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# Management changes and vessel-level technical efficiency in the Eastern Tuna and Billfish Fishery: a stochastic frontier analysis

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## Abstract

Changes in fishery management can influence vessels' efficiency, thereby changing the fishery's ability to achieve a catch target consistent with maximising net economic returns to the Australian community. The stochastic frontier method is used to analyse the vessel-level technical efficiency achieved in the Eastern Tuna and Billfish Fishery over the period 2001–02 to 2010–11. A significant reduction in fleet size in this fishery following implementation of the Securing our Fishing Future structural adjustment package in 2006 is shown to have had a negligible effect on vessel-level technical efficiency. Also, effort creep was avoided during the period of effort controls; 2008–09 to 2010–11. Tracking changes in technical efficiency over time can help managers of Commonwealth fisheries better achieve their objective of maximising net economic returns to the Australian community.

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# 1 Introduction

The Eastern Tuna and Billfish Fishery is a Commonwealth-managed fishery that targets internationally shared tuna and billfish species off Australia's east coast. With the aim of managing the fishery in a manner consistent with catch level decisions taken by the Western Central Pacific Fisheries Commission and the Commonwealth Harvest Strategy Policy objectives, the Australian Fisheries Management Authority (AFMA) has implemented various forms of input controls in the form of gear restrictions, spatial management and fishing permits over the past five years (Table 1). It is important to study the effect of these management changes on efficiency in the industry, in order to minimise any adverse effects on efficiency. Accordingly, the focus of this paper is to assess the technical efficiency of vessels operating in the fishery over the period 2001–02 to 2010–11, and how management changes have affected this efficiency.

Table 1: Major management actions in the Eastern Tuna and Billfish Fishery, 2006 to 2011

| Year | Management action | Description |
|---|---|---|
| 2006 | Securing our Fishing Future structural adjustment package | Resulted in the surrender of 99 of the 218 longline permits originally available to the fishery. |
| 2009 | ETBF management plan (DAFF 2005) was introduced under transitional arrangements | A total allowable effort of 12 million hooks for the period 1 November 2009 to 28 February 2011. |
| 2011 | Management under total allowable commercial catch commenced (1 March) | The primary management instrument changed from an effort-based system to a quota-based system. |

*Source*: Larcombe et al. 2011

Unlike many other Commonwealth-managed fisheries, where stocks are considered to locate principally within Commonwealth management boundaries, Australian authorities are unable to independently choose fishery catch targets for many species in the Eastern Tuna and Billfish Fishery in a manner consistent with achieving a biomass consistent with maximum economic yield—the stated economic objective in the Harvest Strategy Policy (DAFF 2007). A harvest strategy for the fishery has been developed, which will form the basis for calculating the recommended biological catches for each of the five target species and the whole-of-government negotiating position for Australia at the regional commission meeting (Davies & Dichmont 2011). For the purpose of this study, it is hence reasonable to interpret the stated economic objective of the Australian Fisheries Management Authority in the Harvest Strategy Policy—to maximise the net economic returns to the Australian community—to be profit maximisation for the fishery with given catch targets, which are determined on a species-by-species basis.

Given that the point of profit maximisation is also the point of cost minimisation (Kompas, Grafton & Che 2011), achieving maximum economic efficiency is of vital importance for successful management of a fishery and achieving catch targets in the fishery. Stochastic frontier analysis examines technical efficiency (a component of economic efficiency) while the second component, allocative efficiency, is not directly examined.

Assuming a starting point of overcapitalisation in the fishery, a transition to a point of profit maximisation will result in the least efficient operators exiting the industry, resulting in a higher average technical efficiency in the fishery. Therefore, an indicator of a successful management change will be an increase in average technical efficiency. In an overcapitalised fishery, such an increase is usually associated with a decrease in effort and an increase in profits, assuming constant prices.

