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Regional economic impacts of limited entry fishery management: an application of dynamic input–output model

MAHADEV G. BHAT
Environmental Studies and Economics Departments, Florida International University, Miami, FL 33199, USA. Email: bhatm@fiu.edu

RAMACHANDRA BHATTA
Fisheries Economics Department, College of Fisheries, Mangalore, 575002, India. Email: rcbhat@sancharnet.in

ABSTRACT. Economic impacts that entry regulations have within the fishery industry are well documented in the economics literature. This study looks at how fishery regulations will impact other sectors of a regional economy. By developing integrated models of fishery bioeconomics and dynamic, inter-industry economic linkages, the paper estimates sector-wise economic gains and losses over time from an entry regulation. A case study from India shows that primary fishing and processing sectors realize significant wage and profit gains after a period of transition. Sizable losses in wage and industry profits are incurred by non-fishery sectors but are smaller than the profit gains in the primary sectors. The paper makes policy recommendations on how to ease the adverse regional impacts of fishery policies.

Introduction

Many coastal countries in the world have adopted the policy of limited access to protect their fisheries from overexploitation. The limited-access policy imposes restrictions on capital and labor in fishing. Reducing fishing inputs and thereby harvesting intensity has the potential to increase the net economic efficiency of production (Smith, 1981; Bishop *et al*., 1981). This policy could improve the efficiency of the general economy as labor and capital partially get reallocated to other sectors.

Fishery economics literature is replete with studies that highlight economic problems that entry regulations cause within fisheries, such as stock depletion, rent dissipation, increasing costs, and asset non-malleability (Dupont, 1990; Townsend, 1990; Wilen, 1988; Clark, 1976; Clark *et al*., 2005). The regulations are also known to cause two types of inequity within fisheries: (a) inter-generational inequity that would arise as current generation fishers bear the costs, while future generation fishers

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bear the benefits of regulation (Sumaila and Walters, 2005); and (b) intra-generational inequity that arises if the entry regulation denies employment opportunities for some people (Panayotou, 1986). The displaced fishing communities may not find alternative employment easily.

The impacts of access restrictions that permeate beyond the primary fishery industries have received limited attention in economics. According to regional economic growth theory, the effects of changes in the primary fishery sector are not limited to itself. The policy impacts could spill over into other sectors of the economy (Stanley, 2003; Hastings and Brueker, 1993; Letson, 2002). When fishery sectors reduce their spending and possibly reduce production as well, the businesses that serve the former must buy less labor, materials, and service, and cut down on their own production. Thus, the fishery sectors that are forced to reduce their spending will have a ripple effect on other businesses that supply inputs to them, and, in turn, those businesses affect others down or up the supply chain throughout the region. This paper focuses on the relative economic impacts of access regulations *within* and *outside* fishery sectors.

The fishery managers are often confronted with the problem of resolving conflicting goals. While effort reduction policies increase biological stocks and economic efficiency, the same could jeopardize the fishery labor community, and the rest of the regional economy. A policy-relevant question is how to minimize such inter-sectoral imbalances. Classical bioeconomic theory suggests that when effort is reduced without increasing the unit costs of harvesting, the economic rent from a given fishery increases (Clark, 1976). The primary objective of this paper is to check whether the additional rent generated through fishery regulation is large enough to offset the regional economic losses. We compare income and wage measures over time between open-access and restricted-access scenarios. Focusing on a representative marine fishery in the Indian state of Karnataka, the paper attempts to explore the policy instruments that help transfer partial welfare benefits of fishery regulation to sectors that experience negative impacts.

This paper adopts an integrated analysis framework by combining two dynamic models: a fishery bioeconomic model and a regional inter-industry economic model. The bioeconomic component is a multi-gear harvesting model that estimates the temporal impacts of effort restrictions on species-wise landings. The inter-industry economic component is a Leontief dynamic input–output (DIO) model that measures the magnitude of policy impacts on key regional indicators. To our knowledge, no study has ever attempted to integrate a fishery economic model with a DIO model. Moreover, we have developed a simple spreadsheet approach to solving a complex DIO model, without having to write detailed algorithms.

The rest of the paper is organized as follows. In the following section, we present the conceptual bioeconomic and DIO models. The model data and analytical procedure are explained in the next section. The results of two model scenarios – open-access harvesting and restricted-access harvesting – are compared next in order to assess the within- and outside-fishery impacts of access regulation. The policy implications are discussed in the final section.

Analytical approach

In this section, we first present a dynamic bioeconomic fishery model, wherein fishing efforts of multiple gears are linked with the profit-seeking behavior of firms in an open-access regime. This model incorporates the time-variant biological production function for each major vessel class and its effects on industry outputs. Then, we develop a dynamic input–output model for the study region that characterizes the economic linkages between fishery and non-fishery sectors. This model receives input from the bioeconomic model and then tracks the temporal region-wide effects of market and policy changes in the fisheries.

Bioeconomic fishery harvesting model

The performance of a real-world fishery depends on the dynamic interplay of stocks and the rent-seeking behavior of fishers. In an open-access fishery, when a certain vessel class is making profits, existing and new fishers are attracted to increase their fishing effort (Smith, 1968). This rising effort could serve to deplete the stocks over time, decrease fishery productivity, and, in turn, drive the industry's profit margin down. Rising costs and declining profits will force some firms out of the fishery. This will allow fishery stocks to recoup somewhat. At any sign of profit, firms will reenter the fishery. Thus, it is after a period of cyclical adjustment, that a fishery will tend to stabilize itself. Wilen (1976) empirically verified this cyclical stabilization in fishery stocks and capital.

