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Relative Effects of Fisheries Support Policies

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RELATIVE EFFECTS OF FISHERIES SUPPORT POLICIES

Roger Martini and James Innes, OECD

The effects of six common forms of fisheries support are estimated using a bioeconomic model of the global fishery. The results show that all have the potential to provoke overfishing, to lead to fish stocks being overfished, to encourage illegal, unreported or unregulated (IUU) fishing and to increase fleet capacity, but that their effects can vary significantly both in scale and how they are distributed at the fleet level. The fisheries management system can mitigate, though not entirely eliminate, these impacts. Supports based on reducing the cost of inputs purchased by fishers provoke the greatest increase in fishing effort, with associated risks of overfishing. This includes fuel subsidies, which are also shown to deliver less than 10% of their value in actual benefits to fishers in some cases, making them the least effective means of transferring income to fishers of those evaluated. Payments based on improving fishers' business operations provided the greatest benefit to fishers and had relatively less tendency to increase fishing effort. If only USD 5 billion in fuel support was converted into support of this type, fishers would see increased income of more than USD 2 billion, while at the same time reducing effort and improving fish stocks. Such a change would also provide relatively more benefit to smaller fishers.

Key words: Fisheries support, subsidies, overcapacity, overfishing, fisheries policy, fisher welfare

JEL codes Q22 H23 H53 Q28 Q57

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Table of contents

Abbreviations	5
Executive summary	6
1. Why analyse the effects of support policies?	8
2. A bio-economic model of fisheries production with multiple inputs, two fleet segments and multiple management systems.....	10
2.1. Bio-economic structure of the model.....	10
2.2. Initial state of the model and sources of data.....	14
2.3. Understanding the model output	16
3. Effects of fisheries support policies	18
3.1. Relative effects of fisheries policies on overfishing and IUU fishing	19
3.2. Relative effects of fisheries policies on fish stocks becoming overfished.....	22
3.3. Relative effects of fisheries policies on overcapacity.....	24
3.4. Relative effects of fisheries policies on incomes for fishers.....	27
3.5. An experiment in shifting support	32
3.6. Summary and conclusions	34
References	37
Annex A. Further detail on the FishPEM model	40
Annex B. Results tables.....	55

Tables

Table A A.1. Variables and parameters in FishPEM	42
Table A.A.2. FishPEM model equations	43
Table A A.3. FishPEM calibration variables, parameters.....	46
Table A A.4. FishPEM calibration equations	47
Table A A.5. Input level data and elasticities	48
Table A A.6. Input elasticities of substitution (σ_{ijs}).....	49
Table A A.7. Transfers mapped to individual inputs ($t\tilde{f}_{jfs}$)	49
Table A A.8. Support shocks in the model	51
Table A A.9. Indicators produced by FishPEM for this report	53
Table A B.1. Model results under open access conditions	55
Table A B.2. Model results under derby TAC conditions	56
Table A B.3. Model results under TAC conditions	57
Table A B.4. Cases with no significant differences	59

Figures

Figure 2.1.	Input market, biology, and output market in FishPEM	11
Figure 2.2.	Three management systems in the model.....	12
Figure 2.3.	IUU fishing expands effort beyond the TAC	13
Figure 2.4.	Support level and rate in a market.....	13
Figure 2.5.	Distribution of costs shares for fixed and towed gears.....	15
Figure 3.1.	Payments based on the use of variable inputs are the most likely to provoke over-fishing	20
Figure 3.2.	Change in fishing effort under open access by segment, percentage	21
Figure 3.3.	Change in fishing effort under a TAC by segment, percentage	22
Figure 3.4.	All six policies reduce fish stocks to some extent; a TAC moderates this effect.....	23
Figure 3.5.	Change in harvest in open access by segment, percentage	23
Figure 3.6.	Change in harvest under a TAC by segment, percentage.....	24
Figure 3.7.	Payments based on vessels increase fleet capacity the most	25
Figure 3.8.	Change in vessel quantity under open access by segment, percentage	26
Figure 3.9.	Change in vessel quantity under a TAC by segment, percentage	26
Figure 3.10.	Change in vessel quantity under a derby TAC by segment, percentage	27
Figure 3.11.	Policies based on the use of fuel provide little benefit to fishers; others do better	28
Figure 3.12.	Change in income under open access by beneficiary and segment, USD Billions	29
Figure 3.13.	Change in income under a TAC by beneficiary and segment, USD billions	30
Figure 3.14.	Distribution of benefits of support by type	31
Figure 3.15.	Change in income under a derby TAC by beneficiary and segment, USD billions	32
Figure 3.16.	Shifting the basis of support can increase stocks and income for fishers.....	33
Figure 3.17.	Ordering of policy impacts by type.....	35
Figure A A.1.	Calibrating the model to different initial conditions based on management system ...	50
Figure A A.2.	How a support level enters an input market	52
Figure A A.3.	Change in producer surplus in an input market due to a policy shock	54

Abbreviations

FishPEM	Fisheries Policy Evaluation Model	OECD model of fisheries policy that is the subject of this report.
FSE	Fisheries Support Estimate	OECD Database of policies providing support to fisheries. See oe.cd/FSE
ITQ	Individual Transferrable Quota	A right to harvest a particular amount of resources, that can be transferred, e.g. by sale, lease, or will. A type of quota (a part of a Total Allowable Catch) allocated to individual fishermen or vessel owners and which can be sold to others.
IUU	Illegal, Unreported and Unregulated Fishing	<p>Illegal fishing refers to activities conducted in a country's EEZ in contravention of its laws and regulations as well as to fishing in international waters in violation of that country's flag state law and regulations related to its obligations under the international treaties and regional fisheries management organisations (RFMO) convention arrangements to which it is party.</p> <p>Unreported fishing refers to fishing activities that have not been reported, or have been misreported, to the relevant national authority or RFMO, in contravention of the laws, regulations and reporting procedures of that country or organisation. This can occur both within EEZs and on the high seas.</p> <p>Unregulated fishing refers to fishing activities in areas or of fish stocks where there are no national, regional or international conservation or management measures applicable to a particular fishery or fishing vessel. Unregulated fishing can occur in an unmanaged fishery within an EEZ or on the high seas by vessels without nationality, or by vessels flying the flag of a country that is not a party to international conventions or a relevant RFMO.</p>
MEY	Maximum Economic Yield	When relating total revenues from fishing to total fishing effort in a surplus production model, the value of the largest positive difference between total revenues and total costs of fishing (including the cost of labour and capital) with all inputs valued at their opportunity costs
PEM	Policy Evaluation Model	OECD model of agricultural policy developed in the late 1990s. https://www.oecd.org/tad/agricultural-policies/39265834.pdf
STECF	Scientific, Technical and Economic Committee for Fisheries	https://stecf.jrc.ec.europa.eu/about-stecf
TAC	Total Allowable Catch	The TAC is the total catch allowed to be taken from a resource in a specified period (usually a year), as defined in the management plan. The TAC may be allocated to the stakeholders in the form of quotas as specific quantities or proportions
OA	Open Access (fishery)	Open access is the condition where access to the fishery (for the purpose of harvesting fish) is unrestricted; i.e., the right to catch fish is free and open to all. Access to fisheries is not excludable but rival in consumption.

Executive summary

Support policies are intended to help governments reach their objectives for the fishing sector and are a part of the policy toolbox in most countries. However, some supports can negatively affect the fishing sector, by unsustainably increasing fishing effort or causing overcapitalisation and excess capacity of fishing fleets.

Poorly designed policies can lead to increased fishing effort, overfishing, and depletion of fish stocks, as well as making illegal unreported and unregulated (IUU) fishing more attractive for fishers. All of this taken together reduces the profits and income of fishers, leads to less fish for consumers rather than more, and brings risks to the health of the ocean environment.

Improved understanding of subsidies and their impacts would assist governments to reform their support policies toward achieving sustainable fisheries, and contribute toward the global effort as agreed under the United Nations Sustainable Development Goals (UNSDG) target 14.6, which calls for the elimination of subsidies that contribute to overcapacity and overfishing, or to IUU fishing. Members of the World Trade Organization (WTO) are currently engaged in negotiations to establish rules for fisheries subsidies to deliver on this agreement. An agreed understanding of different subsidies and their impact, both beneficial and detrimental, could assist in this endeavour. The research in this report is intended to contribute toward that understanding, and to provide policy makers with a way to compare different policy approaches in more specific detail than has been previously possible.

The results of the model-based analysis used in this report show that all six fisheries support policies investigated have the potential to provoke overfishing, to lead to fish stocks being overfished, to encourage IUU fishing, and to increase fleet capacity. However, their effects vary significantly in scale, and they can affect different fishers in different ways.

Support that is based on the costs of fishing, such help to purchase fuel, gear or bait, can increase fishing effort more than other policy options. These types of support are the most likely to increase IUU fishing effort and to lead to stock depletion. They also tend to favour larger fishers, to the point where others in the fishery may be made worse off by support.

Depending on the management context, many fisheries support policies do little to improve fishers' livelihoods. In particular, as little as 10% of government expenditures to reduce the cost of fuel for fishers can translate to real income gains. However, the potential benefits of such transfers are lost to increased effort and lower fish stocks or are captured by those selling the subsidised inputs.

By contrast, payments that are designed to help the profitability of fishing operations bring significant benefits to fishers while also having relatively benign effects on effort and capacity. These include, for example, programmes that ensure that capital markets function to provide working capital for operations, or programmes to increase the business or operational skills of fishers. Payments that directly target fishers' incomes, such as disaster payments or employment insurance, also do a good job of delivering benefits to all participants in the fishing sector.

The results overall show that it is possible to support the fishing sector and deliver benefits to fishers without unduly provoking overfishing or overcapacity. Moving existing support (as estimated in the OECD Fisheries Support Estimate (FSE) database, a partial estimate of the global total) away from gear, fuel, vessels or other inputs towards helping fishers to

better operate their business and deal with disasters could improve fishers' income by as much as USD 2 billion, reduce pressure on stocks and increase harvest by almost half a million tonnes per year.

Key messages

- The six support policies investigated all reduce fish stocks to some extent. An effective fisheries management system can mitigate, though not entirely eliminate, this effect.
- Policies designed to reduce the cost of things purchased by fishers, like bait or fuel, are the most likely to provoke overfishing and IUU fishing.
- Payments designed to support efficient business operations and develop human capital have the lowest negative impacts while delivering significant benefits to fishers. Payments based on vessels are similar, but are the most likely of all policies to result in overcapacity of the fishing fleet.
- Some increased fishing effort resulting from support will take the form of IUU fishing, with negative effects on law-abiding fishers. As a result, support policies could provide positive benefits to IUU fishing at the expense of legal fishing activities.
- Policies provide a much greater benefit to fishers when an effective Total Allowable Catch (TAC) is in place. Solving the fisheries management problem is a pre-requisite to effective support policies.
- Support policies create winners and losers. In particular, support based on the use of fuel can make smaller fishers worse off than they would be without them as they are displaced by more fuel-intensive fishing operations.
- Policies can have an important effect on the composition of the fishing sector by favouring one segment over another, even when those policies make no distinctions between the type of recipient.
- Most of the policies investigated have only a small likelihood of promoting overcapacity; payments linked to vessels are a notable exception.

1. Why analyse the effects of support policies?

Support policies are intended to help governments reach their objectives for the fishing sector and form part of the policy toolbox in most countries. However, it is recognised that some supports can have negative effects, by unsustainably increasing fishing effort or causing overcapitalisation and excess capacity of fishing fleets.

Poorly designed policies can lead to increased fishing effort, overfishing, and depletion of fish stocks, as well as make IUU fishing more attractive for fishers. All of this taken together reduces the profits and income of fishers, leads to less fish for consumers rather than more, and brings risks to the health of the ocean environment.

Improved understanding of subsidies and their impacts would assist governments to reform their support policies toward achieving sustainable fisheries, and contribute toward the global effort as agreed under the United Nations Sustainable Development Goals (UNSDG) target 14.6, which calls for the elimination of subsidies that contribute to overcapacity and overfishing, or to IUU fishing. The WTO membership is currently engaged in negotiations to establish rules for fisheries subsidies to deliver on this agreement. An agreed understanding of different subsidies and their impact, both beneficial and detrimental, could assist in this endeavour.

Most previous investigations into the effects of fisheries support policies focus on how subsidies change the level of fishing effort and the subsequent changes to the fish stock. One of the earliest of these studies divided the effects of support into three possible categories—beneficial, harmful or ambiguous (Sumaila et al., 2016^[1]; Sumaila et al., 2010^[2]).¹ Most studies take an aggregate view of subsidies, either considering only a single type of subsidy (Da-Rocha et al., 2017^[3]; Heymans et al., 2011^[4]; Merayo, Waldo and Nielsen, (n.d.)^[5]), or lumping them into subsidies to “fixed” or “variable” inputs.² For example, a recent study investigated how subsidies to fuel, combined with below-market wage rates for crew, changed patterns of fishing on the high seas (Sala et al., 2018^[6]).

These studies have been of limited impact for policy making for a number of reasons. By painting policies with a broad brush, they do not help policy makers identify what specific forms of support are problematic. The exception to this is policies that reduce the cost of fuel, which have received some detailed attention. By focussing only on the negative consequences of support, these studies do not help policy makers to identify beneficial policy alternatives.

This report is designed to address these limitations and improves on the current state of understanding of the effects of support policies in three ways:

¹ Sumaila et al. famously characterised these as “good, bad and ugly” (Sumaila et al., 2010^[2]). “Beneficial subsidies” are programmes that lead to investment in natural capital assets (fish stocks), and “harmful subsidies” are those that lead to disinvestments in natural capital assets such that fishing capacity develops to a point where resource overexploitation makes it impossible to achieve maximum sustainable long-term benefits. “‘Ambiguous subsidies’ are programs whose impacts are undetermined, i.e. they may lead to either investment or disinvestment in the fishery resource.