Another aim of this paper is to develop a methodology appropriate for assessing the economic performance of data-poor fisheries. Determining whether vessels in a fishery are reaching a point of profit maximisation generally relies on development of expensive bioeconomic models with input from comprehensive surveys of vessel revenue and costs and detailed biological information. Moreover, success of financial surveys is dependent on the voluntary contribution of operators' financial information to researchers. Using stochastic production frontier analysis, vessel level profit maximisation can be analysed through the proxy of technical efficiency. Such studies can vary in the complexity of information, potentially including similar data to that used in bioeconomic models. Similarly, they can rely on more basic information, generally available through catch logbook data collected by fisheries management agencies. This information includes catch and effort data, and vessel characteristic data, such as vessel length and engine size. The latter method is used in this study, as an example for future application to data-poor fisheries.

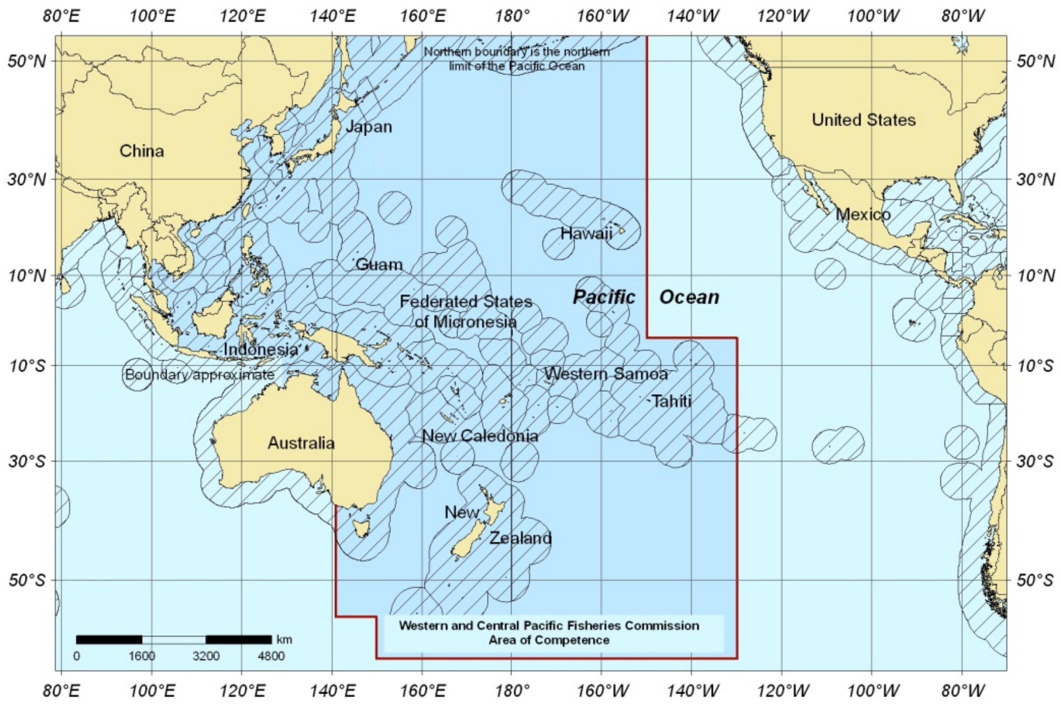
The remainder of this paper is arranged as follows. Section 2 describes the fishery, including a discussion on the main characteristic of technical efficiency in the fishery. Section 3 outlines the methodology employed, including the benefits of using stochastic frontier analysis compared with other methodologies. Section 4 presents the main results and Section 5 concludes.

# 2 Eastern Tuna and Billfish Fishery

The Commonwealth-managed Eastern Tuna and Billfish Fishery primarily comprises internationally shared fish stocks. As such, the majority of stock assessments and associated recommended catch levels are taken from the Western and Central Pacific Fisheries Commission, of which Australia is a member.