Bhat and Bhatta (2006) have developed a bioeconomic model for determining an optimal mix of multiple vessels and species for the study area. Their model, however, does not capture the profit-seeking behavior of firms operating under free market conditions. Whitmarsh (1995) developed a single-species model that sought to characterize the entry and exit behavior of economic agents. In a multi-gear fishery, there is a significant variation across vessel types in terms of their cost efficiency and profit-making ability. More cost-effective vessels will have a competitive edge over less mechanized vessels. The latter vessel types, which normally belong to traditional fishing communities, will be 'choked' out of the market by the former. It is important, therefore, to explicitly recognize the techno-economic relationships between vessel classes and how they affect the entry and exit of each other class. The model presented below combines the elements of both the above studies.

Vessels of each technology type target certain species, although there may be species overlap between two different harvesting technologies. For each period, the model keeps track of the effort applied by all vessel types toward each model species in terms of standardized fishing effort. Knowing this fishing effort, the total catch is determined using the catch–effort–stock relationships. The dynamic nature of the fishery is incorporated through a dynamic stock growth equation. This equation balances the stock in each period to the previous period's stock, plus net growth minus harvest. The annual effort by each vessel class is modelled as a function of the profit (or loss) margin in the previous period.

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The model first computes the value of effort directed by multiple vessel types toward a given species (T_{ft}).

$$T_{ft} = \sum_{i=1}^{K} s_i d_{if} E_{it} \quad \text{for all species } f \text{ and time period } t \tag{1}$$

where E_{it} is actual effort exerted by harvesting sector (or vessel class) i in period t, and d_{if} is the constant proportion of total effort of vessel class i directed toward species f. Thus, the product $d_{if} E_{it}$ is the effort of vessel i directed toward a given species. However, the efforts of different vessel types are technologically different. Therefore, we convert each vessel's effort to standardized effort before we aggregate them to estimate the total effort T_{ft} toward each species. The standardization parameter s_i – the ratio of the catch-per-unit effort (CPUE) of each vessel to that of the vessel class that has the highest CPUE – normalizes the efforts of different fishing technologies to a uniform effort.

A non-linear catch–effort–stock relationship simulates the amount of catch for each f and t. Formally

$$C_{ft} = q_f T_{ft} S_{ft} \tag{2}$$

where S_{ft} is the natural stock of fish, C_{ft} is the amount of catch, and $q_f > 0$ is the catchability coefficient, the proportion of stock caught by a unit fishing effort.

The following equation balances the fish stock in period $t+1$ to the current period's stock, *plus* net recruitment *less* catch

$$S_{ft+1} = S_{ft} + r_f S_{ft}\left(1 - \frac{S_{ft}}{K_f}\right) - C_{ft} \tag{3}$$

for all f and t except the initial period. The expression $r_f S_{ft} \left(1 - S_{ft}/K_f\right)$ represents the density-dependent, annual rate of net growth of stock. r_f and K_f are the intrinsic growth parameter and carrying capacity of species f respectively. The initial year stock is exogenously set at S_{f0}.

The annual profitability of the fishery (π_{it}) is computed by

$$\pi_{it} = \sum_{f=1}^{F} p_f \left[\frac{s_i d_{if} E_{it}}{T_{ft}}\right] C_{ft} - c_i E_{it} \tag{4}$$

where F is the number of species, p_f is market price of fish, and c_i is unit cost of effort. The term in the square brackets measures the contribution of vessel i to the total effort T_{ft} dedicated to species f. This ratio apportions the total species catch C_{ft} among the constituent vessel classes. Thus, the first term on the right-hand side measures the total value of fish caught by vessel class i, or total revenue (R_{it}). The second term reflects the total cost of effort. The total amount of effort will depend on the percentage of profit in the preceding year. When fishing is profitable, firms spend more time fishing or bring in more vessels in the following year. Conversely, if they incur a loss in the previous year, firms downsize their effort. The rate at which effort increases in response to a profit may differ from the rate at which effort recedes in response to a loss (Whitmarsh, 1995). The following dynamic equations capture the entry and exit behavior of the firms in each harvesting sector, I, in response to profitability

$$E_{it+1} = E_{it}\left(1 + \xi\frac{\pi_{it}}{R_{it}}\right) \quad \text{entry function} \tag{5a}$$

$$E_{it+1} = E_{it}\left(1 + \zeta\frac{\pi_{it}}{R_{it}}\right) \quad \text{exit function} \tag{5b}$$

where ξ and ζ are exit and entry parameters, respectively.

Equations (5) allow for substitution of more efficient fishing technology for less efficient ones over the long run. Relative efficiency of a certain technology at a given point in time will depend on the combined effects of biological (equation (2) and (3)), economic (equations (4) and (5)), and technical (equations (1) and (2)) parameters. More interestingly, the efficiency of each vessel class is time variant; that is, certain technology that may not be efficient in certain periods may hold a profit advantage over others in the future and vice versa. Equations (1)–(5) can be recursively solved, knowing the initial-year effort and stock values. To see the effects of an access restriction policy, equation (5) can be replaced by a set of policy-determined effort levels.

Dynamic input–output model

The interaction of the fishery industry with the rest of the economy can be visualized as follows: (1) the *primary* fishery (PF) industries will produce a variety of fish to meet the basic necessities of life, mainly food; (2) part of this production will go directly to households (HH), a portion to processing industries or *forward-linked* industries (FL), and part as exports to consumers outside the region. The movement of fish products from fishers to intermediate and household consumers involves a variety of market intermediaries (wholesale and retail traders, brokers, processors, etc.); (3) PF and FL industries draw inputs from input manufacturing and service industries or *backward-linked* industries (BL); (4) government (local, state, and central) and HH are the key sectors that interact with the three industry categories – PF, FL, and BL sectors – individually and connect these industries with the rest of the economy.