² All the short-run costs faced by firms can be broken into those for fixed or variable input. Fixed inputs are independent of output and include things like rent, buildings or machinery. Variable costs vary with output and include wages, utilities and materials used in production.

- It includes six different support categories based on the OECD Fisheries Support Estimate (FSE) classification, providing a means to compare different policy approaches in more specific detail than was previously possible.
- It investigates the impacts of these forms of support on not only fishing effort, but also fleet capacity and the benefits generated for fishers and other sector participants. This allows for a more complete comparison of the benefits and costs of each policy category, and can help identify not only those policies deemed harmful but also more beneficial alternatives.
- It investigates the impacts of different forms of support in both a theoretically and empirically consistent manner, taking into account the uncertainty regarding the economics of fishing activity. This analysis moves beyond first-principles analysis of effects by developing a model based in economic theory of production. It builds upon the commonly used Pella-Tomlinson model of the fishing economy, calibrated with empirical data to represent the global capture fishery in 2015.

It is frequently noted that the effects of different support policies depend on many external conditions. The most important of these is the management system in place; in general, it is assumed that the impacts of support policies are smaller in fisheries where an effective management system is in place. For this reason, the effects of different support policies in this report are shown for three broad management categories: open access, an effective total allowable catch (TAC) that controls total harvest but does not control the effort of individual fishers (often termed a derby or Olympic fishery with a “race to fish”), and a TAC where individual effort is also controlled.

The connection between fisheries support and IUU fishing is also of great interest for the on-going international discussions. IUU fishing is estimated to account for 20% of catches, and reducing IUU fishing is a longstanding and common goal (Agnew et al., 2009^[7]). Policy support should not inadvertently increase this kind of activity, and this analysis helps shed some light on this connection by considering the motivations for IUU activity.

Finally, policy makers commonly have different objectives for the many participants in the fishing sector based on factors that can include their size, whether they use traditional gear types, depending on the fishery targeted. The analysis in this report differentiates between a larger, more technically efficient fishing segment and a smaller one with less flexible production technology.

Section 2 introduces the modelling framework used in the analysis, and Section 3 presents the results. Additional detail on model structure is presented in Annex A. Annex B presents the model results in detail and an overview of the statistical analysis.³

³ Some additional details, including a statistical analysis of the results and a consultant’s report on parameter values can be found in an expanded version of the document (TAD/FI(2018)2/FINAL), at <https://oe.cd/2qG>.

2. A bio-economic model of fisheries production with multiple inputs, two fleet segments and multiple management systems

The Fisheries Policy Evaluation Model (FishPEM) is designed to help understand the impacts of fisheries policies on fishing effort and capacity. It simulates the fishing sector by reflecting the biology, economics, and management of a single global fishery pursued by two different fishing segments, one large and one small. Each segment is modelled as a representative fishing operation that maximises profits subject to the management system. Fishers in the two segments use a combination of purchased inputs and their own resources to catch fish, which are sold into a domestic market. Fishers can opt to undertake IUU fishing and pay a fine if they are caught doing so. Fisheries in the model can be either open-access or subject to two different forms of TAC-based management. A detailed technical description of the model, data and indicators are provided in the Annex A.

2.1. Bio-economic structure of the model

FishPEM is derived from the Policy Evaluation Model (PEM) that has been used by the OECD to investigate the impacts of agricultural policies since 2001. A full description of the heritage and economic concepts used in this model is available in (OECD, 2001^[8]) and (OECD, 2005^[9]).

The biological component of the model connects fishing effort to harvest and stock levels, following the general approach of the Pella-Tomlinson model (Pella and Tomlinson, 1969^[10]). The model solves for the steady-state stock, harvest and effort levels given the growth function of fish, the production function producing fishing effort, the supply functions for each input, and prices.

In the model, fishers purchase inputs from suppliers in input markets and combine these with their own assets to produce fishing effort, which is applied to a single, shared fish stock representing the global fishery. There are currently two purchased inputs in the model, fuel and a broad “other purchased inputs”. Assets controlled by fishers are vessels (measured as capital depreciation and maintenance), crew labour and “fishers’ own capital”, which covers all intellectual and managerial assets of the fishing firm, plus any non-vessel investments.⁴

The level of effort chosen by fishers, and how it responds to changes, depends on how these input markets function and their relative intensity of use. The supply of purchased inputs such as fuel are more responsive to price changes while fisheries-specific capital such as vessels are less so.

The economic and biological components of the model operate as a system of simultaneous equations that are jointly solved to produce model outcomes (Figure 2.1). All prices and quantities are endogenous to this model solution, so changing any one of them generally results in a change to all others. For example, changing the price of fuel will change the

⁴ Fishers’ own capital can mainly be considered as the return to entrepreneurship; or equivalently the value of a normal rate of return on investment in the fishing operation, including for working capital. In the case of an owner-operator, it is also effectively the skippers’ wage. A good mental shorthand is to think of this as return to fishing operations.

number of crew hired, fishing effort, stock level and harvest, as well as the price of fish and quantity consumed.⁵

Figure 2.1. Input market, biology, and output market in FishPEM

There are three different options in the model for fisheries management: open access, a TAC with individual effort controls, and a TAC with no individual effort controls (termed a derby TAC or Olympic fishery) (Figure 2.2). In open access, fishers will expand fishing effort to the point where revenue equals cost. The resource rents potentially available from the fishery are lost, and firms earn only normal economic profits. When a TAC is introduced, fishers are constrained from adding effort beyond the amount where harvest equals the TAC. This results in some resource rents generated, but only if fishers do not race to catch the TAC as quickly as possible. This situation, a derby TAC, results in the cost per unit of effort being increased as fishers compete to fish faster and faster. The TAC is enforced, but once again the resource rents potentially available are lost.⁶

⁵ This paper does not examine the welfare effects of support on consumers of fish or taxpayers.

⁶ The specific details of TAC implementation are not included in the model. In general, TAC systems that generate rents are based on an individual quota system that eliminates incentives to race to fish, while derby TAC systems have no individual allocations of fishing rights, either in terms of effort or harvest. The TAC is not tradeable between fishing segments.

Figure 2.2. Three management systems in the model

“Open access” equates revenues and costs, TAC controls effort, leading either to resource rents (effective effort control) or to higher costs (derby race to fish).

Note: OA=“open access”, TC=“total cost”. When fishers race to fish, they spend more to put the same effective level of effort into the fishery. They buy bigger, more powerful boats, hire more crew, and fish in less favourable circumstances. This process continues and worsens until all the resource rents are competed away. This raises the TC curve, shown here as the dashed line, so that it touches the revenue curve at the point of the TAC.

In the model TAC is defined according to effort, limiting the amount of effort that each segment may apply to the fishery. IUU fishing occurs when effort beyond that allowed by the TAC takes place. Fishers can choose to undertake IUU fishing, and balance the additional profit from doing this with the chance of paying a fine. The amount of the fine is fixed and the probability of being caught increases with the share of IUU effort in the total. The economics of this are described in *Why Fish Piracy Persists* (OECD, 2005^[11]). There is no IUU fishing under open-access management as in this case fishers may already fish as much as they want, nor under a derby TAC as in this case all potential resource rents are already competed away.

This representation deals only with rent-driven IUU fishing. Because stocks are aggregated to a single global fishery, there are no closed stocks that could be exploited by IUU fishing. As each segment is represented by a single fisher, there is no heterogeneity within segments that would lead certain fishers to do IUU fishing and others not; it must be globally optimal. The results therefore only partially capture how support affects IUU effort. They are therefore a lower bound of the true impact on IUU fishing.

Adding additional effort, especially when the TAC level of effort is set close to MSY, results in lower total harvest for the fishery in the long run and lower resource rents generated. Essentially, IUU fishing moves the equilibrium away from MSY and closer to open access (Figure 2.3). The model tracks the share of effort that is legal and the share that is put into IUU fishing.

Policy simulations are carried out by applying a subsidy to some combination of input markets or the market for fish. This changes the supply and demand prices in those markets by adding a “wedge” between the supply and demand price equal to the rate of support. New prices, quantities, effort and stock levels can be observed after adjustment to these

price changes, reflecting the outcome of the policy scenario represented by the policy shock (Figure 2.4).

Figure 2.3. IUU fishing expands effort beyond the TAC

The result is generally lower resource rents and harvest in the long-run

Note: The expected fine (the fine times the probability of being caught) acts like an additional cost beyond the TAC level—represented by the difference between the TC line and the dashed line in the figure. Fishers can ignore the TAC by undertaking IUU fishing, and the new equilibrium point is here labelled IUU.

Figure 2.4. Support level and rate in a market

Note: The support level corresponds to the amount of budgetary support provided by a policy, as it would appear in the FSE. The rate is the support divided by the amount of the thing being supported— Q in this figure. As Q get larger, support is spread over more economic activity and the rate of support per unit declines. The rate of support is what matters more for the impact of a policy than the level.

The benefits of support accrue to the producers' surplus in each input market. Simply put, a higher price for purchased inputs means more benefits for those who supply them. This is also true for crew wages and the returns to investment by fishers. Tracking how these change in a policy scenario reveals the distribution of the benefits of support.⁷

⁷ Inputs controlled by fishers are crew (who are fishers themselves), fishers' own capital and vessels. The producer surplus accruing to these inputs are counted as benefits to fishers.

2.2. Initial state of the model and sources of data

The FishPEM model is a flexible modelling framework; it can apply to a number of scales or locations depending on how the biological growth function is defined. The economics of production is determined by the parameters of input supply and production technology that can represent virtually any situation from completely fixed proportions in input use, to a technology that allows inputs to be freely and perfectly substituted. This section describes the sources of the data used for the model and its initial state.

In the version used here, the model is calibrated to describe the global fishery by adopting the same growth function and parameters as were used in the recent report “The Sunken Billions Revisited” (World Bank, 2017^[12]). As was the case for that study, a Pella-Tomlinson growth function is used. This is a modified version of the commonly-used logistic growth function. By adding a skewness parameter, this growth function avoids the constraint of the symmetrical logistic function that requires that MSY always be half of carrying capacity of the stock. This growth function is fully specified by the carrying capacity and MSY level of the stock, and the Pella-Tomlinson parameter. All of these values are taken from the *Sunken Billions* report.

The model is calibrated to the situation that existed in 2015, the most recent year for which there is a complete set of data. The global harvest level recorded in 2015 was taken from the *OECD-FAO Agricultural Outlook* report (OECD/FAO, 2018^[13]). This updates the *Sunken Billions Revisited* report, which was based on 2012 data. The harvest level, combined with the parameters of the growth function, fully define the biology in the model.

Initial support levels in the model come from the OECD Fisheries Support Estimate (FSE) database (OECD, 2017^[14]; OECD, 2018^[15]). This database contains information for 2015 on USD 6 billion worth of support in the six support categories included in the model out of about USD 13 billion in support overall.⁸ The FSE database does not contain global support totals, as it covers support in only 38 countries, but taken together these countries represent 50% of global fisheries landings.

The main economic parameters are: (1) the way supply of each input changes with its price (input supply elasticity), (2) the share of each input in total expenditure (input cost shares), and (3) the degree by which inputs may be substituted for each other in production (elasticities of substitution). Elasticities of substitution are calculated based on a translog cost function (Mardle, 2018^[16]). The data for this, and the cost shares for inputs, are based on STECF data for 2017 (Carvalho et al., 2017^[17]). Cost shares roughly correspond to fixed gear operations for the small segment and towed gears for the large segment. These cost data show some variability (Figure 2.5), so values in FishPEM are chosen to emphasise a relatively labour-intensive production for the small sector and a relatively energy-intensive production for the large sector.

⁸ Total support in the FSE, which includes OECD countries and a number of other important fishing economies (Argentina, Brazil, the People’s Republic of China, Colombia, Costa Rica, Indonesia, Peru, Philippines, and Chinese Taipei), is USD 13 billion. Of this total, almost USD 6 billion is included in the categories covered by the analysis. The model is a global one, so makes no distinction between OECD economies and others.

Figure 2.5. Distribution of costs shares for fixed and towed gears*Top panel: Fixed gear. Bottom panel: Towed gear*

Note: These data shows a distribution of observed cost structures for many firms in the STECF dataset. For fixed gear operations, labour is most commonly reported as between 40-50% of total cost, while for towed gear it is most commonly observed to be between 20 and 40% of costs. In the case of energy, both operations report costs most commonly as being between 10- 20% of costs. For fixed-gear operators, observations of costs above this amount are rare but are relatively common for towed gear operators, with many operators observed to spend 20-30% or 30-40% of their costs on energy.

Source: (Carvalho et al., 2017^[17])

The fine for IUU fishing is set so that initially 15% of fishing effort is IUU, somewhat below available estimates (Agnew et al., 2009^[7]). There are no good empirical estimates of the global probability of paying a fine for IUU fishing, so this probability is treated in a simple way by making it proportional to the amount of effort that is IUU.

2.3. Understanding the model output

FishPEM is a medium-term model that represents a steady state system after all adjustments by economic actors have taken place and the biological system has reached equilibrium. Indicators produced from the model therefore reflect the difference between an initial situation and future state of affairs after a change in policy. The model is designed to represent an adjustment period of several years, long enough that firms can choose their optimal mix of inputs and where the fish stock returns to balance such that the annual harvest equals the growth rate of the stock.⁹

The model is designed as a policy impact model, not a forecasting or predictive model. While care has been taken to select parameters that are appropriate and based on the best available information, the point is not to have a single set of results using the “right” parameters. The point is to find results that hold regardless of parameter choice; if an outcome holds as true regardless of what parameters are chosen, that is evidence of its general validity.

