.3	82714.1	176.2	3344.9	179.4	53246.5
g(Bt)/beta=1	841.9	228.2	456.0	2547.9	40239.8	152.9	1958.3	201.1	43700.7

VII. SUMMARY

A fishery consists of a number of different fishing activities and characteristics, including the types of fish to be harvested and the types of vessels and gear use. There may be many species of fish being harvested by a variety of different vessels.

Fisheries market is the subject of increasing interest to many people around the world. To project the impact of changes in demand and supply, and of other structural or policy changes, on the fisheries market a regional model is required. In this paper we provide a review of a Computable General Equilibrium Model (CGE) with application to the fishing industry of Salerno in Italy. Our CGE model is one of the first regional CGE models for fisheries, which distinguishes between different species and identifies fisheries by region.

To examine possible differential impacts on individual fishing sectors, we disaggregate sectors into separate harvesting sectors and processing sectors. In addition to that, other sectors and categories are presented through the Social Accounting Matrix (SAM) of Salerno.

Furthermore, our general equilibrium model takes into account two main parts: the economic one (i.e. economic production functions) and the biological production functions in order to estimate the CGE and take into account for the reactivity of fleets regarding a variation in the Italian fishing effort targeting a given group. To do so, we consider two different biological scenarios based on the Pella-Tomlinson and Fox models.

Our results show the link between economics and biology in terms of equilibrium conditions. Two different scenarios of reactivity are considered in order to illustrate the potential range of responses of the stock to fishing exploitation. These scenarios are the following: (i) foreign fleets exactly follow the variation in effort allocation of the Italian fleet, and (ii) foreign fleets do not modify their fishing effort.

In this report, we do not discuss any economic simulation scenarios. Our main objective is to provide the link between economy and biology, and show how we can present it in the static form of a CGE model under the optimisation software package GAMS. The next step is the development of a dynamic CGE model for fisheries (this is, of course, close to reality). Since, the dynamics of fishery is very important for economic analysis, it is necessary to answer the questions “how is dynamic equilibrium reached?” and “will dynamic equilibrium reached?”.

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APPENDIX 1: REGIONAL SOCIAL ACCOUNTING MATRIX (SAM)

Structure of a Regional Social Accounting Matrix

	Industry	**Commodity**	**Labor**	**Capital**	**Household**	**Government**	**S-I**	**ROW**
Industry		Gross Output (Make Matrix)						
Comm.	Intermediate Input Use (Use Matrix)				Household Purchase	Government Purchase	Investment	Exports
Labor	Labor Factor Income							
Capital	Capital Factor Income							
Household			Resident Labor Income	Resident Capital Income		Transfer to Household		
Government	Indirect Business Tax			Corporate tax & Property tax	Personal Income Tax	Transfer to Government		
S-I				Depreciation & Retained Earnings	Household Savings	Government Savings		
ROW		Imports	Labor Income Leakage	Capital Income Leakage			- (External Savings)	