A DIO model is selected as an analytical framework as it probably best captures the inter-industry linkages. The biological nature of the fishery stocks and the changing technology interactions with stocks will change the factor contributions (i.e., industry production functions) over time. The DIO model has the ability to trace the reaction paths of industry economics in response to technological changes, investment changes, and growth or recession due to other exogenous factors (Johnson, 1993). DIO models are also used to analyze effects of business cycles, employment, and capacity utilization issues, and the co-existence of new and old technologies (Ryaboshlyk, 2003). In an input–output model, the welfare effects of market-driven or policy-driven changes in the economy are measured in terms of industry output, wages, profits, and government revenues.[1]

[1] In contrast, a classical welfare analysis framework uses indicators such as consumer's and producer's surplus (Just *et al.*, 1982). Our study assumes that the

For the purpose of easy exposition, we first present the static version of an input–output (IO) model. The output of an industry sector is equal to the demand for that commodity by all the endogenous sectors (called intermediate use), including the sector in question, *plus* the final demand for that sector's output. In matrix notation, the IO model is represented as

$$AX + Y = X \tag{6}$$

where X is the $n \times 1$ column vector of outputs, $A = ((a_{ij}))$ is the $n \times n$ technical coefficient matrix, Y is the $n \times 1$ column vector of the sales from each regional sector to final demand (investment, government purchases, and exports), and n the number of endogenous sectors. Each technical coefficient a_{ij} represents the amount of good of sector i that is needed to produce one unit of good of sector j. In the above model we include the HH sector as an additional column (representing household consumption) and an additional row (representing wage payments) to matrix A. This implies that when HH receives income from the industry sectors, households increase their consumption, and, in turn, induce production sectors to produce more.

In a dynamic environment, the underlying production relationships change over time due to market- or policy-driven changes. Thus, the portions of the technical coefficient matrix A become time variant, and certain exogenous variables in Y become endogenous. Therefore, the following Leontief-type dynamic model is more suitable to our case

$$A_t X_t + \left[B^{bl}_{1t+1} X_t + B^{bl}_{2t+1} \dot{X}_t + B^{fl}_{t+1} \dot{X}_t\right] + \left[Y_t + \dot{Y}_t\right] = X_{t+1} \tag{7}$$

where A_t is the $n \times n$ matrix and has the same interpretation as A. The terms in the first square brackets represent three types of temporal changes that occur as a result of changes in fishery effort and output. First, as the effort in a PF sector changes in period $t+1$, the amount of inputs that the PF sector purchases from some BL industries will also change by the same percentage as the fishery effort does (e.g., net-making and manufacturing sectors). B^{bl}_{1t+1} is $n \times n$ matrix with non-zero coefficients only for the above BL sector rows and PF sector columns. This matrix has the effect of periodically adjusting the coefficients in A_t for changes in factor requirements of PF sectors due to effort changes. B^{bl}_{1t+1} has an advantage of capturing time-variant production technology, including input substitution. Input substitutions commonly occur in fisheries as a result of changes in factor prices or regulation on certain inputs or technology (Boyce, 2004; Townsend, 1990). However, for lack of better information, we assume no input substitution within each vessel class. Therefore, the economic measures estimated in this study should be viewed as upper-bound impacts. Each non-zero element of B^{bl}_{1t+1} is computed by multiplying the corresponding (i, j) elements in A_t and the

producers of the study region are price takers and will not have much influence on market prices. Thus, we do not expect major impacts on consumer's welfare either. However, an IO model captures the effects of economic or policy changes on consumers' (households') income and, in turn, on the overall consumption expenditure. Further, our model explicitly recognizes changes in producer's profits (rent) over time due to biological and technological changes.

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proportionate change in effort of the respective PF sector ($\dot{E}_{it}/E_{it}$). $\dot{E}_{it}/E_{it}$ is obtained from the bioeconomic model explained earlier.

Secondly, factor purchases of each PF sector from some other BL sectors (e.g., ice, fishery marketing services and HH labor) are functions of the PF sector's output. For these BL sectors, matrix B^{bl}_{2t+1} – of size $n \times n$ and non-zero elements only for selected BL sector rows and PF sector columns – adjusts their factor sales based on the changes in the respective PF sector output ($\dot{X}_t$). The non-zero elements of this matrix are the same as the corresponding elements of matrix A_t. Thirdly, with changes in PF sector outputs, the quantities of fish handled by FL sectors (e.g., processing sectors) and, in turn, the value of their total industry outputs will also change. As a result, the factor purchases of FL sectors need to be adjusted in proportion to their own $\dot{X}_t$. We assume that the production functions of FL sectors will not change. Matrix B^{fl}_{t+1} – of size $n \times n$ and non-zero elements only for FL sector rows and their corresponding BL sector columns – will make the above periodic adjustments in factor purchases. Again, the non-zero elements of this matrix are identical to the corresponding elements in A_t.

The $\dot{X}$ and $\dot{Y}$ are $n \times 1$ vectors of changes in X and Y, respectively. $\dot{X}$ for PF and FL sectors are computed from the fishery bioeconomic model, and they capture the effects of periodic changes in the biological stocks. The term $Y + \dot{Y}$ recognizes that the final demand variables can be endogenous (Leontief, 1963). Any shortage or excess in the regional supply will be adjusted in the periodic value of exports.

After knowing the factor purchases, labor payment, taxes, and total value of each PF sector's output (computational procedure explained later), the industry profits can be easily determined (i.e. total output *minus* the costs of factors of production, taxes, and imports). Unlike in a static IO model, the industry profits will not be in a fixed proportion to total output. The profit margins could vary between PF sectors and over time. This will allow us to realistically describe the changing underlying economics (profits or losses) as the fishery goes through industrial re-organization either in a free-entry or access-restricted world.

As Leontief notes, many DIO models unrealistically assume that investment is completely reversible and allow for instantaneous capital accumulations and decumulations. We overcome this assumption partially by including differential rates of entry and exit (equation (5)) for fishery effort. However, in our model non-fishery sector capital is assumed completely reversible. We also assume exogenous market prices. This assumption is not too unrealistic since fishers of the study region are price takers in the larger national/world markets. The above model can be easily modified to incorporate exogenous or endogenous price changes through equation (4). This revision will not change the general results of our study.