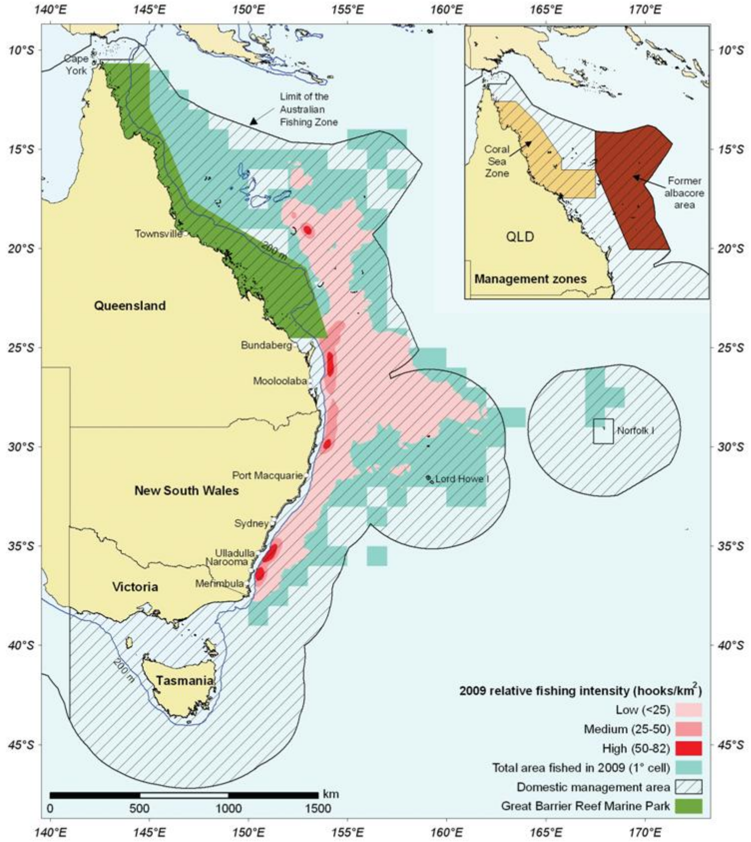
Tuna and billfish species are highly migratory, and are largely covered by the Western and Central areas of the Pacific Ocean, roughly encompassed by the Western and Central Pacific Fisheries Commission areas of competence (Figure 1). The relationship between catch of these species in the Eastern Tuna and Billfish Fishery and the large stocks covering this area is poorly understood, and is subject to ongoing research. The stock availability—that is, the part of the overall stock that falls within the Australian Fishing Zone in any given period—is thought to be influenced by various factors, one of which is the total abundance of stock. It is also thought to be influenced by oceanographic factors, which influence migration of tuna to and within the fishery, particularly as the southern half of the Australian Fishing Zone is at the extreme migration range for many of these species (Kompas, Che & Gooday 2009).

**Figure 1 Western and Central Pacific Fisheries Commission areas of competence**



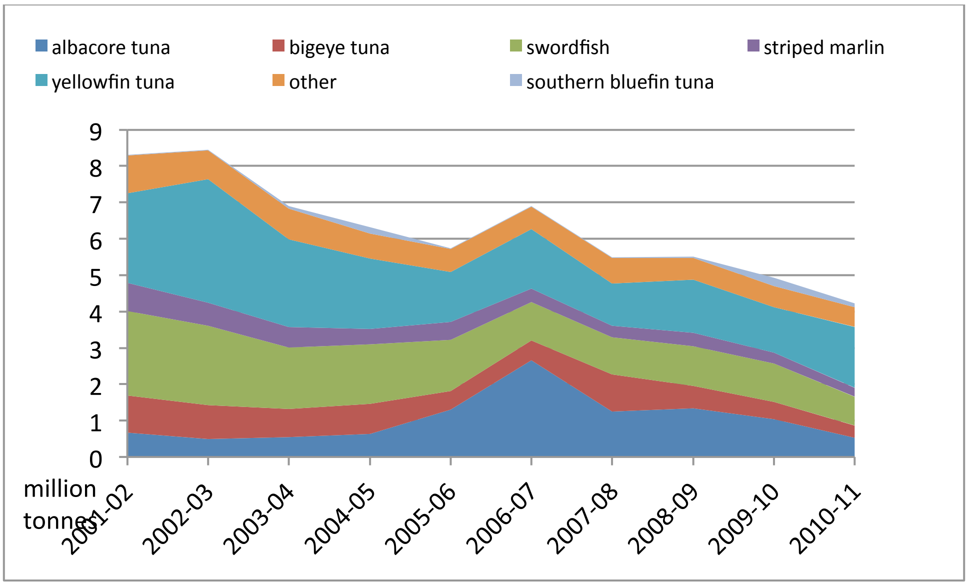
The fishery extends from Cape York to the Victoria – South Australia border, including waters around Tasmania and Lord Howe Island (Figure 2). Spatially, it overlaps with the Southern Bluefin Tuna Fishery. Some vessels target southern bluefin tuna off New South Wales during winter, after fishing for tropical tuna and billfish species earlier in the year, while others catch them incidentally when targeting other tuna. Because this study assesses vessel-level efficiency, and there is potential for catch in the Southern Bluefin Tuna Fishery to play a significant role in the revenues for individual vessels, southern bluefin tuna catch associated with operating in the Eastern Tuna and Billfish Fishery has been included in the analysis of technical efficiency even though, from a management perspective, southern bluefin tuna caught in the fishery is not considered part of the Eastern Tuna and Billfish Fishery.