In order to establish the generality of the results presented here, a statistical method known as “monte carlo analysis” is used (Judge et al., 1985^[18]). This method subjects model results to a sensitivity analysis in which all parameters are systematically varied between half and double their base values. Model parameters are drawn in this way from a uniform distribution, and the model re-run 1 000 times to generate a set of results that encompass a broad range of possible parameter values.

The sensitivity analysis is summarised as error bars that show an interval representing two standard deviations from the mean – that is, a range that encompasses 95% of the probability distribution of the indicators generated by the sensitivity analysis. While these bars (shown in the figures in the following section) indicate the observed distribution of results, overlapping bars do not indicate that there is no difference between the results.¹⁰

Two sets of t-tests were undertaken, one to determine whether the observed impacts of policies were significantly different from zero (i.e. the support had a significant impact) and another to determine whether the impacts of policies were significantly different from one another (i.e. can differences in the impact of specific forms of support be distinguished and ranked).

In all cases but one, the impacts of all forms of support considered in this analysis are statistically different from zero at the 0.1% confidence level (i.e. t-test p value of <0.001). That is, there is a 0.1% chance that zero is included in the actual distribution of possible impacts of the support policy. The single exception was for small vessels under a TAC management system, where support to fuel use was not seen to have a significant impact on effort (p value 0.205).

⁹ This medium term time frame eliminates the short-run distinction between fixed and variable inputs. All inputs can vary in use, with different degrees of ease.

¹⁰ The sensitivity analysis, including the results of t-tests used to test the significance of the results and differences between policy effects, is covered in detail in Annex C of an expanded version of the document (TAD/FI(2018)2/FINAL), available at: <https://oe.cd/2qG>.

Differences between the mean observed impacts of policies are also significantly different at the 0.1% confidence level in the majority of cases, an outcome that provides strong support for ranking the alternative policies on the basis of their observed impacts. There are a few cases for which specific policy impacts are not significantly different i.e. where differences in impact could not be confirmed at the 10% level (p value of >0.1).¹¹

The main indicators have to do with the propensity of a policy transfer to lead to overcapacity, overfishing or IUU fishing as well as the effectiveness of policy transfers in increasing the income of fishers—defined as holders of licences, owners of vessels, vessel operators or crewmembers. These are measured through the change in capacity (measured by the use of the vessels input), effort and stock size. Income effects are measured using transfer efficiency, the percentage of the value of the transfer that is reflected in higher income for fishers. Higher income is measured by the change in producer surplus accruing to inputs owned by fishers plus resource rents generated in the fishery.

Results are shown for two fleet segments. The two segments, generically referred to as “large” and “small” are differentiated to highlight different characteristics of fishing operations in the following way:

- The large segment is relatively fuel-intensive in production, while the small segment is relatively labour-intensive.
- The large segment has more flexibility to substitute between inputs, which implies a superior production technology.
- The large segment catches 75% of the total harvest in the base case, both for open access and TAC.
- The large segment has higher revenues, so the fines from IUU fishing create a smaller relative penalty.

Some of the elements of the model, such as fishing effort, are unitless measures or are indexes, such as the price of inputs. In most cases, the best way to understand the model output is to consider the percentage change in their values. However, when looking at the effect on policies on the two fleet segments in the model, large and small, their different sizes can make it worthwhile to look at changes in levels in some cases.

¹¹ These are reported in Annex B, Table A B.4.

3. Effects of fisheries support policies

The purpose of this analysis is to establish a sound economic and empirical basis for determining the differences in the effects of different support policy types in fisheries. The following four important impact areas are reviewed to assess the policy effects: fishing effort, fishing capacity, fish stock size, IUU fishing, and income for fishers.

The results are presented by the type of impact considered. First is the potential impact of increased support on overfishing and IUU fishing. Second is a section on stock effects. Third is overcapacity of fishing fleets, and fourth is the income effects of fishing policies. The results under different management systems are contrasted, as are the relative impacts on the large and small fishing segments.

Support policies are a transfer of funds from the government to a recipient. These can also be termed policy transfers or government financial transfers, some of which may commonly be considered subsidies and others not. In each case, scenarios are built based on increasing the amount of support in six different categories by USD 5 billion, representing a significant increase in the transfer provided.¹² The results are expressed as the percentage change in the indicator of interest provoked by the increase in support.

The six support policy categories in the analysis are:

- *Payments based on fishers' income.* These are transfers made depending on the current income of the recipient. This would include employment insurance, disaster payments, wage subsidies, special income tax concessions and similar.
- *Payments based on fishers' own capital.* These transfers are based on investment in fishing operations or working capital for operations. This category includes, for example, concessional loans, special tax treatment on investment or returns on investment other than for capital in fishing vessels. Support that increases operators' capacity to profit from the fishery, such as upskilling, marketing training and assistance would also fall in this category.
- *Payments based on vessels.* These transfers are made on the basis of the purchase, alteration, or scrapping of a fishing vessel.
- *Payments based on variable input use.* These transfers are made on the basis of the running costs of the fishing operation, such as payments contingent on the purchase of gear, bait or ice, or the use of port services.
- *Payments based on fuel use.* These transfers are made on the basis of the quantity of fuel used by the fishing operation. This includes for example fuel tax concessions or fuel subsidies.
- *Payments based on output.* These transfers are made on the basis of the price of fish. They include tariffs, market interventions and consumer subsidies.

¹² For context, total support in the OECD area is estimated between USD 6 and 7 billion. Other global estimates of fishing subsidies put them on the order of USD 35 billion (Sumaila et al., 2016^[35]). The size of the shock does not affect the results except in terms of scale (i.e. relative impacts and rank order will not change) and is chosen to ensure a meaningful magnitude of change in the indicators.

The results shown in the following sub-sections provide evidence that there are significant differences in the effects of fisheries policies and these differences persist for a wide set of parameter choices. These differences mean some policies perform better on some indicators, and worse in others.

3.1. Relative effects of fisheries policies on overfishing and IUU fishing

Overfishing is a condition in which fishing effort is above the desired amount, usually the level that produces maximum sustainable yield (MSY).¹³ In open-access situations, fishers ultimately operate at the point where their total revenue equals total cost. Typically, this results in harvests less than MSY, stock size below that which produces MSY, and no generation of resource rents from the fishery.¹⁴ Additional support transfers lower the effective price paid for inputs—for example, more support to fuel use lowers the price of fuel. The effect of this is to lower the cost of fishing, changing the level of effort where revenue equals cost, usually with the effect of increasing effort until this revenue=cost condition is restored.

A TAC controls fishing effort and reduces its response to changes in support policies.¹⁵ However, fishers may still choose to undertake IUU fishing, a decision that is informed by many factors, including their fishing costs. The TAC is set near the MSY level, so any IUU fishing effort will lower long-term harvest levels by reducing the fish stock below the level that yields MSY. Despite this, fishers will still wish to increase effort as they compete to capture the resource rents in the fishery. Fishers will add IUU effort to the point where the additional profits from doing so equal the expected fine they face. The change in effort under a TAC shown in the results below are entirely the result of additional IUU fishing effort above that allowed by the TAC.

Different forms of support effect fishing effort and potentially overfishing in different ways. For example, transfers based on the running costs of the fishers, such as the price of fuel, the use of gear or crew costs, will have a larger impact than those based on fixed assets as the former can be changed relatively easily and rapidly in response to policy changes (Figure 3.1). Payments based on fishers' own capital increase fishing effort by the smallest amount; payments based on vessels have a similar low effect on effort.

¹³ Yield, harvest, and output are equivalent terms for the purpose of this report.

¹⁴ When price equals marginal cost, fishers earn “normal” economic profits. When price is above marginal cost, the additional profits earned are called “resource rents.” Technically speaking, economic rents are payments (imputed or otherwise) to a variable above the marginal costs of supplying that variable. The variable in the fishery is the resource itself, hence the term resource rents. In this context, resource rents are the excess of price over marginal cost, times quantity harvested (Arnason, 2006^[34]).

¹⁵ Section 2 of the report discusses the representation of a TAC and a derby TAC in the model. Except where specified, in the section, results from the non-derby TAC formulation are shown.

Figure 3.1. Payments based on the use of variable inputs are the most likely to provoke over-fishing

This figure shows the percentage change in fishing effort under a TAC and open access. The TAC reduces the increase in effort provoked by the policy by about half, an amount that depends on the quality of enforcement of IUU fishing. Payments based on fishers' own capital have the smallest impact.

Note: Variable inputs like gear, crew, fuel and other things purchased rather than owned by fishers can be changed relatively easily and rapidly in response to policy changes. Things like vessels and other capital assets (including normal investment returns) are much stickier. So policies that target capital provoke a smaller change in effort than those based on running costs.

Source: OECD FishPEM model.

The impact of changes in support policies differs across fleet segments. For example, increasing support based on the use of fuel leads to an overall increase in effort of about 1.7%, but effort by the large fishing segment increases by more than 3% while effort in the small fishing segment declines by 3% (Figure 3.2). Fishers in the large segment, using fuel relatively more intensively, displace some effort by fishers in the small segment, who reduce their effort despite the reduction in their fuel cost. The reduced overall yield and catch per unit effort resulting from the increased effort by fishers in the large segment makes it unprofitable for fishers in the small segment to increase effort after the increase in fuel support.

This indicates a potentially important distributional and compositional effect of policies. While both segments receive the same increase in support, the nature of competition for the common fish resource can negatively affect the segment less well-placed to take advantage of it. Payments based on the use of fuel or on vessels confer a competitive disadvantage on the fleet in the small segment that reduces their long-term effort. Other forms of support confer a relative benefit to fishers in the small segment, though the difference is not as pronounced and fishers in the large segment increase effort when any type of support transfer is increased.

Figure 3.2. Change in fishing effort under open access by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percentage of base effort.
High-low bars show the range of possible values generated by sensitivity analysis and reflect two standard deviations from the mean outcome.

Note: Payments based on the use of fuel bring about a highly imbalanced effect, with the more fuel-intensive fishers in the large segment disproportionately increasing effort. Effectively, fishers in the small segment are out-competed by fishers in the large segment, even though they also see a reduction in fuel cost. Investment aids have the smallest impact on effort, while support based on output has the most even distribution of effect between fishers in the both segments.

Source: OECD FishPEM model.

There are two reasons why the response of the large segment to support tends to be greater than that of the small segment. First, the greater size of the large segment in terms of total catch means that a given percentage change in its effort will reduce the equilibrium stock level by an amount that can affect the small segment's profitability. That is, the increase in effort in the large segment lowers the optimal effort by fishers in the small segment when they exploit a common resource. The same percentage increase in effort by the smaller segment will not affect the large segment to the same degree. The second reason is that the large segment is assumed to have a superior technology; fishers in the large segment can more dynamically re-allocate the use of inputs in their production process than can fishers in the small segment, who are more constrained (for example by the continued use of traditional fishing methods).

The results under a TAC differ considerably from those in Figure 3.2. In this case, the TAC is constraining effort, both segments enjoy resource rents and the price of fish is above their marginal cost. For this reason, the stock effect described above does not occur. Both segments increase effort when support is increased, though the large segment, which is less dissuaded by the fine for IUU fishing, increases effort more (Figure 3.3). The large segment is less constrained, and increases effort by more than 1.2% in response to the increase in support based on variable inputs or fuel, and by about 1% for payments based on output or income.

Figure 3.3. Change in fishing effort under a TAC by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percentage of base effort. Fishers in the large segment increase IUU fishing effort under most policy support types, though the greatest increase is for payments based on fuel or variable inputs. Payments based on fishers' own capital have the smallest impact on IUU effort.

Note: The relative results between the small and large segments are driven by a number of factors, but the relative attractiveness of IUU fishing is the most important for this indicator.

Source: OECD FishPEM model.

3.2. Relative effects of fisheries policies on fish stocks becoming overfished

Closely related to overfishing is an overfished condition, where the fish stock is depleted, leading to reduced harvests and risks to sustainability. The mechanism of effect is straightforward: more fishing effort temporarily increases harvest, but stock size is reduced as a result. This leads to long-term declines in harvest.

All increases in support policies evaluated in this report result in lower fish stocks (Figure 3.4). Under open access, the policy shock reduces stock size by about 2.5% on average, with largest impact coming from payments based on variable inputs at over 3%. The results of the monte-carlo analysis show greater variation in possible policy impacts under open access.

An effective TAC reduces the impact of the policy shock on stock size, to about 0.9% on average across all policy types. The largest effect is observed for support based on fuel or the use of variable inputs, which reduce stocks by about 1.1%.

In percentage terms, the patterns of change in harvest follow those for effort quite closely, though the percentage change in harvest is less than the percentage change in effort due to the negative stock effect. The greater is the increase in total effort (i.e. aggregate small and large), the larger will be the reduction in total harvest. The reduction in harvest resulting from increased support can be substantial; fishers in the small segment see their yield decline by more than 6% after support to fuel use is increased (Figure 3.5).

IUU fishing under a TAC management regime reduces overall harvest in the long run, with some redistribution taking place between segments (Figure 3.6). The effect of the additional IUU effort on harvest via stock size changes is clearly seen in the reduction in harvest experienced by the small segment. Despite modest increases in their fishing effort, harvest by this segment declines by more than 1% for some policies and by 0.81% on average.