Empirical application

Study area

The study covers the former Dakshina Kanada district of Karnataka state on India's west coast. Mangalore is the main port city of the region and hosts major industries such as oil, fertilizers, chemicals, and thermal electricity. Commercial species including prawns, sardines, mackerels, oil sardines, and some crustaceans are harvested in the region. The coastal Karnataka comprises of three districts along its 300 km of coastline and has more than 26,600 fishing units. Twenty-nine per cent of them are mechanized, contributing 90 per cent of the total catch, and the remaining are motorized with outboard engines. The productions of certain species, such as soles, mackerel, clupids, lactarius, and oil sardines, have been decreasing over the years. There has been a shift in the catch composition from high-valued shrimps (e.g., seer fishes and pomfrets) to low-valued fishes (e.g., squilla, lizardfish, pink perch, and croakers).

With the improvement in the market infrastructure, such as roads, storage, ice plant, and communication, there has been a tremendous change in the availability and accessibility of fish to consumers. Infrastructure development has made fresh fish available to consumers throughout the year. The consumer preferences also have changed with increasing income and changing life style. The preference for fresh fish has increased. The demand for dry fish by the middle- and upper-middle-income groups has drastically declined.

Recognizing the signs of overexploitation of fisheries, the state government enacted the Karnataka Marine Fisheries (Regulation) Act in 1986. Formal and informal rules exist stating that no mechanized fishing takes place near the shore. Mechanized fishing is prohibited during the monsoon (breeding) season. All fishing vessels need mandatory registration. The Act also stipulates mandatory effort reduction. However, the state Fishery Department has been unable to enforce the legislative provisions due to concerns of negative regional economic impacts. The case study exemplifies many developing country fishery regimes that are caught up in the classical dilemma of balancing future environmental sustainability and current economic development. No attempt has been made as yet to analyze if and to what extent the effort reduction policies will indeed affect the regional economy.

Data development

This section applies the integrated bioeconomic and DIO models to the study region. The primary goal of this application is to demonstrate how the model framework can be used to analyze the regional economic tradeoffs of effort reduction policies within and outside the fishery sectors. The models are based on limited data. The application is largely illustrative and, therefore, warrants caution when using its results.

The data for DIO tables come from three different sources, namely a primary survey of fishery units, secondary data from district and state agencies, and the national Social Accounting Matrix developed by Pradhan *et al.* (1999). The process of IO data computation is more thoroughly explained in Bhatta *et al*. (2000). The national IO matrix would have just one or two sectors relevant to the fishery industry. Since the input requirements and species output profiles of different fishing technologies vary, we characterize the fishery sector with as much detail as possible in the model. The fishery industry is divided into several broad groups:

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(a) nine PF sectors by vessel types, (b) five fishery-related BL sectors (e.g., boat building, net making, ice, etc.), (c) six FL sectors (e.g., frozen, meal and oil, canning, etc.), and (d) one fishery marketing sector. Also included in the model are agriculture, forestry, manufacturing, and miscellaneous sectors. Through a survey of various primary harvesting units, input manufacturing units, processing units, the required data for the DIO fishery sectors are developed. The total outputs of PF sectors are estimated using the landings data available from the Central Marine Fisheries Research Institute (CMFRI), India.

Harvested fish are processed for two different markets, namely, domestic and export. Processing sectors that cater to the domestic market include fresh fish suppliers and cured/dried fish producers. Processors for export include more organized sectors such as freezing, canning, and fish oil and meal. A list of all the existing processing companies such as freezing, canning, fish meal and oil units is obtained from the Karnataka State Fisheries Department. A sample of two to three units in each category is sampled to collect relevant information on the species-wise raw material consumption, utilization of total production capacity, cost, returns and prices. The average data for the sampled units are extrapolated to each processing sector.

In the DIO transaction table, only the value-added portion of the marketed output of each FL is shown as its industry output. The value of raw fish handled by an FL sector is deducted from the value of its total output. This is done to avoid double counting of raw fish, which already shows up once in the DIO table as the final output of PF sectors.

The data on non-fishery sectors are obtained from the Karnataka State domestic product accounts (Government of Karnataka, 1999). The final demand vector Y (capital, government purchase, and export sectors) in equation (7) is computed based on the survey data gathered from harvesting, processing and retail units. For non-fishery sectors, household consumption and export levels are computed using the ratios of consumption (export) to total output in the national IO matrix. Factor payments such as wages, rent and profit also are computed from the survey data to complete the IO tables.

All parameters for the bioeconomic model except equation (5) are estimated using secondary and primary data. The estimation procedure is reported in Bhat and Bhatta (2006) and Bhatta and Bhat (2001). For lack of better information, the exit (= 0.2) and entry parameter (= 0.3) values in (5) are based on our best educated guess.

Model integration

Both the bioeconomic and DIO models are recursive in nature, and therefore, can be solved for each year successively. The bioeconomic model is first simulated using the Generalized Algebraic Modeling System for 15 years. From the model results, the values of $\dot{X}_t$ and $\dot{E}_{it}$ in percentages are computed for relevant PF, FL and BL sectors. Bhat and Bhatta (2006) developed the original model for Mangalore, the largest port in the South Kanara district. We assume that the estimated percentage changes for the