## Figure 2 Eastern Tuna and Billfish Fishery



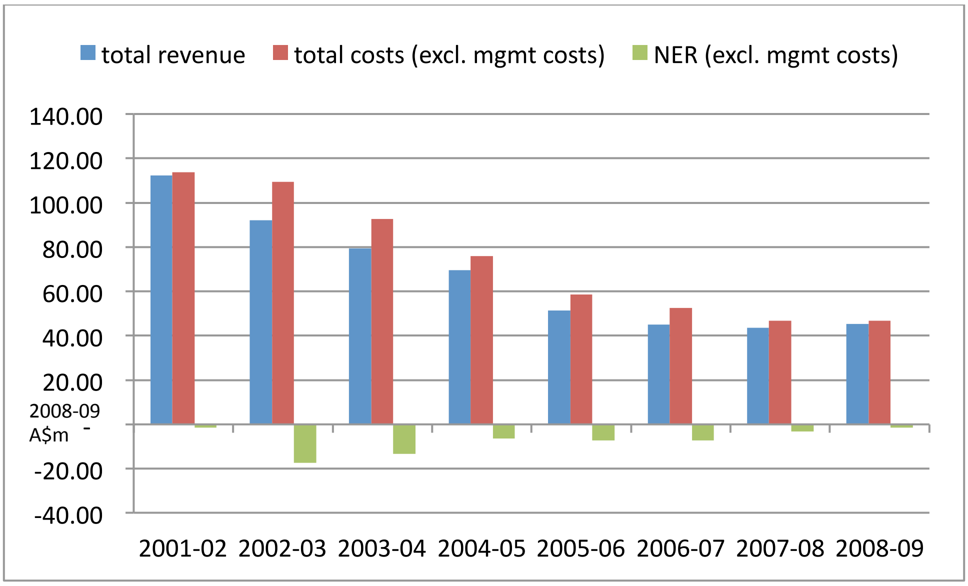
The main species of fish caught in the fishery are yellowfin tuna (1451 tonnes valued at $10.6 million in 2009–10), broadbill swordfish (1278 tonnes, $7.3 million), bigeye tuna (686 tonnes, $6.4 million), albacore tuna (1210 tonnes, $2.4 million) and striped marlin (329 tonnes, $2.2 million). Together, these five species accounted for around 96 per cent of the gross value of production in the fishery in 2009–10 (Figure 3).

## Figure 3 Landed catch, Eastern Tuna and Billfish Fishery and Southern Bluefin Tuna Fishery, longline



Net economic returns (excluding management costs) increased from –$7.4 million in 2006–07 to –$3.3 million in 2007–08 (Figure 4). In 2008–09, net economic returns improved, but remained negative at –$1.5 million. With the inclusion of management costs, net economic returns in 2008–09 were –$4.5 million (Perks & Vieira 2010).