Note: 1. S-I denotes savings-investment
2. ROW denotes rest of the world

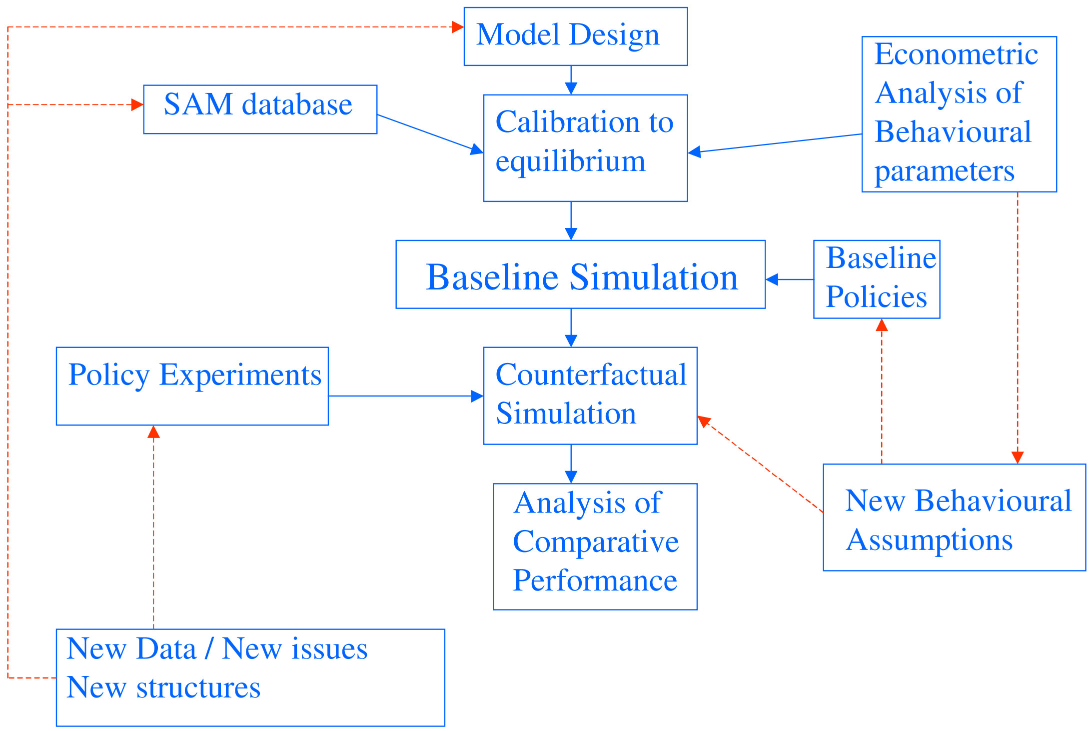
APPENDIX 2: SOCIAL ACCOUNTING MATRIX (SAM) FOR FISHERIES

(Houshak *et al*., 1997)

Social Accounting Matrix with Disaggregated Fishery Sectors

	HARVESTING SECTORS	PROCESSING SECTORS	NONFISHERY SECTORS	HARVESTING COMMOD	PROCESSING COMMOD	NONFISHERY COMMOD	LABOR	CAPITAL	HOUSEHOLD	GOV'T	SAVINGS-INVESTMENT	REST OF WORLD
Harvesting sectors				Make matrix M1	Make matrix M2	Make matrix M3						
Processing sectors				Make matrix M4	Make Matrix M5	Make matrix M6						
Nonfishery sectors				Make matrix M7	Make matrix M8	Make Matrix M9						
Harvesting commodities	Use matrix U1	Use matrix U2	Use matrix U3						Household Purchase H1	Gov't Purchase G1	Investment IN1	Exports E1
Processing commodities	Use matrix U4	Use matrix U5	Use matrix U6						Household Purchase H2	Gov't Purchase G2	Investment IN2	Exports E2
Nonfishery commodities	Use matrix U7	Use matrix U8	Use matrix U9						Household Purchase H3	Gov't Purchase G3	Investment IN3	Exports E3
Labor	Labor income L1	Labor income L2	Labor income L3									
Capital	Capital income K1	Capital income K2	Capital income K3									
Household							Resident Labor Income	Resident Capital Income		Transfer to Household		
Gov't	Indirect business tax T1	Indirect business tax T2	Indirect business tax T3					Corporate tax & Property tax	Personal Income Tax	Transfer to Gov't		
Savings-investment								Depreciation & Retained	Household Savings	Gov't Savings		
Rest of world				Imports IM1	Imports IM2	Imports IM3	Labor Income Leakage	Capital Income Leakage			- (External Savings)	

APPENDIX 3: CGE MODELLING IN PRACTICE



APPENDIX 4: SETS, PARAMETERS and VARIABLES (Salerno-CGE Model)

SETS

$a \in A$ activities
$c \in C$ commodities
$c \in CM$ (C) imported commodities
$c \in CNM$ (C) nonimported commodities
$c \in CE$ (C) exported commodities
$c \in CNE$ (C) nonexported commodities
$f \in F$ factors
$h \in H$ (I) households
$i \in I$ institutions (households, government, and rest of world)

PARAMETERS

ad_a production function efficiency parameter
aq_c shift parameter for composite supply (Armington) function
at_c shift parameter for output transformation (CET) function
ica_{ca} quantity of c as intermediate input per unit of activity a
mps_h share of disposable household income to savings
pwe_c export price (foreign currency)
pwm_c import price (foreign currency)
qg_c government commodity demand
$qinv_c$ base-year investment demand
$shry_{hf}$ share of the income from factor f in household h
te_c export tax rate
tm_c import tariff rate
tq_c sales tax rate
$tr_{ii'}$ transfer from institution i' to institution i
ty_h rate of household income tax
α_{fa} value-added share for factor f in activity a
β_{ch} share of commodity c in the consumption of household h
δ_{cq} share parameter for composite supply (Armington) function
δ_{ct} share parameter for output transformation (CET) function
θ_{ac} yield of commodity c per unit of activity a
ρ_{cq} exponent ($-1 < \rho_{cq} < \infty$) for composite supply (Armington) function
ρ_{ct} exponent ($1 < \rho_{ct} < \infty$) for output transformation (CET) function
σ_{cq} elasticity of substitution for composite supply (Armington) function
σ_{ct} elasticity of transformation for output transformation (CET) function