Figure 3.4. All six policies reduce fish stocks to some extent; a TAC moderates this effect

Note: Results from an increase of USD 5 billion in support, by support type, expressed in change in the size of the fish stock in percentage. An effective TAC reduces the impact of policy transfers on stocks, but all policies have some negative effect on stock size due to increased IUU fishing. Under open access, a larger increase in fishing effort reduces stocks more.

Fishers in open access can increase effort as much as they wish; higher effort reduces stock size in the long-run. Under a TAC, effort is controlled to some extent, though IUU fishing can still put pressure on fish stocks (depending on the fine they face for doing so). The points show the mean results from the model after 1000 random draws of possible parameters. The high-low bars for each point show the variability of the results when parameters are changed, reflecting two standard deviations or 95% of the probability distribution of the impact of each policy.

Source: OECD FishPEM model

Figure 3.5. Change in harvest in open access by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percentage of base harvest. Harvest can increase for the sector that is relatively favoured by a support policy, but total harvest declines in all cases. Payments based on income or fixed capital lead to increased harvest for the small segment, while payments based on vessels or fuel increase it for the large segment.

Note: The model results are quite robust to changes in parameter choice. The high-low bars show significant variation in results only for small harvest when support based on vessels or fuel is increased.

Source: OECD FishPEM model.

Figure 3.6. Change in harvest under a TAC by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percentage of base harvest. Large segment harvest increases proportionally less than the amount of additional effort they exert.

The increased effort by the large segment leads to reduced harvest overall, and especially by fishers in the small segment due to the effect of lower stocks on CPUE.

Note: The pattern of effect on harvest across policy types mirrors the effect on effort, though with reduced harvest due to increasing effort above MSY. Payments based on the use of fuel or variable inputs have the most negative impacts on harvest. Recall TAC is expressed in terms of effort, not harvest; fishers in the small segment have increased (IUU) effort slightly.

Source: OECD FishPEM model.

3.3. Relative effects of fisheries policies on overcapacity

Overcapacity is a condition in which the fleet size, as measured by the number of vessels or fishing power, is greater than the need for available fishing opportunities. It becomes a problem when it puts pressure on fisheries managers to allow more fishing, provides greater opportunity for IUU fishing, or results in higher than necessary capital costs for fishing firms. The analysis here considers fleet size in terms of the capital stock of the fishing fleet, and measures the potential effect of policies according to the amount that this changes.

Support based on vessels can increase fleet size by as much as 8% in response to the policy shock, while support based on variable inputs actually reduce it slightly (if a TAC is in place) (Figure 3.7). Increased fleet capacity in the model in response to increased support is an indication of the potential for a policy to cause overcapacity.

When a change in a policy transfer increases effort, it also increases demand for all inputs, including vessels. That is, there is a general effort-driven demand for fishing vessels. However, there is an important compositional effect as well, where policies can affect the cost of capital for vessels relative to other costs faced by the fishing firm. When policies reduce the relative cost of vessel capital, vessels will become a larger part of the input mix. When policies increase the relative cost of vessels, by providing support for other inputs such as fuel or gear, the relative share of vessels in total cost declines.

Figure 3.7. Payments based on vessels increase fleet capacity the most

This figure shows the change in the quantity of vessel capital used in response to the policy shock of USD 5 billion by policy type. All policies increase capacity under open access, if only slightly, but payments based on vessels lead to the largest percentage increase in fleet size. Payments based on income have the next highest effect, but is less than half as likely to provoke overcapacity.

Note: There are two effects at play here: an expansion effect where increased effort leads to increased fleet size, and a composition effect where vessel costs are reduced relative to other inputs when support based on vessels is provided. This composition effect is in reverse where support is provided to inputs other than vessels, which tend to reduce the importance of fishing vessels in the overall cost structure as fishers use more of the supported inputs.

Source: OECD FishPEM model.

Support based on vessel use has the greatest impact on the fishing fleet. Payments based on vessels, output, or fishers' income increase the importance of the capital stock of vessel in the production mix of fishing operation, while other forms of support reduce it.¹⁶

The large segment increases fleet capacity more than does the small segment in response to increased support to fishing vessels (Figure 3.8 and Figure 3.9). The large fleet also increases fleet size in response to increased support based on fuel under open access. The large change in their effort caused by this type of support is enough to overcome the compositional effect from relative input prices, which acts in the opposite direction. Otherwise the effects are similar; small changes resulting from all policies except for vessel-related support.

¹⁶ Scrapping or decommissioning schemes will add a constraint on use of vessels, effectively mandating reduced investment. This effect is not accounted for in the model so the results for such policies as a separate category of support may be different. How different the results would be depends on the amount of existing excess capacity and the effectiveness of controls on fleet size connected with the policy.

Figure 3.8. Change in vessel quantity under open access by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percent change in “vessel” input quantity. Not surprisingly, payments based on vessels have the largest impact on their use. The sensitivity analysis reveals some variability on the impact of transfers based on vessels for the large segment, though this does not affect the ranking, only the magnitude.

Note: The indicator is the quantity demanded of the input “vessels”. All inputs are flows in the model, so this input is equal to depreciation and maintenance for vessels.

Source: OECD FishPEM model.

Figure 3.9. Change in vessel quantity under a TAC by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percentage change in “vessel” input quantity. Payments based on vessels have the largest effect on fleet size, with a pattern of effect across policies similar to that seen under open access.

Note: The results are driven by the effect of the policy transfer on the relative price of vessels (in the sense of the user cost of capital) versus other inputs. That is, the composition effect. The scale effect resulting from the change in fishing effort is smaller under a TAC than for open access.

Source: OECD FishPEM model.

Figure 3.10. Change in vessel quantity under a derby TAC by segment, percentage

Results from an increase of USD 5 billion in support, by support type, expressed in percentage change in “vessel” input quantity. Payments based on vessels has the largest impact on fleet capacity; those based on the use of fuel the least.

Note: The results here broadly mirror that for open access, though there is more variability shown from the sensitivity analysis.

Source: OECD FishPEM model.

3.4. Relative effects of fisheries policies on incomes for fishers

The different effects of policy transfers on income depend on the nature of the policy and the management system that is in place. A TAC that effectively controls effort results in policy transfers being uniformly more effective at increasing fishers' income than in the case of open access (Figure 3.11). This is measured as “transfer efficiency”, the percentage of a policy transfer that accrues as higher income for fishers. The average transfer efficiency of the six policies considered in the analysis when a TAC is in place is 75%, but drops to 35% under open access to fisheries.

Transfers based on the use of fuel are the least effective means of the six tested here at increasing the income of fishers. Less than 10% of the value of this transfer winds up in the pockets of fishers under open access. This rate improves under a TAC, where about half of the transfer ultimately benefits fishers. The rest is lost to increased fishing effort or is captured by other sector participants.¹⁷

The most effective type of policy to improve the income of fishers is that based on income itself. Combined with a TAC, this kind of policy can have a transfer efficiency as high as 90%, so 90 cents of every dollar spent on such policies end up as income for fishers.

¹⁷ Other sector participants are providers of inputs such as those selling fishing gear, fuel, or any other item purchased by fishers.

Figure 3.11. Policies based on the use of fuel provide little benefit to fishers; others do better

Results from an increase of USD 5 billion in support, by support type. Transfer efficiency, shown here is the percentage of the policy transfer that accrues to fishers as additional income. An efficiency of 100% indicates a perfect transfer—one euro spent by government equals one euro net benefit to fishers. The results here vary between 90% for payments based on income under a TAC, to less than 10% for subsidies based on fuel in the case of open access.

Note: TACs control effort, and thereby change how fishers respond to policies that lower their costs. This tends to reduce any negative distortions in economic behaviour induced by the policy, increasing the transfer efficiency.

Source: OECD FishPEM model.

Transfer efficiency reflects the overall welfare change for all types of fishers. The transfer generated by policy support can be further decomposed into its effects on different sector participants. Four potential beneficiaries are identified in the analysis:

- Licence or quota holders (resource rent generated in the fishery)
- Vessel owners (the input “vessels”)
- Vessel operators (the input “fishers’ own capital”)
- Crew members (the input “crew”)

The distribution of benefits across these four sector participants follows the initial incidence of the policy type—the input market first affected by the policy transfer (Figure 3.12). Payments based on vessels are quite transfer-efficient but result in income transfers that are highly concentrated on vessel owners, especially those in the large fishing segment who capture more than 90% of the benefits delivered by this transfer. Payments based on fishers’ own income are next in terms of transfer-efficiency, but again this is highly concentrated on vessel operators.

Under open access, fishers tend to increase effort when policy transfers lower their costs. The additional costs they bear to do this, combined with the reduction in catch per unit effort, reduces the net value of the policy transfer. The policies that are most effective at improving fishers’ income under open access still only deliver about half of their value as income. Solving the fisheries management problem therefore appears as a pre-requisite to effective income support policies.

Figure 3.12. Change in income under open access by beneficiary and segment, USD Billions

Results from an increase of USD 5 billion in support, by support type. Payments based on vessels transfer the largest amount to the sector, but almost entirely to vessel owners in the large segment. Payments to fishers' own capital or based on fishers' income are more balanced between sectors, and payments based on income are more equally shared among beneficiaries.

Note: The policy shock is USD 5 billion, so a value of 5 in this graph would represent 100% transfer efficiency, 4 would be 80% and so on. Under open access, no resource rents are generated by the fishery. This is the standard result of the open access problem where fishers expand effort until total revenue equals total cost. Payments based on fishers' income are assumed to benefit owners, operators and crew while payments based on fishers' own capital target operators and payments based on vessels target owners.

Source: OECD FishPEM model.

Payments based on fishers' income have a transfer efficiency of about 46% under an open access regime, but deliver their benefits much more evenly across different stakeholders and are also relatively balanced between the large and small segments. Payments based on the use of variable inputs or fuel perform poorly in terms of increasing incomes for fishers; fuel subsidies actually make vessel owners and operators in the small segment worse off than they would be without the support. The net transfer efficiency of support based on fuel for both segments is only about 9%.

By moderating the increase in effort provoked by a policy support increase, TAC reduces both deadweight losses and resource inefficiency. The TAC also maintains a situation in which the revenues from fishing are higher than the costs, producing resource rents for licence and quotas owners, which are calculated as unit rents (price minus marginal cost)

times harvest.¹⁸ Policies can only increase resource rents when an appropriate TAC is in place.

Four of the six policies considered reduce welfare for at least one type of sector participant (Figure 3.13). In general, a TAC results in the benefits of support shifting from producers' surplus towards resource rents. Who captures these resource rents determines the ultimate distribution of benefits of support policies. Typically, it is assumed that resource rents become capitalised in the value of licences or quotas, or in the value of fishing vessels with access rights to the resource. This depends on the nature of tenure rights for resource access.¹⁹

Figure 3.13. Change in income under a TAC by beneficiary and segment, USD billions

Results from an increase of USD 5 billion in support, by support type. Payments based on fishers' income deliver the most benefits to the sector. Increased resource rents account for most of the welfare gain for all policy types except for transfers based on vessels. Transfers based on fuel use almost exclusively benefit the large segment.

Note: Unlike open access, fisheries under a TAC generate resource rents. Lowered production costs increase rents, but changes in effort and cross-effects can influence their distribution.

Source: OECD FishPEM model.

¹⁸ See Figure 2.2

¹⁹ Tenure rights are key to determining who captures resource rents. In general, the value of rents are capitalised in the value of the licence or quota. If there is some reason why the price of these cannot increase as rents change, the value tends to be captured in the value of the most fixed input in production attached to the resource—probably fishing vessel prices.

Payments based on vessels or fuel mainly benefit the large segment, which is not only larger, but also specialised in fuel use. Payments based on income or fishers' own capital provide more benefits to the small segment, though the large segment still captures the majority of benefits. Given the relative size of the segments, a proportional distribution of the benefits occurs when 75% is captured by the large segment (Figure 3.14).

Figure 3.14. Distribution of benefits of support by type

This figure shows the share of benefits of support to the large and small segments and between groupings of asset owners versus skippers and crew resulting from an increase in support of USD 5 billion by support type. A TAC increases the transfer efficiency (larger points in the figure are more transfer efficient), but also result in more of policy benefits accruing to resource rents, which benefit those with tenure rights or who own capital associated with the fishery. Payments based on fishers' own capital under a TAC provide a nearly equal distribution of benefits in both dimensions.

Note: The dotted lines denote equal distribution of benefits. On the horizontal, that is drawn at the point where 50% of benefits accrue to crew and operators and 50% accrue to licence or vessel owners. For the vertical axis, it is drawn where 75% of the benefits accrue to the large segment, as this segment harvests 75% of the resource. *Source:* OECD FishPEM model. The share of benefit for support to fuel under open access management conditions is an outlier that sits in the top left of the plot (236% to large segment, -2.9% to crew and operators) and has been excluded to improve readability.

The sector does not generate resource rents under a derby fishery, and this remains the case after an increase in support. Any reduction in costs is lost to increased inefficiency of input use as fishers race to catch the TAC (Figure 3.15).

For a derby TAC, the pattern of benefits largely mirrors that for open access, because in both cases there are no resource rents generated and the benefits accrue to producer surplus for fisher-owned inputs. Under a derby TAC however, effort remains constant and so the

slight redistribution of effort towards the large segment seen in open access does not occur. For this reason, the benefits of support are shared more equally.

Figure 3.15. Change in income under a derby TAC by beneficiary and segment, USD billions

Results from an increase of USD 5 billion in support, by support type. The welfare benefits of policy support under a derby TAC are very similar to those under open access, with slightly more benefit being received by the small segment.