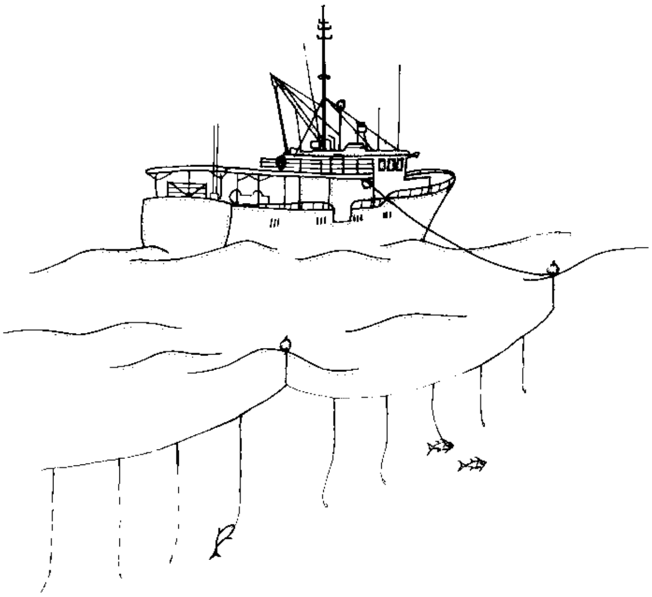
**Figure 4 Revenue, costs and net economic returns in the Eastern Tuna and Billfish Fishery (excl. management costs)**



Throughout the 1990s, increases in costs were proportional to increases in revenue, with the result that net economic returns were positive into the late 1990s. However, by 2001–02 the positive net economic returns of the late 1990s were dissipated following significant increases in effort and localised depletions of inshore stocks (Vieira et al. 2010). Net economic returns have remained negative in the fishery in every year surveyed since 2001–02. Negative economic returns over this period have been strongly linked to reductions in swordfish availability. Swordfish stock depletion was shown to have reduced the average profit per boat by around 14 per cent a year between 1997–98 and 2006–07 (Kompas et al. 2009).

The vast majority of commercial fishers in the fishery use the longline fishing technique (Figure 5), with a few vessels using the minor-line technique. Longlining involves a single line shot with multiple hooks set. Before 2006, most longliners were set in mid-water; however, in response to reduced swordfish availability, high operating costs and increasing market demand, some operators began to use deep-setting techniques in 2006 to target albacore tuna (Larcombe et al. 2011).

Figure 5 Longline technique



The Eastern Tuna and Billfish Fishery underwent significant change following the Australian Government's Securing Our Fishing Future structural adjustment package introduced in 2006. The package was aimed at addressing overfishing and rebuilding overfished stocks and included a $149 million fishing concession buyback involving a voluntary tender (AFMA 2005). The fishery was one targeted in the buyback, which concluded in December 2006 and resulted in 99 longline and 112 minor-line permits being surrendered (Abetz 2006). Following the buyback, 119 longline permits and 118 minor-line permits remained in the fishery.

In November 2009, the Australian Fisheries Management Authority set a total allowable effort limit, with tradeable statutory fishing rights, adjusted by a sub-area factor, which are 'differential decrement rates of an operator's effort allocation depending on where they fish' (Wilcox et al. 2011). This arrangement was in effect for 16 months, ending in February 2011. In March 2011, this system of input controls was replaced by output controls comprising the setting of total allowable commercial catch with a system of individual transferrable quotas.