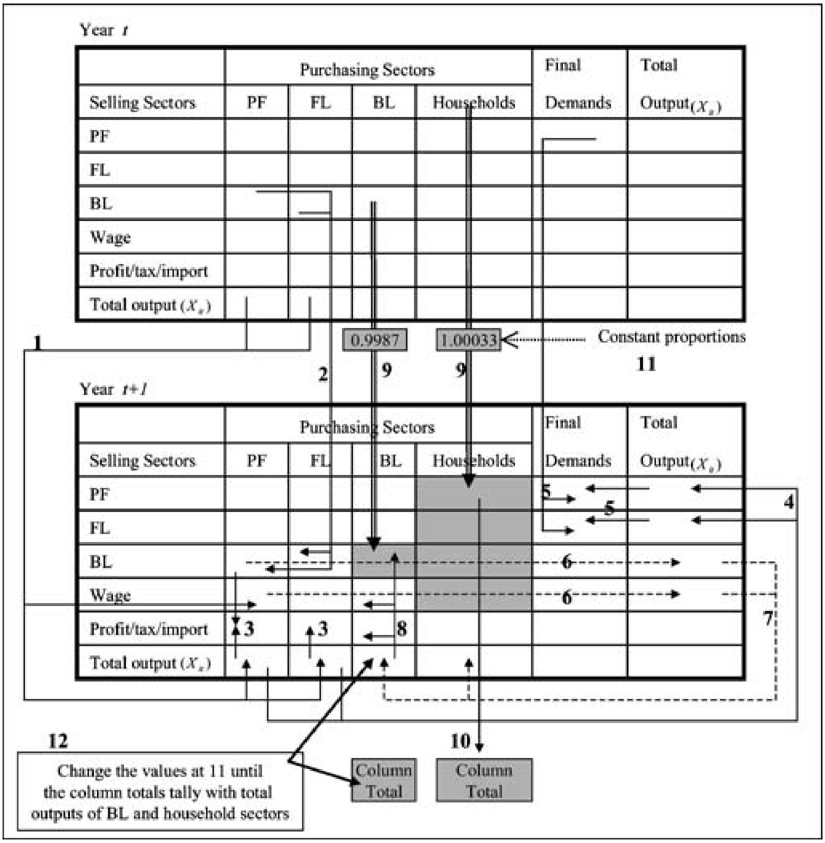

Figure 1. *Numerical simulation of dynamic input–output model using Excel spreadsheet (refer to table 1 for details).*

Mangalore port will apply to the study area that consists of two other smaller ports. Two scenarios are simulated: (a) the baseline scenario where PF sector efforts respond to the signals of profit and losses (equation (5)); and (b) an access restriction scenario where efforts for profit-making sectors such as multi-day trawlers and purse seines are set at their 1998 levels and for the rest, efforts are reduced by 20 per cent from their 1998 level over a period of four years. This 20 per cent reduction reflects a current policy of three-month season restriction on certain types of boats. Scenario 2 is for illustrative purposes only and is one of the several management options that the agency could exercise.

The DIO model (7) is cast on an Excel spreadsheet. See figure 1 and table 1 for details. We start with the $n \times n$ direct transaction table (of PF, FL, BL, and HH sectors), final demand variables, industry profits, imports and taxes, and final outputs for the initial year 1998. For each subsequent year, a formula for every model variable is constructed on the spreadsheet. The annual growth values from the bioeconomic models are placed on a

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Table 1. *Procedure for simulating the dynamic input–output model on an Excel spreadsheet*

Steps	*Description*
0	Set the initial year's transaction table with final demand variables, industry profits and imports, and column and row total values of output
1	For period 2, compute the new total output values of PF/FL sectors, $X_t + \dot{X}_t$
2	Update factor purchases that each PF/FL sector makes from each of their respective BL sectors using the rate of changes in effort, $\dot{E}_t/E_t$
3	Compute wages, taxes, and imports for PF/FL as fixed proportions of total outputs, and industry profits as difference between total outputs and the sum of all costs and imports
4	Set column totals of PF/FL equal to their respective row totals
5	Compute PF/FL export as difference between the row total and the sum of all the row entries
6	Set the final demands of BL to their previous year values; compute BL/wage row total as sum of all the entries in the respective row. For some BL totals, the entry in its own column must not be included in the summation formulas because of 'circular reference' error in Excel. In such cases, the row total must be increased by a factor equivalent to BL sector's own direct requirement co-efficient from the previous year.
7	Set row totals of BL/HH equal to their respective column totals
8	Compute profit, tax, import, wages, and some factor purchases of BL sectors as fixed proportions of column totals, using the direct requirement coefficients of the previous year.
9	For certain BL sector and HH sector, compute purchases as constant proportions of previous year purchases. Constants proportion factor for each BL/HH is placed in convenient cell.
10	Compute the column totals of BL and HH and place them down below the respective column totals of the transaction table
11, 12	Manually adjust constant proportions until the column totals for each BL/HH sector become approximately equal to the total output value
13	For successive years, copy and paste the block of formulas created for the second year DIO table. The call references to $\dot{X}_t$ and $\dot{E}_{it}$ in the column entries of PF/FL sectors and constant factors for iteration must be updated. Place the values of $\dot{X}_t$ and $\dot{E}_{it}$ on a separate sheet for easy reference

Note: Use this table in conjunction with figure 1.

separate spreadsheet and are linked with the spreadsheet carrying the main DIO model.

Results and discussion

In this section, we first present the main results on the regional economic linkages of the fishery industries. We will then present the biological and

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direct economic impacts of effort reductions within the fishery sectors. Finally, we compare the intra-fishery sector impacts and economy-wide impacts of the proposed policy change.

Economic linkage effects of fishery sectors

Table 2 presents the indicators of some important regional economic effects of the fishery sectors. For brevity, non-fishery sectors are not shown. The second column shows the total output of each fishery sector. Deep trawlers produced the maximum output in 1998 among the PF sectors, followed by purse seines. Frozen and fresh fish were the top two producers among the FL sectors. The fish marketing sector was also a major contributor in terms of total industry output.