Note: Welfare benefits are similar to open access, the difference being that resource inefficiency losses are removed in a derby TAC, as effective effort remains constant even as input use increases.

Source: OECD FishPEM model.

3.5. An experiment in shifting support

The results show in general that support based on the use of variable inputs or fuel have the most negative impacts on the fishery, while those based on fisher's own capital are relatively benign. The FSE contains an estimation of the level of support to variable inputs and fuel totalling approximately USD 5.4 billion in 2015, while only USD 200 million is recorded as payments based on capital.²⁰ An experiment where all support currently delivered for fuel or inputs is shifted to support for capital was carried out. The total level of support is unchanged in this experiment.

The results show that shifting the basis of support as such could improve stocks by 1.3%, increase harvests by 440 000 tonnes per year and increase income for fishers by USD 2

²⁰ The FSE covers 38 countries representing about half of global fishing harvests, so this experiment does not cover the entirety of global support for fuel or input use.

billion (Figure 3.16). Harvests of fish increase even as effort decreases, due to the improved condition of the fish stock.

Figure 3.16. Shifting the basis of support can increase stocks and income for fishers

This figure shows the percentage change in effort, harvest, stock and fleet size in percentage, and the change in fishers' income in USD billions of shifting fuel support to support based on fishers' own capital. The top panel is when a TAC is in place, the bottom is open access. Changing the basis of support increases stocks, harvest and income while reducing fishing effort. The small segment is the main beneficiary of the change in the structure of support, though the big segment also sees its income increase.

Note: The results shown in this figure are the consequence of shifting USD 5.37 billion in support from fuel or inputs to fishers' own capital. The income change is the result of the increased transfer efficiency of the latter form of support. The shift in effort and harvest towards the small segment is because the support for fuel and variable inputs had previously favoured the big segment, while payments based on capital are more neutral.

Source: OECD FishPEM model

Under both open access and TAC management, both large and small fishing segments are made better off by shifting the basis of support. The net gain is USD 2.4 billion under open access and USD 1.2 billion under a TAC. However, the small segment benefits relatively more and sees its effort and harvest increase, while that for the large segment decreases slightly. The shift in effort and harvest in favour of the small segment is because the previous support mix had favoured the large segment more. Moving to a form of support that provides a more level playing field for the two segments allows the smaller segment to gain a larger share of the fishery.

This experiment shows that the basis of support is at least as important as its level in terms of risks of overfishing and delivering benefits to fishers. It is possible to obtain significant improvements without reducing overall support, and possible to reduce support without harming fishers.

3.6. Summary and conclusions

This study has investigated how an increase in the level of support provided via six different policy types affects effort, harvest, stocks, fleet size and fishers' income. An increase in effort can lead to overfishing, leading to an overfished stock. When a policy encourages effort beyond that allowed by fisheries management controls, the result is increased IUU fishing, which caused long-term harm to all those engaged in the fishery by depleting the resource base upon which legal fishers depend.

The results show that fisheries support policies can provoke overfishing, lead to fish stocks being overfished, encourage IUU fishing or increase fleet capacity. However, fisheries policies are not uniform in their effect on these things, and they can affect different fishers in different ways, even if no distinction between fishers is made in how they are implemented.

Support based on the costs of fishing, such as aids to purchase fuel, gear or bait, can increase fishing effort more than other policy options. These types of support are the most likely to increase IUU fishing effort and to lead to stock depletion. They also tend to favour larger fishers, to the point where others in the fishery may be worse off after a support is increased.

Most of the policies investigated have only a small likelihood to promote overcapacity; payments based on vessels are a notable exception. While other policies increase fleet capacity as a consequence of increased fishing effort, payments based on the construction or modernisation of vessels encourage fishers to invest more in the fleet for a given amount of fishing effort.

Depending on the management context, many common policies are relatively inefficient at improving fishers' livelihoods. In particular, as little as 10% of government expenditures to reduce the cost of fuel for fishers translate to real income gains. The potential benefits of such transfers are lost to increased effort and lower fish stocks or are captured by input suppliers rather than fishers. Having an effective TAC in place generally increases the benefits of support to fishers.

By contrast, payments based on fishers' own capital performed well in terms of transfer efficiency while having relatively benign effects on effort and capacity. These payments are designed to improve the profitability of fishing operations and include for example policies designed to support efficient business operations and develop human capital.

Payments that directly target fishers' incomes such as disaster payments or employment insurance also deliver significant benefits to all participants in the fishing sector.

The relative effects of each policy type can be seen by expressing their effect as a percentage of the policy with the largest impact on the outcome of interest. For example, payments based on input use has the largest effect on effort. All other policies' impacts on effort can be expressed as a percentage of the effect of those payments. So if an increase in payments based on vessels results in an increase in effort half as large, it would have a value of 0.5. Doing this for all four impacts considered in this report allows the results shown in Figures 3.1, 3.4, 3.7 and 3.11 to be summarised in a single figure (Figure 3.17).

Figure 3.17. Ordering of policy impacts by type

This figure shows the relative performance of the six policy types considered with respect to four indicators for open access (panel a) and TAC (panel b). Support based on fuel use provide the least benefit to fishers' income while having a relatively high chance of provoking overcapacity and overfishing. Payments based on fishers' own capital generally have the lowest negative impacts while delivering significant benefits to fishers.

Note: The impacts of each policy category are normalised in this figure so that the policy with the largest impact has a value of “1” and all others are expressed as a proportion of the effect of that policy. For example, for capacity, payments based on fishers' income has a value of 0.4, showing that its effect on fleet size is 40% of that of payments based on vessels. Four possible impacts are listed on the X axis—fishing effort, fleet capacity, fishers' income and stock size. A higher number indicates a greater impact. For example, payments based on variable input use have the largest impact on fishing effort and reduce stock size the most.

Source: OECD FishPEM model.

In the 2017 report *Support to Fisheries: Levels and Impacts*, a hypothetical rank ordering of the effects of different policy types was produced (OECD, 2017_[14]).²¹ This analysis updates and improves upon that early estimate by applying an empirically-based rigorous theoretical approach to this question. The picture is complex, but the results show a clear separation between policies that are based on what fishers *buy* (fuel, other inputs) and what fishers *own and do* (vessels, capital, income). The former tend to pose the greatest risk to overfishing and depletion of fish stocks while the latter provide the greatest benefits to fishers.

²¹ See Table 4 of that report.

The results overall show that it is possible to support the fishing sector and deliver benefits to fishers without provoking overfishing or overcapacity. Moving the basis of support away from gear, fuel, vessels or other inputs toward ensuring that fishers have access to working capital, have the skills needed for their businesses and helping fishers deal with disasters can bring greater benefits to fishers at lower cost to government, all the while reducing the negative impact of support on the sustainability of fish stocks.

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Annex A.

Further detail on the FishPEM model

The FishPEM is a partial equilibrium model of the fishing sector based on the existing OECD Policy Evaluation Model (PEM). The basic analytical structure for the PEM was elaborated in (Gardner, 1987_[19]). First developed by Hicks to study issues in labour economics, the model has been widely applied in general economic policy analysis. An important first application of this type of model was in an analysis of housing and urban land economics by Muth. Its application for the FishPEM follows most closely applications found in (Atwood and Helmers, 1998_[20]), (Gunter, Jeong and White, 1996_[21]), and (Hertel, 1989_[22]).

The bio-economic features of the model follow the Gordon-Schaefer model (Gordon, 1954_[23]; Schaefer, 1957_[24]). The specific biological growth function used comes from the model developed by Ragnar Arnason for the World Bank (World Bank, 2017_[12]). The IUU fishing component draws on the economics of crime and punishment, the basis of which are the work of Becker (Becker, 1968_[25]) and Stigler (Stigler, 1971_[26]).

The model is based on the principle of equilibrium displacement (Gardner, 1987_[19]). The model is calibrated to be in equilibrium in its initial state, with supply equal to demand in all markets and the biological effort-yield relationship at its long-term equilibrium point. This initial condition is perturbed by a policy shock, which results in a re-adjustment to a new equilibrium.

The FishPEM is a medium-run model, so there are no fixed inputs. All inputs may be varied in the quantity used, and all are substitutes. The closest analogue to fixed costs in the model is the differentiation between inputs that are inelastic in supply vs. those that are elastic. The main interest in different categorisation of inputs in FishPEM has to do with whether the input is owned by fishers or is purchased from an input supplier. This is because this largely determines the distribution of the benefits of support.

FishPEM currently provides a stylized representation of effort, harvest and consumption for a single species fish stock that is being exploited by a two fleet segments. Supply and demand behavioural relationships are combined with the equilibrium requirements that supply must equal demand to simultaneously clear all markets as well as maintain the fish stock in a steady-state. This system of equations is calibrated to replicate the global fishery in 2015.

A change in the value of an exogenous policy parameter, such as the level of support provided as transfers to variable inputs, output support or transfers based on fuel used can be introduced and the model solved for a new set of equilibrium values for all endogenous prices and quantities as a result of this change. This procedure is termed a policy simulation experiment and the change in support level is the related policy shock.

Constructing FishPEM required information regarding (1) the response of input supply and fish demand to price changes (2) the biology of the resource, including carrying capacity, maximum sustainable yield and current harvest (3) the technology used by fishers, (4) the level of policy support. Economic theory and results of previous studies guided choices about the structure of the model.

The classification of support measures in the FSE guided development of how policies are represented in the model. The purpose of developing the model is to provide a closer connection between measurement of support as done using the Fisheries Support Estimate (FSE) and quantitative analysis of the relative impacts and distribution of such support.

All the variables and parameters used in the model are listed and defined in Table A A.1, the model equations are then set out in Table A A.2. Factor input level data and elasticities, calibration parameters, variables and equations, and other supporting information are provided in Table A A.3 to Table A A.9.²²

FishPEM can represent a fishery under either open access (OA) conditions or one subject to a binding TAC. In the case of the TAC, the fishery may control individual effort, or allow fishers to compete to catch the allowable TAC (so-called derby or Olympic fishery). All differences in the parameters, variables and equations under these specifications are highlighted in the tables that follow and discussed in the accompanying text. Some parts of the model are common to all versions but have no practical effect; for example, there is no IUU fishing under open access even though the equations that determine this are present.

There are a number of future developments possible for the model. Adding a second fish stock would allow for spillover effects of support between different fisheries. Additional support categories would broaden the scope of policy investigation and advice. More management options will help refine the understanding of the interaction between management and the effects of support. Regional and local implementations of the model can refine the advice provided by the model for different contexts.

Model equations

The model comprises a set of equations and endogenous variables solved simultaneously, subject to exogenous parameters (Table A.A.1). There is an output market for fish, separate markets for inputs each with supply and demand, a Pella-Tomlinson growth function representing the fishery resource, and a set of equations representing individual policies. Two fishing sectors purchase inputs from the same suppliers of variable inputs (fuel, crew, other) and use segment-specific capital in the form of vessels and other owned capital assets.

²² The sensitivity of the model results to assumptions about elasticity values have been formally tested and are reported in full in Annex C of an expanded version of the document (TAD/FI(2018)2/FINAL), available from: <https://oe.cd/2qG>.

Table A A.1. Variables and parameters in FishPEM

Endogenous variables are	Stands for	Model specification
p^d, p^s	Demand and supply prices for fish	all
D	Quantity of fish demanded	all
E_s	Effort by segment s	all
Y_s	Yield (quantity of fish supplied) by segment s=large, small	all
X	Stock size	all
$x_{j,s}^d, x_j^s$	Input demand and supply quantities $j=1$ to 5 inputs; fuel (fu), vessels (ve), hired crew (hc), fishers' owned capital (oc), other purchased inputs (op). Demand is by segment s.	all
w_j^d, w_j^s	Input demand and supply prices	all
SR_{fs}, SR_{out}	Rate of support by policy variable (fs) and output (out)	all
SL_{fs}, SL_{out}	Level of support by policy variable (fs) and output (out)	all
TAC	Total Allowable Catch	binding TAC only
MC	Marginal cost of effort	binding TAC only
$IUU\%$	Share of effort coming from IUU fishing (excess of effort above that which produces TAC harvest)	binding TAC only
δ	Technical inefficiency generated by race to fish	Derby TAC only
Policy variable symbol	Stands for rate of	
inc_j	Transfers based on fisher's income ($j = ve, hc$ and oc)	all
var_j	Transfers based on variable input use ($j = fu, hc$ and op)	all
$fuel$	Transfers based on fuel use	all
cap	Transfers based on fixed capital formation	all
ves	Transfers to vessels	all
out	Transfers based on quantity harvested (output)	all
Exogenous parameters are	Stands for	
r	Intrinsic growth rate	all
K	Carrying capacity	all
γ	Pella-Tomlinson skewness parameter for growth function	all
q	Catchability coefficient	all
η	Demand elasticity for fish	all
$c_{j,s}$	Cost share of input j in producing fishing effort for segment s	all
$\sigma_{ij,s}$	Input elasticity of substitution between input i and j for segment s	all
ε_j	Input elasticity of supply for input j	all
$FINE$	Penalty (fine) for IUU fishing	binding TAC only
θ	IUU probability of control parameter	binding TAC only
sk_{fs}, sk_{out}	Support shock to policy variables (fs), output (out)	all
sk_{TAC}	Support shock when there is a TAC	binding TAC only
$tfi_{j,fs}$	Transfers mapped to individual inputs	all