VARIABLES

EG government expenditure
EXR foreign exchange rate (domestic currency per unit of foreign currency)
$FSAV$ foreign savings
$IADJ$ investment adjustment factor
PA_a activity price
PD_c domestic price of domestic output
PE_c export price (domestic currency)

PM import price (domestic currency)
PQ_c composite commodity price
PVA_c value-added price
PX_c producer price
QA_a activity level
QD_c quantity of domestic output sold domestically
QE_c quantity of exports
QF_{fa} quantity demanded of factor *f* by activity *a*
QFS_f supply of factor *f*
QH_{ch} quantity of consumption of commodity *c* by household *h*
$QINT_c$ quantity of intermediate use of commodity *c* by activity *a*
$QINV_c$ quantity of investment demand
QM_c quantity of imports
QQ_c quantity supplied to domestic commodity demanders (composite supply)
QX_c quantity of domestic output
WALRAS dummy variable (zero at equilibrium)
WF_f average wage (rental rate) of factor *f*
$WFDIST_{fa}$ wage distortion factor for factor *f* in activity *a*
YF_{hf} transfer of income to household *h* from factor *f*
YG government revenue
YH_h household income

EQUATIONS

Import Price
$PMc = (1 + tm_c) \cdot EXR \cdot pwm_c \quad c \in CM$

Export Price
$PEc = (1 - te_c) \cdot EXR \cdot pwe_c \quad c \in CE$

Absorption
$PQ_c \cdot QQc = [PDc \in QDc + (PMc \cdot QMc)| c \in CM](1 + tq_c) \quad c \in C$

Domestic Output Value
$PXc \cdot QXc = PDc \cdot QDc + (PEc \cdot QEc)| c \in CE \quad c \in C$

Activity Price
$PA_a = \Sigma \; PXc \cdot \theta_{ac} \quad a \in A$

Value-added Price
$PVA_a = PA_a - \Sigma \; PQ_c \cdot ica_{ca} \quad a \in A$

Production and Commodity Block

Activity Production Function
$QAa = ada \cdot \prod f \in F \; Qffa \; \alpha fa \quad a \in A$

Factor Demand
$WFf \cdot WFDIST_{fa} = (a_{fa} \cdot PAa \cdot QAa)/QF_{fa}$

Intermediate demand
$QINT_{ca} = ica_{ca} \cdot QA_a \quad c \in C,\ a \in A$

Output Function
$QX_c = \Sigma\ \theta_{ac} \cdot QA_a \quad c \in C$

Composite Supply (Armington) Function

$$QQ_c = aq_c \cdot (\delta_{cq} \cdot QM_c^{-\rho_c^q} + (1 - \delta_{cq}) \cdot QD_c^{-\rho_c^q})^{\frac{-1}{\rho_c^q}} \quad c \in CM$$

Import-Domestic Demand Ratio

$$\frac{QM_c}{QD_c} = \left(\frac{PD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q}\right)^{\frac{1}{1+\rho_c^q}}$$

Composite Supply for Nonimported Commodities
$QQ_c = QD_c \quad c \in CNM$

Output Transformation (CET) Function

$$QX_c = at_c (1 + \delta_c^t QE_c^{\rho_c^t} + (1-\delta_c^t) * QD_c^{\rho_c^t})^{\frac{1}{\rho_c^t}} \quad c \in CE$$

Export-Domestic Supply Ratio

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PD_c} * \frac{1-\delta_c^t}{\delta_c^t}\right)^{\frac{1}{\rho_c^t - 1}} \quad c \in CEQDc\ PDc\ \delta ct$$

Output Transformation for Nonexported Commodities
$QX_c = QD_c \quad c \in CNE$

Institution Block

Factor Income
$YF_{hf} = shry_{hf} \cdot \Sigma\ WF_f \cdot WFDIST_{fa} \cdot QF_{fa} \quad h \in H, f \in F$

Household Income
$YH_h = \Sigma\ YF_{hf} + tr_{h,gov} + EXR \cdot tr_{h,row} \quad h \in H$

Household Consumption Demand

$$QH_{ch} = \frac{\beta_{ch}(1-mps_h)(1-ty_h)YH_h}{PQ_c}$$

Investment Demand
$QINV_c = qinv_c \cdot IADJ \quad c \in C$

Government Revenue

$YG = \Sigma\ ty_h \cdot YH_h + EXR \cdot tr_{gov,row} + \Sigma\ tq_c \cdot (PDc \cdot QDc + (PMc \cdot QMc\ )|\ c \in CM) +$
$\Sigma\ tm_c \cdot EXR \cdot pwm_c \cdot QMc + \Sigma\ te_c \cdot EXR \cdot pwe_c \cdot QE_c$