The economic contributions of the PF/FL sectors are also evident from their economic linkages with the rest of the region's economy. It is clear from the third column that a large proportion of the fishery sectors purchased many of their inputs locally. For instance, fishery boat and equipment, steel trawlers, multi-day trawlers, and canning sectors bought locally available raw materials and service inputs to the extent of more than 80 per cent of their total output; that is, the portion of imported inputs as a percentage of industry output was minimal for these sectors. The high rates of regional purchases are an indication of significant economic impacts on the regional economy.

Except for the labor-intensive sectors like *pattabale* and *rampani* nets (traditional type of fishing with nets fitted with out-board engines), wages as a percentage of total output were fairly low for most fishery sectors. On the contrary, deep trawlers (35 per cent) had high profit margins among mechanized sectors. Frozen fish (49 per cent) processing units also had fairly high profit margins. Dry and fresh fish sectors have had very high profit margins primarily because they operated as self-employed operational units. Although direct wage income effects of fishery were relatively low, high industry profits of some sectors and high percentages of regional consumption and purchases would mean fairly significant overall economic impacts of the fishery on the local economy.

Open-access harvesting and the long-run impacts

The baseline scenario simulated the behavior of the PF sectors under free market conditions. Firms chose to enter or exit the industry based on their profit margins in the preceding year. Since certain PF sectors competed for the same fish stocks, the profitability of each sector depended not only on its own total effort but also on that of other sectors. Table 3 presents the performance of selected PF sectors. Deep trawlers were the single largest harvesting sector in terms of total value of output and net earnings throughout the simulation period. Their total output first increased from Rs. 2,421 million in 1998, reached a maximum of Rs. 2,914 million in 2004, and later declined [1 US$ = 45 Indian Rupees (Rs.)]. The industry profits also increased the first three years and later declined rapidly. The bioeconomic model results showed that there was a rapid increase in the deep trawlers fishing effort, and a decline in the stocks of fish that these vessels were after.

Table 2. *Direct economic linkage effects of fishery sectors on the regional economy of Dakshina Kannada District, Karnataka*

Fishery sectors	*Sector output in 1998 (million rupees)*	*BL industries' direct coefficients*[1]	*Wage coefficients*[2]	*Profit ratio*[2]	*HH and investment ratio*[3]	*Export ratio*[4]
Fishery boats and equipment	215	0.83	0.01	0.00	0.35	0.47
Deep-sea trawlers (multi-day)	2,421	0.58	0.08	0.35	0.45	0.55
Deep-sea trawlers (steel)	13	0.82	0.11	0.08	0.42	0.58
Long liners	110	0.66	0.11	0.23	0.60	0.40
Purse seiners	491	0.68	0.16	0.16	0.90	0.10
Single day trawlers	395	0.85	0.12	0.03	0.50	0.50
Gillnetters	401	0.66	0.26	0.08	0.60	0.40
Rampani	60	0.40	0.53	0.08	0.70	0.30
Pattabale	72	0.58	0.42	0.00	0.60	0.40
Matubale	64	0.60	0.25	0.15	0.60	0.40
Frozen fish	573	0.46	0.04	0.49	0.00	1.00
Fish meal and oil	116	0.71	0.07	0.20	0.00	1.00
Canning	130	0.81	0.05	0.11	0.00	1.00
Dry fish	488	0.23	0.26	0.45	1.00	0.00
Fresh fish	511	0.09	0.08	0.84	1.00	0.00
Fish products	1	0.00	1.00	0.00	1.00	0.00
Fishery marketing services	935	0.27	0.47	0.24	0.00	0.00

Notes: [1]Ratio of the value of regionally purchased inputs to the total output value.
[2]Ratios of profits to the total output value.
[3]Ratio of the value of regional consumption plus investment to the total output value.
[4]Ratio of the export value to the total output value.

Table 3. *The market values of output and profits made by major harvesting sectors under the open-access harvesting conditions*

	Deep trawlers		*Purse seines*		*Day trawlers*		*Gillnets*	
Year	*Output*	*Profit*	*Output*	*Profit*	*Output*	*Profit*	*Output*	*Profit*
	In millions of rupees							
1998	2,421	843	491	80	395	12	401	34
1999	2,610	881	490	69	383	4	388	22
2000	2,742	887	487	60	367	−4	368	10
2001	2,843	871	486	51	345	−12	329	−2
2002	2,898	831	502	45	325	−18	303	−12
2003	2,890	763	485	35	303	−24	275	−21
2004	2,914	702	466	26	280	−28	245	−28
2005	2,895	626	450	19	257	−30	216	−33
2006	2,832	546	430	13	237	−31	188	−35
2007	2,771	476	415	9	220	−30	163	−36
2008	2,715	419	399	6	205	−28	139	−34
2009	2,652	374	407	5	191	−26	117	−32
2010	2,614	347	389	3	180	−22	108	−31
2011	2,602	338	377	2	169	−18	106	−33
2012	2,613	346	352	1	175	−15	104	−33

Particularly, the catches of some major species such as breams, mackerel, prawns, and cephalopods declined over the years.

The profit margins for purse seines, single-day trawlers and gillnets were relatively less to begin with. The level of purse seines effort slightly increased initially, but by the year 2012 reached the 1998 level. However, the bioeconomic model called for a steady decline in the day trawlers' and gillnets' operations. The net profits for all these sectors declined continuously: from Rs. 80 million (1998) to Rs. 1 million (2012) for purse seines, from a profit of Rs. 12 million (1998) to a loss of Rs. 15 million (2012) for day trawlers, and from a profit of Rs. 34 million (1998) to a loss of Rs. 33 million (2012) for gillnets. These profitability trends demonstrated that the subject harvesting sectors did not withdraw effort soon enough or at a rate high enough to sustain productivity and profits. These results are consistent with fishery economics literature (Kirkley *et al.*, 2003; Wilen, 1988) in that the open-access fishery in the study region would lead to excess fishing capacity. In addition, the study results demonstrated that the less mechanized fishing vessels such as gillnets and *rampani* nets, and also less efficient day trawlers would be outcompeted by more mechanized boats.