Table A A.2. FishPEM model equations

Equations (dot above variable indicates percentage change) are		Model specification
<i>Output market:</i>		
$P^d = P^s - SR_{out}$	Demand (consumer) price for fish in the output market	all
$\dot{D} = \eta \dot{P}^d$	Consumer demand for fish in the output market	all
$D = \sum_s Y_s$	Output market equilibrium	all
<i>Input market:</i>		
$\dot{x}_j^s = \varepsilon_j \dot{w}_j$	Input supply. Supply of vessels and capital also segment-specific and so indexed on s.	all
$\dot{x}_{j,s}^d = \sum_i c_{i,s} \sigma_{ij,s} \dot{w}_i + \dot{E}_s$	Input demand for segment s	all
$\dot{x}_j^s = \sum_s \dot{x}_{j,s}^d$	Input market equilibrium condition	all
$w_j^d = w_j^s \sum_{fs} (SR_{fs} \Leftarrow t f i_{j,fs} = 1)$	Input market demand price ($t f i_{j,fs} = 1$ denotes only the selection of cases where transfers accrue to specific individual inputs)	all
$Y_s \cdot P^s = \sum_j x_j w_j + FINE * IUU\%_s^{1/\theta}$	Zero-profit condition including expected fine from IUU fishing. IUU% proxies the probability of being caught.	All (IUU only in binding TAC)
$IUU\%_s = \left(\frac{[(E_s - \bar{E}) + ABS(E_s - \bar{E})]}{2} \right) / \bar{E}$	Share of effort that is above the TAC, in percent, by segment ($\bar{E} = TAC$)	binding TAC only
$P^s > MC \Rightarrow (Y - Y0 - sk_{TAC}) = 0$	Endogenization of a binding TAC	binding TAC only
<i>Biology:</i>		
$Y_s = q E_s \left(r - \frac{q E_s}{\beta} \right)^{\frac{1}{r-1}}$	Yield (harvest) as a function of effort for segment s from Pella-Tomlinson growth function	all
<i>Support:</i>		
$sk_{fs} = 0 \Rightarrow$ $\left(SL_{fs} = SR_{fs} \sum_s \sum_i (x_j^s w_j^s \Leftarrow t f i_{j,fs} = 1) \right)$ $\wedge (SL_{fs} = SL0_{fs} + sk_{fs})$	Support shock level (at the policy variable level)	all
$sk_{fs} = 0 \Rightarrow$ $(SR_{fs} = SR0_{fs})$ $\wedge \left(SR_{fs} = \frac{SL_{fs}}{\sum_i^n (x_j^s w_j^s \Leftarrow t f i_{j,fs} = 1)} \right)$	Support shock rate (at the policy variable level)	all
$sk_{out} = 0 \Rightarrow (SL_{out} = SR_{out} Y)$ $\wedge (SL_{out} = SL0_{out} + sk_{out})$	Output support level	all
$SK_{out} = 0 \Rightarrow$ $(SR_{out} = SR0_{out})$ $\wedge (SR_{out} = SL_{out}/Y)$	Output support rate	all

Note: Variables ending in “0” indicate the baseline (initial) value of that variable, before any policy shock. Consumer demand $D = Y$ (harvest) if there is no trade. For equations where the form may depend upon the value of another parameter or variable, e.g. in the equation for support shock level, logic notation is used to indicate that if a given condition is met ‘then’ ($\Rightarrow$), and where an alternative is relevant ‘otherwise’ ($\wedge$).

Most policies relate to inputs and produce wedges between the supply and demand price for specific inputs or groups of inputs. Support based on output results in a wedge between the demand and supply price of fish. The indicators produced by the model are either directly observed from the endogenous model variables or calculated *ex post* after a model run and are not represented as endogenous model equations or variables. The following paragraphs provide some more detail on the specific equations in the model.

In the output market for fish, equilibrium is imposed by setting consumer demand (D) equal to production (Y). The demand price of fish (P^d) is equal to the supply price (P^s) less any output support, with these prices endogenously determined. The demand for fish is represented by a downward sloping demand function with elasticity η .

Fishery yield per segment (Y_s), also commonly termed “harvest”, is determined directly through the yield function, on the basis of effort (E_s) and a set of exogenous fishery-specific parameters (q , K , r and γ). In the input market to produce fishing effort, a system of input demand ($x_{j,s}^d$, w_j^d) and input supply (x_j^s , w_j^s) equations represent demand and supply responses for five categories of inputs used in the fishing process. These input demand equations reflect the usual assumptions of profit maximisation constrained by the production relationship. The supply of fishing effort (E_s) is embedded in the equations that determine equilibria in these input markets.

No fishery inputs are entirely fixed in production and all inputs are substitutes, the input elasticities of supply reflect the assumption that vessels and fishers’ own capital are relatively more fixed than hired crew and the purchased inputs fuel and other purchased inputs – so have been assigned lower input elasticities of supply (Table A A.5). A supply response corresponding to a medium term adjustment horizon of three to five years is reflected in the values assumed for the price elasticities of input supplies and the parameters measuring the substitutability of inputs in production as well as the input shares.

The two fleet segments in the model are designed to represent generically “large” and “small” fishing operations. The two segments are differentiated to highlight different characteristics of fishing operations in the following way:

- The large segment is relatively fuel-intensive in production, while the small segment is relatively labour-intensive.
- The large segment has more flexibility in factor use. This is reflected in the model as $\sigma_{ij}^{industrial} > \sigma_{ij}^{coastal}$ for all inputs i and j . This implies a superior production technology.
- The large segment catches 75% of the total harvest in the base case.
- The large segment is less penalised for IUU fishing as a share of revenue.

When a TAC is present, fishers may still choose to exert effort beyond that which would produce it. The basic decision rule for this is that fishers will set:

$$Y \cdot P^s = \sum_j^n x_j w_j + E(Fine).$$

That is, fishers will add effort until the total revenue from fishing equals the total cost, including any expected fines from IUU fishing. $E(fine)$, the expected fine, equals the fine for IUU fishing times the probability of being caught. This is expressed as follows:

$$E_s(Fine) = Fine * IUU\%_s^{1/\theta}.$$

The probability of being caught equals the proportion of effort exerted by each segment that is IUU (that is, above that implied by the TAC), modified by a scaling parameter θ . when $\theta > 1$ the probability is greater than the share of effort that is IUU.

If the fine is zero, fishers will ignore the TAC and fish at the open access level where total revenue equals total cost. If the fine is very large, fishers will reduce the probability of being caught by doing less IUU fishing, with the limit case being they obey the limit set by the TAC. The fine is set such that the initial level of IUU fishing is about 15%, a relatively conservative amount below recent estimates (Agnew et al., 2009_[7]).

For the equations relating to fishery support, the relationship between quantities, levels and rates of support follow the basic relationship of *level=rate*quantity*. The way that levels of support (*SL*) are calculated differs slightly depending on how it accrues in the fishery but the basic principle remains. In the absence of a shock to a policy category, its rate of support is fixed and the level is found by multiplying that by quantity. In the case of a policy shock, the level of support is fixed and the rate is found by dividing the level by quantity.

The growth function in the model is of the form:

$$G(X) = rX - \beta X^\gamma.$$

This is termed the Pella-Tomlinson growth function and is a variation of the logistic growth function that is typically used for Gordon-Shaefer style models. The parameter γ represents the degree of skewness; if $\gamma=2$ then the standard logistic model is recovered (and β will equal r/K). It is commonly assumed that $\gamma < 2$ (Branch, Hively and Hilborn, 2013_[27]; Pella and Tomlinson, 1969_[10]), reflecting a situation where MSY is achieved at a stock size less than half of the carrying capacity of the stock.

The MSY stock size and carrying capacity of the resource, along with γ , are used to calculate the parameters r and β as follows:

$$r = \left(\frac{MSY}{K}\right) \left(\frac{\gamma}{\gamma-1}\right), \quad \beta = \left(\frac{MSY}{K^\gamma}\right) \left(\frac{\gamma}{\gamma-1}\right).$$

Yield comes from the standard approach where harvest is a function of effort times stock size times a catchability coefficient:

$$Y = qEX.$$

At the steady state, $Y=G(X)$ such that harvest equals the growth rate of the stock. With observed values of Y and X and with E normalised to one, q can be easily found. This harvest function can be solved for Y as a function of E only by substituting the growth function into the above equation and simplifying:

$$qEX = (rX - \beta X^\gamma) \rightarrow Y = qE \left(\frac{r-qE}{\beta}\right)^{\frac{1}{\gamma-1}}.$$

This relation between Y and E is how the growth function is implemented in the model. Stock size, X , can be recovered ex-post using either Y or E . Yield by segment is found by the following:

$$Y_s = qE_s \left(\frac{r - q \sum_s E_s}{\beta}\right)^{\frac{1}{\gamma-1}}$$

Model data and calibration

Before the model can be run and the impacts of any policy shocks tested initial starting values for the main parameters and variables must be either assigned or calculated. All variables or parameters ending in “0” indicate that it is the baseline (initial) value of that variable or parameter. These represent conditions in the fishery in its initial equilibrium state, before any policy shocks have been introduced (the baseline). Changes between the baseline values and those that result from a policy shock are then used to calculate the set of indicators discussed in Section 3.

Table A A.3. FishPEM calibration variables, parameters

Endogenous variables are	Stands for	Source
$SR0_{fs}$	Subsidy rate for each policy in the base period	Calculation
$w0_j^d$	Input demand price in the base period	Calculation
$x0_j^d$	Input demand quantity in the base period	Calculation
Exogenous parameters are	Stands for	
$r = 1.644$	Intrinsic growth rate	Calculation
$K = 980$	Carrying capacity (million tonnes)	World Bank
$q = 0.378$	Catchability coefficient	Calculation
$\gamma = 1.188$		World Bank
$X0 = 244.2$	Benchmark stock size in the open access specification (million tonnes)	Calculation
$P0^s = 1.59$	Benchmark supply price (USD/kg)	OECD/FAO
$P0^d = P0^s - SR0_{out}$	Benchmark demand (consumer) price for fish	Calculation
$SL0_{fs}, SL0_{out}$ = please refer to	Benchmark support level to policy variables (<i>fs</i>) and output (<i>out</i>)	OECD FSE
$SR0_{out} = \frac{SL0_{out}}{Y0}$	Benchmark output support rate, equals level of support divided by yield	Calculation
$w0_j^s = 100$	Benchmark input supply prices	Index
$\eta = -1.2$	Demand elasticity for fish	Assumption
c_j = please refer to Table A A.5	Cost share of input <i>j</i> in producing fishing effort	STECF
σ_{ijs} = please refer to Table A A.6 for the values	Input elasticity of substitution between input <i>i</i> and <i>j</i> , by segment <i>s</i>	Mardle 2018
ε_j = please refer to Table A A.5	Input elasticity of supply for input <i>j</i>	Assumption
$tfi_{j,fs}$ = please refer to Table A A.7	Transfers mapped to individual inputs	Design
$tfi_{j,fs} = 1 \Rightarrow$	Share of each support category that accrues to a particular input: $sh_s_{j,fs}$ (<i>j</i> * <i>fs</i> matrix)	Calculation
$sh_s_{j,fs} = \frac{c_j}{\sum_j (c_j \Leftarrow tfi_{j,fs} = 1)}$		
$E=1$	Effort in the base period	Normalisation
$Y0 = 92.3$	Yield in the base period (million tonnes)	OECD/FAO
$IUU\% = 15\%$	Share of fishing effort that is associated with IUU	Assumption
$IUU\ fine = 150$	Fine for IUU fishing (USD billion)	Calculation
$\theta = 2$	Scaling parameter for IUU fine probability	Assumption

Note: Variables ending in “0” indicate the baseline (initial) value of that variable, before any policy shock. For equations where the form may depend upon the value of another parameter or variable, e.g. in the equation for effort in the base period, logic notation is used to indicate that if a given condition is met ‘then’ ($\Rightarrow$), and where an alternative is relevant ‘otherwise’ ($\Leftarrow$). “World Bank” refers to (World Bank, 2017_[12]), OECD/FAO refers to (OECD/FAO, 2018_[13]), STECF refers to (Carvalho et al., 2017_[17]), OECD FSE refers to (OECD, 2017_[14]).

Table A A.4. FishPEM calibration equations

Equations are	Stands for	Model specification
$SR0_{fs} = \frac{SL0_{fs}}{\sum_j^n (x0_j^d w0_j^s \Leftarrow t f i_{j,fs} = 1)}$	Rate of support in the base period by policy where: $t f i_{j,fs} = 1$ denotes only the selection of cases where transfers accrue to specific individual inputs	All
$w0_j^d = w0_j^s (1 - \sum_{fs}^n (SR0_{fs} \Leftarrow t f i_{j,fs} = 1))$	Input demand price	All
$x0_j^d = \frac{Y0 P0^s c_j}{w0_j^d}$	Input demand under the open access specification	OA only
$x0_j^d = \frac{Y0 M C0 c_j}{w0_j^d}$	Input demand under the binding TAC specification	Binding TAC only

Note: Variables ending in “0” indicate the baseline (initial) value of that variable, before any policy shock. For equations where the form may depend upon the value of another parameter or variable, e.g. in the equation for rate of support in the base period, logic notation is used to indicate that if a given condition is met ‘then’ ($\Rightarrow$).

External data is used to provide initial values to the following sets of economic parameters and variables using available data:

- input cost shares (c_j),
- elasticities of supply (ε_j),
- demand elasticity for fish (η),
- initial supply price of fish ($P0^s$),
- initial levels of support ($SL0_{fs}$, $SL0_{out}$) and
- initial yield ($Y0$)
- carrying capacity (K),
- point of maximum sustainable yield (MSY)
- the parameter γ of the Pella-Tomlinson growth function.

In addition to these initial values, the level of effort corresponding to open access is normalised to one and input supply prices ($w0_j^s$) are normalised to 100.