Government Expenditures

$EG = \Sigma\ tr_{h,gov} + \Sigma\ PQ_c \cdot qg_c$

System Constraint Block

Factor Markets

$\Sigma\ QF_{fa} = QFS_f \ \ f \in F$

Composite Commodity Markets

$QQc = \Sigma\ QINT_{ca} + \Sigma\ QH_{ch} + qg_c + QINV_c \quad c \in C$

Current Account Balance for RoW

$\Sigma\ pwe_c \cdot QE_c + \Sigma\ tr_{i,row} + FSAV = \Sigma pwm_c \cdot QM_c$

Savings-Investment Balance

$\Sigma\ mps_h \cdot (1 - ty_h) \cdot YH_h + (YG - EG) + EXR \cdot FSAV = \Sigma\ PQ_c \cdot QINV_c + WALRAS$

APPENDIX 5: Explanation for the Equilibrium Condition

The biological production function is given by:

$$B_{t+1} = B_t + g(B_t) - Y_t\left(1+\gamma\left(\frac{Y_t}{B_t}\right)^{\beta-1}\right) \quad (1)$$

with $\gamma = \frac{1-a}{a}\frac{B^{curr}}{Y_{in}^{curr}}$ (2)

We consider two growth models for Salerno:

Fox model $g(B) = rB\ln\left(\frac{K}{B}\right)$ (3)

Pella-Tomlinson model $g(B) = rB\left(1-\left(\frac{B}{K}\right)^{m-1}\right)$ (4)

where B is the biomass of the stock, t is the time step in the model, g is the growth function of the stock, Y is the yield estimated from CGE model, γ is a constant and β is reactivity parameter.

- **Example: Equilibrium Condition**

Consider the case when $a = 1 \Rightarrow \gamma = 0$. Then from equation (1) and (3) we get

$B_{t+1} = B_t + g(B_t) - Y_t$ and

$g(B_t) = rB_t\ln\left(\frac{K}{B_t}\right)$ (Both in general form)

> <u>*Solution:*</u>

<u>For *t = 0*,</u> $B_1 = B_0 + g(B_0) - Y_0$, $g(B_0) = rB_0\ln\left(\frac{K}{B_0}\right)$ where $B_0 = K/10, Y_0$:initial yield from CGE model

<u>For *t = 1*</u>, $B_2 = B_1 + g(B_1) - Y_1$, $g(B_1) = rB_1\ln\left(\frac{K}{B_1}\right)$ where Y_1 :is based on B_1.

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….
….

<u>For *t = t-2*</u>, $B_{t-1} = B_{t-2} + g(B_{t-2}) - Y_{t-2}$, $g(B_{t-2}) = rB_{t-2}\ln\left(\frac{K}{B_{t-2}}\right)$ where Y_{t-2} is based on B_{t-2}.

For $t = t\text{-}1$,
$$B_t = B_{t-1} + g(B_{t-1}) - Y_{t-1}$$
$$g(B_{t-1}) = rB_{t-1}\ln\left(\frac{K}{B_{t-1}}\right)$$
where Y_{t-1} is based on B_{t-1}.

Final step,
$$B_{t+1} = B_t + g(B_t) - Y_t$$
$$g(B_t) = rB_t\ln\left(\frac{K}{B_t}\right)$$
where Y_t is based on B_t.

- **Equilibrium condition**: $B_t = B_{t+1}, (\Rightarrow g(B_t) = Y_t)$

$$\Rightarrow B_{t-1} + g(B_{t-1}) - Y_{t-1} = B_t + g(B_t) - Y_t \Rightarrow B_{t-1} - B_t = g(B_t) - g(B_{t-1}) - (Y_t - Y_{t-1}) \Rightarrow$$
$$\Rightarrow B_{t-1} + g(B_{t-1}) - Y_{t-1} - B_t = g(B_t) - Y_t$$

Then, the equilibrium condition (state) holds when:

$$(B_{t-1} - B_t) + g(B_{t-1}) - Y_{t-1} = 0.$$

Or

$$B_t = B_{t-1} + g(B_{t-1}) - Y_{t-1}$$ (That is true, when $t = t\text{-}1$)

Notes:

1. We start with an initial value for biomass B_o ($=K/10$). At each iteration $t+1$, B_{t+1} is estimated from B_t, $g(B_t)$ and Y_t. Each time B_t is given by previous iteration, $g(B_t)$ by biological function and Y_t by economic model.

2. Each time, biomass B is a new value, which then gives a new $g(B)$ and Y. So, at each step i, Y_i is based on B_i and used to estimate B_{i+1} (i.e. the equilibrium biomass corresponding to Y_i).

3. Finally, the model should be converged, and equilibrium condition holds under $g(B_t)=Y_t$, where B and Y are in steady state.