The long-run effects that open-access harvesting has within and outside fisheries are presented in table 4. The total PF sector output increased during the first few years and fell slightly by the end of the simulation period. In the study region, it was customary to pay crew members a certain proportion of the value of total catch. Therefore, the total PF wage followed the total output. Wage income declined from Rs. 505 million in 1998 to Rs. 369 million in 2012. However, the PF owners suffered a major loss in their rent from an amount of Rs. 1,008 million in 1998 to Rs. 293 million in 2012.

Table 4. *The regional economic indicators of PF, FL, BL, HH, and government sectors under the open-access fisheries*

Indicators	*1998*	*2002*	*2006*	*2010*	*2012*
	In millions of rupees				
PF sectors					
Output	4,026	4,351	3,983	3,558	3,505
Wages	505	504	438	379	369
Profits	1,008	872	499	290	293
FL sectors					
Output	1,820	1,837	1,555	1,302	1,213
Wages	205	209	182	156	147
Profits	968	982	828	689	641
BL sectors					
Output	37,457	37,586	37,369	36,742	36,553
Wages	10,108	10,109	10,016	9,839	9,790
Profits	12,592	12,638	12,562	12,348	12,283
HH income	10,818	10,823	10,636	10,375	10,306
Net fish export	2,682	2,989	2,373	1,742	1,613
Government taxes	1,141	1,149	1,147	1,130	1,124

The processing (FL) sectors paralleled PF in their performance. The total output fell from Rs. 1,820 million in 1998 to Rs. 1,213 million in 2012, a 33 per cent reduction. During the same period, the industry wages as well as profits declined by around the same percentage points. The wage and profit losses mostly occurred in fresh and frozen sectors.

Although BL sectors experienced decrease in all the three indicators during the later years of simulation, the extent of impacts were relatively minor: the total output declined from Rs. 37,457 million in 1998 to Rs. 36,553 million in 2012, wage income from Rs. 10,108 million to Rs. 9,790 million, and industry profits Rs. 12,592 million to Rs. 12,283 million. There was a slight reduction in total household income: from Rs. 11,321 million in 1998 to Rs. 10,231 million in 2012. Most of this reduction occurred in PF and FL sectors. Net fish exports from the region showed nearly 40 per cent reduction, i.e., from Rs. 2,682 million in 1998 to Rs. 1,613 million in 2012. There was no noticeable change in the tax revenue. This is because the fishery sectors were not the major source of tax in the region.

Impacts of access restriction

Table 5 presents the sector-wise economic impacts of access restrictions (scenario 2). The simulated access restriction policy entailed freezing fishing efforts of deep trawlers, purse seines, and non-mechanized boats at their 1998 levels[2] and cutting the hours of other vessels by 20 per cent. The total production, wages and profits of PF sectors were less than their baseline

[2] Based on a review of several limited entry programs, Townsend (1990) concludes that a drastic measure of freezing effort level may be less warranted in some cases. A simple reduction of the rate of entry would be enough to ease the 'crowding effects' in fisheries and increase profits in the short run.

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Table 5. *The estimated changes in economic values from their baseline levels, as a result of effort restrictions*

Indicators	*1998*	*2002*	*2006*	*2010*	*2012*
		In millions of rupees			
PF sectors					
Output	0	−760	−295	273	408
		(−17)	(−7)	(8)	(12)
Wages	0	−71	−1	68	85
		(−14)	(0)	(18)	(23)
Profits	0	−40	405	714	768
		(−5)	(81)	(246)	(262)
FL sectors					
Output	0	−283	16	303	411
		(−15)	(1)	(23)	(34)
Wages	0	−34	−4	26	37
		(−16)	(−2)	(16)	(25)
Profits	0	−149	18	177	238
		(−15)	(2)	(26)	(37)
BL sectors					
Output	0	−1,670	−1,391	−638	−381
		(−4)	(−4)	(−2)	(−1)
Wages	0	−416	−304	−90	−20
		(−4)	(−3)	(−1)	(0)
Profits	0	−559	−462	−206	−119
		(−4)	(−4)	(−2)	(−1)
HH income	0	−520	−309	5	102
		(−5)	(−3)	(0)	(1)
Net fish export	0	−952	−226	574	799
		(−32)	(−10)	(33)	(50)
Government taxes	0	−53	−50	−30	−23
		(−5)	(−4)	(−3)	(−2)

Note: Figures in parentheses are percentage changes from the baseline values.

values for the initial few years, for instance, in year 2002 by Rs. 760 million (17%), Rs. 71 million (14%) and Rs. 40 million (5%), respectively. For the first few years, fishery laborers were found to take home significantly less wage income. This could be due to either layoffs or catch reduction. In 2002, the wage loss of Rs. 71 million was much more than the fishery rent loss of Rs. 40 million. As years go by, access restriction led to stock improvements, catches, and in turn, improvements in both PF wages and profits. By 2012, PF profit gained Rs. 768 million in excess of its baseline level and PF wage in excess of Rs. 85 million.

The above results must be viewed with caution because past studies show that the above simulated economic of improvements would occur only under certain conditions (Flaaten *et al.*, 1995; Townsend, 1990; Dupont, 1990). The rents had improved in programs that significantly reduced the effort rather than those that placed a simple moratorium on entry. Freezing entry long before effort reached the open access level was more effective in improving rents. The downside of the most restrictive programs was that they entailed huge enforcement expenses. Sometimes, tighter gear restrictions also could lead to increases in inputs per vessel and costs per unit effort.