The above listed parameters and variables are used to calculate all remaining required parameters and variables to ensure the model is calibrated to an initial equilibrium state. Both the specific assigned start values (e.g. $K = 980$) and the calculations undertaken to arrive at the remaining parameter and variable values are provided in the tables in this Annex (Table A A.3, Table A A.4, Table A A.7).

Support is currently introduced to the fishery through a set of specific policy variables. Output support acts as a wedge between supply and demand price while other support types accrue to individual inputs in specific ways, e.g. the policy ‘transfers based on fisher’s income’ (*inc*) accrues to vessels, hired crew and fishers’ own capital, whereas ‘transfers to fuel’ (*fuel*) only accrues to the input fuel (Table A A.7). Support is not targeted to specific segments in the model, only to the relevant inputs.

The level of support provided by a policy must be distributed across the inputs to which it accrues in order to determine the ad-valorem rate of support implied. This is done by allocating the support to a given input (sh_{sjfs}) according to the proportional contribution of its initial cost share (c_j) relative to the sum of the cost shares of all inputs to which the given policy (fs) accrues. This produces a rate of support that is equal for all relevant inputs such that the relative input prices stay the same. That is, the policy does not induce re-allocations among the factors to which it directed, only between those inputs receiving support and those that do not.

The rate of support to output ($SR0_{out}$) is calculated as the ratio of support to output in the base period ($SL0_{out}$) and baseline yield ($Y0$).

The baseline demand price ($P0^d$) and quantity ($D0$) for fish are then calculated. Demand price is calculated as the initial supply price of fish ($P0^s$) less the rate of support to output ($SR0_{out}$). Quantity of fish demanded is set to equal yield ($Y0$). Both large and small segments sell into the same market, so the demand price for fish is responding to the sum of the harvest for both segments, and fishers see a single common price for their fish.

Once all of the above values have been calculated a set of three equations are simultaneously solved to determine baseline values for the rate of support by policy variable and factor demand prices and quantities.

The rate of support for each policy variable ($SR0_{fs}$) is calculated by dividing the level of support ($SL0_{fs}$) by the total value of all the inputs (j) it accrues to (defined as sum of all relevant input quantities demanded multiplied by their supply price).

The quantity of each factor input demanded ($x0_j^d$) is determined by dividing the share of revenue associated with each input ($Y0 * P0^s * c_j$) by the baseline demand price for that input. This formulation is implied by the zero-profit condition--input expenditures exhaust revenue. The demand price for each input ($w0_j^d$) is determined by taking its baseline supply price (indexed at 100), and subtracting the rates of support that apply to that input. Each segment has its own demand for inputs, but share a common supply for some but not all inputs (Table A.5).

Table A A.5. Input level data and elasticities

Fishers purchase inputs from input suppliers or use their own capital. The input supply for vessels and fishers' own capital is specific to each sector, reflecting that these are heterogeneous. Purchased inputs (fuel, crew and other) are not differentiated by who uses them.

	Inputs	Elasticity of supply (ε_j)	Large segment cost share (c_{js})	Small segment cost share (c_{js})	Benchmark supply price ($w0_j^s$)
Fisher owned inputs:	Vessels (sector-specific)	0.5	0.25	0.10	100
	Fishers' owned capital (sector-specific)	0.5	0.15	0.20	100
Purchased inputs:	Fuel	2.0	0.30	0.1	100
	Other purchased inputs	2.0	0.10	0.20	100
	Hired crew	2.0	0.2	0.4	100

Input elasticities of substitution are informed by economic assumptions and a report by a consultant commissioned to shed light on this issue.²³ The report uses European cost data and a short-run framework to estimate Allen elasticities of substitution. This approach is only weakly informative for a global, medium term model, but it provides an indication that the set of elasticities in the previous version of the model may have assumed too great a difference in elasticities between fixed and variable inputs.

Table A A.6. Input elasticities of substitution (σ_{ijs})

Sector (s)	Inputs (j)	Fuel (fu)	Vessels (ve)	Hired crew (hc)	Fishers' owned capital (oc)	Other purchased inputs (op)
Large vessels	Fuel		0.6	0.4	0.6	0.4
	Vessels	0.6		0.6	0.5	0.6
	Hired crew	0.4	0.6		0.6	0.4
	Fishers' owned capital	0.6	0.5	0.6		0.6
	Other purchased inputs	0.4	0.6	0.4	0.6	
Small vessels	Fuel		0.4	0.3	0.4	0.3
	Vessels	0.4		0.4	0.3	0.4
	Hired crew	0.3	0.4		0.4	0.3
	Fishers' owned capital	0.4	0.3	0.4		0.3
	Other purchased inputs	0.3	0.4	0.3	0.3	

Note: Please refer to Table A A.3 to see how these values are calculated.

Table A A.7. Transfers mapped to individual inputs ($tf_{i,j,s}$)

Inputs (j)	Transfers based on:				
	Fisher's income (inc)	Vessels (ves)	Fixed capital formation (cap)	Variable input use (var)	Fuel use (fuel)
Fuel	0	0	0	1	1
Vessels	1	1	0	0	0
Hired crew	1	0	0	1	0
Fishers' owned capital	1	0	1	0	0
Other purchased inputs	0	0	0	1	0

Note: Read this table by column—for example, transfers based on fishers' income accrue to vessels, hired crew and fishers' own capital (indicated by "1") but not to fuel or other purchased inputs.

Introducing a TAC

The calibration of the model is initially made at the open access equilibrium where total revenue equals total cost at the given harvest level. At this point effort is normalised to one. After an initial calibration to find input demand quantities, prices and support rates, effort can be modified to reflect a TAC. The same revenue and cost function holds in all cases, only the initial equilibrium of the model differs (though for derby TAC there is an efficiency loss that changes the effective cost curve, though not the fundamental one).

Since effort and yield have a fixed relationship as described in the equation above, the TAC can equivalently be specified in terms of Y or E. In the current version, E is chosen to

²³ The report is reproduced as Annex D in an expanded version of the document (TAD/FI(2018)2/FINAL), at: <https://oe.cd/2qG>.

produce approximately MSY ($E=0.68$). Input quantities and prices are recalculated to produce this level of effort in a new equilibrium (Figure A A.1). This involves both the supply and demand functions for inputs as supply price adjusts to the new quantity of input demanded. This allows the same TC curve to apply to all versions of the model. On the revenue side, the demand price is also adjusted to reflect the new harvest level. This is an intermediate step, followed by either a cost adjustment in the case of a derby TAC, or determining the initial level of IUU fishing for a non-derby TAC. These calibration points are reflected in points B and C in the figure. The TAC is assigned by segment, with 75% allocated to the large segment, and is not tradable between segments.

In the case of a derby TAC, the idea is that the cost of producing a given amount of effort increases as fishers compete to catch the TAC. To calibrate the model, a parameter is introduced into the input demand function that will increase factor demand at a given effort level enough to set revenue equal to cost. This results in a new TC curve intersecting the revenue curve at point B on the figure.

Figure A A.1. Calibrating the model to different initial conditions based on management system

Calibration initially finds the point A corresponding to open access. Then a TAC is introduced and points B and C are found. For a derby TAC, the cost shifter than moves TC to point B is found. For a non-derby TAC, point D is found where some IUU fishing takes place.

Note: In the open access version, scenarios start from point A. For a derby TAC, they start at point B. For a non-derby TAC, they start at point D. Without IUU fishing, the non-derby TAC would generate equal to B-C if there was no IUU fishing, but IUU fishing eliminates these.

A non-derby TAC will produce rents equal to B-C on the figure. This reflects a price higher than marginal cost, which gives fishers an incentive to increase effort. This additional effort above the TAC is IUU fishing effort, which risks the payment of a fine. The fine is a fixed amount with the probability of payment increasing as the share of IUU effort in the total increases. Fishers will add IUU effort up to point D, where revenues equal total expected cost including the fine. Unless the fine is very large, the non-derby TAC will always have some IUU fishing associated with it.

To calibrate the model, the initial level of IUU fishing as a share of total is chosen and the fine set such that point D reproduces that amount. The probability of paying the fine is a function of the share of IUU fishing, modified by a scaling parameter to limit the amount of additional IUU effort produced in any policy scenario.

Representation of policies and policy shocks in the model

FishPEM translates changes in levels of support (“policy shocks”) to indicators of outcomes in the fishery, including on effort, harvest, fleet size and income. The set of possible policy shocks mirrors closely the categories in the FSE database (Table A A.8). The set of shocks will be refined over time to take better account of specific details such as contained in the FSE labels.

Policies create a difference between the supply and demand price in the market of first incidence of the policy, either input or output (termed a “policy wedge”). Some policy support may already be in place in the initial calibration of the model, and indeed the model will eventually be calibrated to reflect policy levels as reported in the FSE. A policy shock changes the level of support and therefore the size of the policy wedge.

Policy wedges may be calculated on a unit basis or an ad-valorem basis. A unit wedge is additive to the price, while an ad-valorem support is multiplicative. Wedges serve to lower the demand price of an input (or fish) below the supply price such that an input (or fish) is less expensive to purchase. The lower purchase price means that, *ceteris paribus*, more will be purchased. More inputs purchased translates to higher effort (Figure A A.2).

Table A A.8. Support shocks in the model

Type of support	Markets of primary incidence	Implementation
<i>Supports affecting input markets</i>		
To vessel construction or modernisation	Vessels	<i>Ad valorem</i> wedge between vessel supply and demand price
To decommissioning	Other fishers' owned capital, vessels	Proportional wedge between supply and demand price of both inputs, constraint on vessel quantity
To fishers' income	Other fishers' owned capital, vessels, hired crew	Proportional wedge between supply and demand price of these three inputs
To fuel use	Fuel	<i>Ad valorem</i> wedge between fuel supply and demand price
To crew	Hired crew	<i>Ad valorem</i> wedge between crew wage earned and paid
<i>Supports affecting output markets</i>		
To consumption of fish	Output market (fish)	Unit price wedge between consumer and producer price

Note: proportional wedges result in a uniform inflation of the affected input prices such that incentives to reallocate between them are unchanged. Three inputs (vessels, other fishers' owned capital and hired crew) are controlled by fishers and so the returns from these inputs collectively represent fishers' income in the model.

Figure A A.2. How a support level enters an input market

Policy support has its initial incidence in one or more input markets, changing the supply and demand price and quantity demanded for that input

Suppliers of inputs benefit as more inputs are purchased and their price increases. It is assumed that fishers own some of the inputs used (vessels, hired crew, other capital) and so the change in producer surplus for these inputs indicates the change in fishers' income. Notice for overall income changes, no distinction is made between vessel owners and crew, though this difference may be tracked and reported in the model output.

Some policies are assumed to accrue to more than one input. Payments based on fishers' income are a good example. This support is divided among these inputs using a single ad-valorem percentage rate. This is done so that the support payment does not induce any relative price changes between the beneficiary inputs. A uniform inflation of the price of these three inputs as a result of this form of support will change the allocation of these three inputs with respect to other inputs, but not among themselves.²⁴ This is an important feature of the model—supports that apply more broadly induce fewer adjustments across input use than supports that target a single input.

Indicators and model results

FishPEM is a medium-run model that represents a steady state system after all adjustments by economic actors have taken place and the biological system has reached equilibrium. Indicators produced from the model therefore reflect the changes that take place between an initial equilibrium and new equilibrium subsequent to a policy shock. The model is designed to represent an adjustment period of several years, long enough that that no factors are entirely fixed in production and that all inputs are substitutes. Elasticities in the model are more elastic than their short-run counterparts would be.

²⁴ Second-order effects in the model means this is not strictly true; changes in the price or harvest level resulting from income support could induce some relative changes in input demand, but these will not come from the initial incidence of the policy itself. Calculating a single ad-valorem subsidy rate applying many inputs that will account for the total subsidy level is not trivial, especially when more than one support type affects a particular input. This must be calculated numerically rather than solved analytically. However, this is only relevant for the initial calibration of the model.

Equilibrium in the model does not imply optimality in the sense of maximising an objective function (though this may in fact be done by definition to find an MEY equilibrium).²⁵ The model equations enforce the first order conditions for profit maximization and the zero profit condition, as well as the effort-yield-stock relationship defined by the growth function²⁶.

Indicators of interest are calculated as changes in endogenous variables in the model after a policy shock (Table A A.9. Changes in effort, stock, harvest (yield), use of inputs and welfare of fishers and others are systematically produced as a result of a policy shock, though other indicators may also be possible. It can as well be convenient to calculate some indicators in proportion to the size of the induced policy shock or as percentage changes.

Table A A.9. Indicators produced by FishPEM for this report

	Formula	Interpretation
Effort	$E-E_0$	Change in fishing effort, by segment
Stock size	$X-X_0$	Change in fish stock size
Harvest	$Y-Y_0$	Change in sustainable harvest level, by segment
Fleet size	$ve-ve_0$	Change in quantity demanded of input "vessels", by segment
Fishers' income	Sum of $(P_i-P_0)*(Q_{i0}+1/2*(Q_i-Q_0))$, $i='ve, hc, oc'$ + $(PY - \text{Sum}(P_i*Q_i)) - (P_0Y_0 - \text{Sum}(P_{i0}*Q_{i0}))$, $i='all'$ inputs	Change in producer surplus of inputs controlled by fishers or crew plus fishing rent
Transfer efficiency	Change in fishers' income/policy shock	Percentage of support that accrues to fishers as income

Note: Variables ending in "0" indicate the baseline (initial) value of that variable before the policy shock. Input names are vessels (by segment), hired crew, fishers' own capital (by segment), fuel, other purchased inputs.