The FL sectors closely followed PF sectors in wages and profits, but in absolute terms their overall impacts were less than the PF impacts. The BL wages and profits, however, were lower than their baseline levels throughout the simulation period. The reduction in the BL profits in 2002 (Rs. 559 million) was much more than the combined reductions in the PF and FL sector profits for the same year (Rs. 40 million and Rs. 149 million). A similar trend was true for BL wages. The loss in the BL profits gradually declined over the years (from Rs. 559 million 2002 to Rs. 119 million in 2012). Relatively speaking, the BL sector losses constituted a small portion of their baseline levels (i.e. 1 to 4 per cent); that is, these losses may not be as significant to the BL sector employees or owners as the wage/profit losses were to those of the PF and FL sectors during the early years of entry restriction.

The access restriction policy resulted in a net loss in the regional HH wage income during the early years, which slightly improved in the later years. This subsequent gain was primarily due to output and wage improvements in PF and FL sectors. Similarly, the region was found to experience a major loss in fishery exports initially (for instance, Rs. 952 million or 32 per cent reduction in 2002). This annual loss was almost reversed by 2012 with an export gain of Rs. 799 million from the baseline amount. This gain can be attributed to increases in PF and FL sector outputs under the access restriction scenario. The access restriction also resulted in 2 to 5 per cent reduction in government taxes. The tax revenue declined for the study period because the intermediate demands for, and outputs of, BL sectors goods and services decreased following the access restriction.

Policy implications and conclusions

The fear of social repercussions within the fisheries from limited entry regulations has often stalled management initiatives. This paper analyzed the social impacts of regulations beyond the primary harvesting sectors and into the larger economy. The extent of these impacts depends on the degree of economic linkage that the fishery sectors have with the rest of the economy. Our case study reveals that the fishery sectors do tend to have significant linkage effects on the economy. These linkages generally lead to output, wage, and profit losses in backward- and forward-linked industries. Fishery access regulations therefore must take into consideration the socio-economic impacts across the region, not just within a fishing community.

According to regional economic theory, fishery owners would spend a significant portion of their incremental rent on capital and consumer goods, which would increase demand for goods and services in other sectors of the economy. These new consumption activities could partially offset income losses in BL and FL industries. As a note of caution, however, we should expect a couple of possibilities that may either slow down or hinder the chances of increased consumption. First, some of the vessel owners who remain in the fishery after regulation may belong to other regions and could transfer their incremental income out of the study region. The second possibility is that fishery owners may have a high propensity to save their income. In either case, there may not be sufficient new consumption activities within the region to compensate the adverse income effects of regulation. In this situation, state and local governments may need more aggressive welfare policies to transfer a better portion of the incremental income to sectors that might have suffered losses, including fishery labor communities. Further, the money recovered from fisheries can be utilized to fund job creation programs, employment training programs, and direct compensation programs.

Also note that the policy-induced profit and wage losses in the non-fishery sectors may constitute negligible portions of their total output, income, and wage payments. The BL sectors – especially when they form a much larger portion of the economy like in our study area – could absorb the above losses through output and/or price adjustments. Such market adjustments may not be necessarily viewed as 'costs' of policy changes, but as pecuniary externalities. Conversely, if the non-fishery sectors are just a small part of the regional economy, their policy-induced economic losses may be too large for these sectors to handle. Particularly, their wage earners may face severe economic hardship for a fairly long period. A policy intervention to transfer a portion of the profit gains of PF/FL sectors to BL sectors would then be desirable and be even Pareto optimal (Just *et al.*, 1982).

Now we return to those familiar implications of fishery access restriction that are internal to PF sectors. First, harvesting gears are non-malleable and entail sunk costs (Schurman, 1996; Clark *et al.*, 2005). Vessel decommissioning, as required by effort reduction programs, would inflict a huge loss on fishery owners. A suitable transfer policy might be necessary to compensate those who suffer sunk costs. This compensation could very well be funded by levying new taxes on *ex post* incremental gain to be made by vessels that remain in the fishery. The government itself could buy some of the gears either for non-use or to transfer them to other fishing regions. Second, depending on the extent of effort reduction, there generally is a transition period during which PF sectors suffer substantial output and income losses. The fishery agencies must cautiously watch whether and how smoothly fishery and the rest of the economy can withstand these losses. Also, during the transition, the enforcement agency must be vigilant since fishers might find ways to circumvent effort reduction plans.

Third, there will be employment losses from capacity cutbacks. As indicated earlier, the employee income of PF and FL sectors would decline with effort reduction during the transition. These wage earners normally lack skill and education that can be utilized in other sectors of the economy. The opportunity costs of this labor force are really low, and sufficient management initiative is therefore needed to re-train fishery laborers for jobs outside the fisheries. The West Coast of India in general and Mangalore in particular have experienced industrial growth in recent years and attracted migratory laborers from out-of-state. Ample non-fishery employment opportunities do exist locally. India has a successful record of implementing the Integrated Rural Development Program, which represents a coordinated effort of various central and state agencies and financial institutions. A similar program might help ease the employment transition from fisheries to manufacturing, construction, and service sectors.

The effort reduction policy must consider inherent biological and economic variability between different vessel classes. A uniform effort reduction across the board may not be necessary. For instance, in the simulated access restriction scenario, efforts of deep trawlers and purse seines were held at their 1998 levels, at which they made substantial profits. The effort levels of day trawlers and gillnets were reduced during the first four years. This non-uniform reduction strategy at best seemed to have solved two types of externalities commonly observed in fisheries (Townsend, 1990): the short-run externalities which result in higher costs of fishing due to vessel 'crowding', and the long-run externalities which occur due to stock collapse following excessive harvesting. In our study, the partial removal of cost-inefficient trawlers and gillnets helped ease the crowding effects early on. The restrictions on future expansion of purse seines and deep trawlers helped restore the stocks particularly of demersal species. These stock improvements ultimately boosted the profit margins of all primary sectors, including the ones making losses *ex ante*. Further, access restriction policy must be constantly revisited to account for stock improvements or periodic or unexpected changes in straddling stocks. Prolonged effort reduction may result in unnecessary decline in production and unwarranted regional impacts.

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