The most complicated indicators are those for welfare changes. These are calculated as the sums of producer surplus of all relevant inputs (vessels, hired crew and other capital for fishers, fuel and other purchased inputs for input suppliers) (Figure A A.3). Input suppliers can generally be interpreted as other participants in the fisheries sector, those providing gear, dock services or similar. Differentiating between owned and purchased inputs allows these benefits to be allocated to fishers vs. other actors in the fisheries economy, providing a view on the distribution of benefits and the effectiveness of different policies in transferring income to fishers.

Resource rents, when they exist, are added to producer surplus to arrive at fishers' total income change²⁷. Such rent is generated when there is an effective control on harvest, such

²⁵ The model solves a set of n simultaneous equations in n unknowns, those unknowns being the endogenous variables in the model. This approach may but need not imply the optimisation of an objective function.

²⁶ The first order conditions for profit maximisation are implicit in the input demand functions, which are derived from the profit function of the firm by taking its derivative with respect to each input, setting it equal to zero and solving for input quantity demanded. The profit function itself need not appear in the model as it is fully characterised by the input demand functions.

²⁷ The zero profit condition is a standard assumption of competitive economic markets, but often seems to clash with observed data showing firms earning a gross margin (revenues over costs). This is reconciled here through the "fishers' own capital" input, which implicitly accrues this into its producer surplus. This may be considered as a return on fishers' investment (ROI) and is included in the fishers' income indicator through this input.

as through a binding TAC, and where there is not an incentive among individual fishers to compete away that rent by racing to fish. This rent is assumed to become capitalised in harvest rights that are possessed by fishers.

Figure A A.3. Change in producer surplus in an input market due to a policy shock

Note: The support policy induces a wedge between supply price (P_1) and demand price (P_0) which acts as a shifter of the demand function. The change in the area under the supply price and above the supply curve is the resulting change in producer surplus for the input owner. For simplicity, this figure is drawn as though there were no initial support to this input; however, this is usually not the case.

Annex B. Results tables

Managed under open access

Table A B.1. Model results under open access conditions

Indicator (change in)	Sector	Fishers' income	Fishers' own capital	Vessels	Use of variable inputs	Use of fuel	Output
Effort (abs)	Large	0.008	0.005	0.014	0.014	0.024	0.012
	Small	0.008	0.007	-0.003	0.006	-0.007	0.005
	total	0.015	0.011	0.011	0.020	0.017	0.017
Effort (%)	Large	1.035	0.613	1.861	1.870	3.259	1.666
	Small	3.030	2.692	-1.174	2.426	-2.969	1.980
Harvest (abs)	Large	-1.090	-0.905	-0.023	-1.090	0.206	-0.914
	Small	0.085	0.169	-0.694	-0.239	-1.327	-0.234
	total	-1.005	-0.736	-0.716	-1.329	-1.121	-1.148
Harvest (%)	Large	-1.574	-1.307	-0.032	-1.574	0.297	-1.320
	Small	0.369	0.731	-3.007	-1.037	-5.749	-1.015
Fleet size (abs)	Large	0.004	0.000	0.014	0.000	0.003	0.003
	Small	0.001	0.000	0.001	0.000	-0.001	0.001
	total	0.005	0.000	0.015	0.001	0.002	0.004
Fleet size (%)	Large	1.574	-0.060	4.889	0.126	0.912	1.186
	Small	2.565	1.323	2.582	0.716	-2.143	1.429
Stock size (abs)		-7.254	-5.349	-5.209	-9.515	-8.071	-8.258
Stock size (%)		-2.581	-1.907	-1.857	-3.379	-2.866	-2.936
Consumption (abs)		-1.005	-0.736	-0.716	-1.329	-1.121	-1.148
Consumption (%)		-1.088	-0.797	-0.776	-1.440	-1.214	-1.244
Fishers' income	Large	1.601	1.722	2.595	0.550	0.814	1.246
	Small	0.725	0.901	0.093	0.387	-0.354	0.460
Rent	Large	0.000	0.000	0.000	0.000	0.000	0.000
	Small	0.000	0.000	0.000	0.000	0.000	0.000
Vessels owners income	Large	0.818	0.016	2.410	0.150	0.492	0.641
	Small	0.176	0.094	0.179	0.057	-0.122	0.103
Crew income	Large	0.295	0.069	0.010	0.311	0.027	0.222
	Small	0.200	0.047	0.006	0.207	0.017	0.148
Income to fishers' owned capital	Large	0.488	1.637	0.175	0.090	0.295	0.384
	Small	0.349	0.760	-0.092	0.123	-0.249	0.209
Input suppliers' income		0.151	0.084	0.134	0.883	1.250	0.587
Transfer efficiency		0.460	0.522	0.531	0.178	0.092	0.329
Consumer welfare		-1.073	-0.797	-0.771	-1.407	-1.208	-1.222
Taxpayer costs		-5.057	-5.024	-5.062	-5.253	-5.010	-5.186
Total welfare change		-3.652	-3.112	-3.013	-4.840	-4.508	-4.115

Source: OECD FishPEM model.

Managed under Derby TAC

Table A B.2. Model results under derby TAC conditions

Indicator (change in)	Sector	Fishers' income	Fishers' own capital	Vessels	Use of variable inputs	Use of fuel	Output
Effort (abs)	Large	0.000	0.000	0.000	0.000	0.000	0.000
	Small	0.000	0.000	0.000	0.000	0.000	0.000
	total	0.000	0.000	0.000	0.000	0.000	0.000
Effort (%)	Large	0.000	0.000	0.000	0.000	0.000	0.000
	Small	0.000	0.000	0.000	0.000	0.000	0.000
Harvest (abs)	Large	0.000	0.000	0.000	0.000	0.000	0.000
	Small	0.000	0.000	0.000	0.000	0.000	0.000
	total	0.000	0.000	0.000	0.000	0.000	0.000
Harvest (%)	Large	0.000	0.000	0.000	0.000	0.000	0.000
	Small	0.000	0.000	0.000	0.000	0.000	0.000
Fleet size (abs)	Large	0.005	0.001	0.013	0.001	0.001	0.004
	Small	0.001	0.000	0.001	0.000	0.000	0.001
	total	0.006	0.001	0.015	0.001	0.001	0.004
Fleet size (%)	Large	1.854	0.216	4.646	0.301	0.363	1.300
	Small	1.953	0.611	3.785	0.646	0.174	1.412
Stock size (abs)		0.000	0.000	0.000	0.000	0.000	0.000
Stock size (%)		0.000	0.000	0.000	0.000	0.000	0.000
Consumption (abs)		0.000	0.000	0.000	0.000	0.000	0.000
Consumption (%)		0.000	0.000	0.000	0.000	0.000	0.000
Fishers' income	Large	1.771	1.918	2.448	0.642	0.473	1.299
	Small	0.587	0.734	0.299	0.373	0.100	0.447
Rent	Large	0.000	0.000	0.000	0.000	0.000	0.000
	Small	0.000	0.000	0.000	0.000	0.000	0.000
Vessels owners income	Large	0.923	0.138	2.298	0.202	0.237	0.665
	Small	0.131	0.047	0.238	0.051	0.013	0.096
Crew income	Large	0.297	0.058	0.042	0.319	0.094	0.234
	Small	0.200	0.039	0.028	0.214	0.063	0.158
Income to fishers' owned capital	Large	0.551	1.722	0.108	0.121	0.142	0.399
	Small	0.256	0.648	0.033	0.108	0.025	0.193
Input suppliers' income		0.209	0.134	0.124	0.932	1.226	0.640
Transfer efficiency		0.464	0.526	0.544	0.193	0.114	0.336
Consumer welfare		0.000	0.000	0.000	0.000	0.000	0.000
Taxpayer costs		-5.080	-5.047	-5.049	-5.261	-5.011	-5.197
Total welfare change		-2.513	-2.260	-2.178	-3.314	-3.211	-2.811

Source: OECD FishPEM model.

Managed under total allowable catch (TAC)**Table A B.3. Model results under TAC conditions**

Indicator (change in)	Sector	Fishers' income	Fishers' own capital	Vessels	Use of variable inputs	Use of fuel	Output
Effort (abs)	Large	0.006	0.004	0.005	0.008	0.008	0.007
	Small	0.000	0.000	0.000	0.000	0.000	0.000
	total	0.006	0.004	0.005	0.008	0.008	0.007
Effort (%)	Large	0.961	0.672	0.845	1.295	1.319	1.152
	Small	0.253	0.193	0.029	0.250	-0.001	0.224
Harvest (abs)	Large	0.053	0.035	0.087	0.088	0.141	0.079
	Small	-0.147	-0.100	-0.161	-0.213	-0.259	-0.189
	total	-0.094	-0.066	-0.074	-0.126	-0.118	-0.110
Harvest (%)	Large	0.068	0.044	0.111	0.112	0.181	0.101
	Small	-0.634	-0.432	-0.699	-0.921	-1.123	-0.817
Fleet size (abs)	Large	0.005	-0.001	0.015	-0.002	-0.002	0.002
	Small	0.000	0.000	0.002	0.000	0.000	0.000
	total	0.005	-0.001	0.017	-0.003	-0.002	0.002
Fleet size (%)	Large	1.982	-0.500	6.501	-1.059	-0.983	0.787
	Small	1.062	-0.794	5.447	-1.334	-0.497	0.238
Stock size (abs)		-3.377	-2.373	-2.776	-4.467	-4.300	-3.972
Stock size (%)		-0.885	-0.623	-0.727	-1.168	-1.123	-1.039
Consumption (abs)		-0.094	-0.066	-0.074	-0.126	-0.118	-0.110
Consumption (%)		-0.094	-0.066	-0.074	-0.126	-0.118	-0.111
Fishers' income	Large	3.401	3.046	3.819	2.729	2.635	3.199
	Small	1.035	0.978	0.234	0.793	-0.025	0.808
Rent	Large	2.337	1.674	2.052	3.033	3.089	2.759
	Small	0.869	0.661	0.130	0.832	0.045	0.754
Vessels owners income	Large	0.577	-0.116	1.913	-0.265	-0.255	0.235
	Small	0.029	-0.025	0.164	-0.039	-0.014	0.005
Crew income	Large	0.144	-0.073	-0.060	0.119	-0.047	0.063
	Small	0.087	-0.045	-0.037	0.073	-0.029	0.039
Income to fishers' owned capital	Large	0.342	1.562	-0.085	-0.159	-0.153	0.141
	Small	0.050	0.387	-0.022	-0.073	-0.027	0.010
Input suppliers' income		-0.197	-0.169	-0.180	0.478	0.814	0.215
Transfer efficiency		0.896	0.815	0.821	0.675	0.524	0.783
Consumer welfare		-0.100	-0.071	-0.085	-0.132	-0.131	-0.119
Taxpayer costs		-4.951	-4.939	-4.934	-5.214	-4.980	-5.118
Total welfare change		-0.813	-1.154	-1.145	-1.346	-1.686	-1.016

Source: OECD FishPEM model.

Sensitivity analysis summary

The main source of uncertainty in the model lies in the values of the parameters used. The robustness of the model results to changes in parameter values were tested by systematically varying parameters and observing the effect this had on the results. The model re-run 1 000 times to generate a set of results that encompass a broad range of possible parameter values. Model parameters were all drawn from uniform distributions and varied simultaneously. The parameters varied were:

- Demand elasticity for fish (η)
- Input elasticities of supply (ε_j)
- Input elasticities of substitution between inputs by segment ($\sigma_{ij,s}$)
- IUU probability of control parameter (θ)
- Pella-Tomlinson parameter (γ)

The demand elasticity for fish, input elasticities of supply, and the input elasticities of substitution between inputs were systematically varied between half and double their base values.

In the model factor elasticities are grouped according to their responsiveness (i.e. elastically or inelastically supplied) and, where relevant, the fleet they relate to. Each group is assigned the same absolute values, e.g. elasticities of substitution between all elastically supplied factor inputs (e.g. fuel and hired crew) receive the same elasticity value. The full set of elasticity groupings are between elastically supplied factors (i.e. fuel, hired crew, other purchased inputs), between inelastically supplied factors (vessels, fishers' own capital), and between elastically and inelastically supplied factors.

The IUU probability of control parameter was varied between absolute values of 0.5 and 3. The Pella-Tomlinson parameter was varied between absolute values of 1.05 and 2, allowing the fishery's resilience to effort to be varied.

T-tests were performed on the results of the sensitivity analysis. These were used to determine both whether the mean observed impact of a policy measure on a specific indicator (e.g. stock size) was statistically different from zero (i.e. no effect), and whether the impacts of policy measures were different from each other (e.g. is the mean impact of support to variable input use on effort statistically different to the impact of support based on fuel use). Significant differences in impact were seen in almost all instances, cases where significant differences between policy impacts were observed (for at least the 10% level) are reported in table Table A B.4.²⁸

²⁸ The complete set of sensitivity analysis results (density plots and tables of t-test results) are available in Annex C of an expanded version of the document (TAD/FI(2018)2/FINAL), at: <https://oe.cd/2qG>.

Table A B.4. Cases with no significant differences

Instances where statistically significant differences could not be confirmed
between the impacts of policies at the 10% level

Indicator	Management conditions	Sector	Payments based on	Payments based on	P value
Stock size	Open access	-	Fishers' own capital	Vessels	0.156
Stock size	Open access	-	Fuel use	Output	0.180
Effort	Open access	Large	Vessels	Variable input use	0.695
Effort	TAC	Small	Fishers' income	Variable input use	0.756
Fleet size	Open access	Small	Fishers' income	Vessels	0.537

Source: OECD FishPEM model sensitivity analysis.