# 3 Methodology

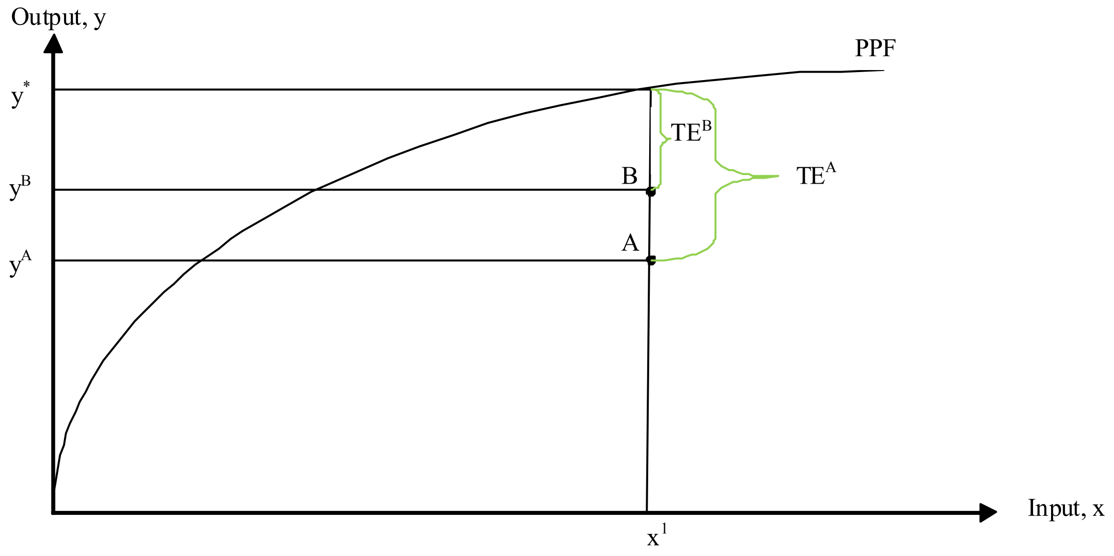
Economic efficiency is an important area of study, especially for those parts of the economy in which the government intervenes in markets. Such studies can help policy makers create market structures that can achieve regulatory objectives at least cost to the overall economy.

Economic efficiency can be split into two categories: technical efficiency and allocative efficiency. Technical efficiency is a measure of a firm's ability to maximise output with a given set of inputs. Allocative efficiency measures the ability of firms to achieve a given amount of output with the most cost-effective mix of inputs (Coelli et al. 2005). In the absence of any regulatory barriers, firms are assumed to choose the optimal mix of inputs, and are thereby assumed to be allocatively efficient. However, many factors can contribute to technical inefficiency, which is the focus of this report.

Technical efficiency is measured using the stochastic production frontier method. Commonly used production frontier-based approaches compare the actual output of a firm (vessel) with an estimate of that firm's maximum potential output. That is, an estimate of an individual firm's maximum possible output that could be achieved for its given set of inputs (for example, labour, fuel, time), or the output a firm would achieve if it were perfectly efficient. The difference between a firm's actual output and its perfectly-efficient equivalent output represents technical inefficiency. This is graphically presented in Figure 6, which is a simplified single-input-single-output model. This representation can be extended by considering the single input as a vector of inputs and the single output as an index of multiple outputs.

In Figure 6 point A and point B represent production points of hypothetical firms A and B, respectively. Firm A uses $x_1$ amount of the single input and produces $y_A$ amount of output, whereas firm B uses the same amount of input as firm A but produces a higher level of output, $y_B$. The production possibilities frontier (PPF) represents the maximum possible output for a given level of input.

Figure 6 Graphical representation of technical efficiency



The maximum possible output for the level of input $x_1$ is represented by y*. Because the output of firms A and B are below this point, both firms are less than perfectly efficient. The technical inefficiency of firms A and B are represented by $TE^A$ and $TE^B$, respectively, which is the difference between y*, and $y_A$ and $y_B$, respectively.

Following the methods of Battese and Coelli (1995) and Coelli et al. (2005), the stochastic output frontier in a multiple input/output fishery is given by:

$$Y_{it} = f(\boldsymbol{X}_{it}, \boldsymbol{t})^{v_{it}-u_{it}}$$

Where:

$Y_{it}$ = aggregate catch index of vessel i in time period t.

$X_{it}$ = vector of inputs, including number of shots and average hooks.

t = vector of time trend terms

$v_{it}$ = symmetrical normally distributed random variable

$u_{it}$ = non-negative technical inefficiency variable.

Technical efficiency, therefore is given by:

$$TE_i = \frac{y_i}{y_i^*} = \frac{f(x_i;\beta)\mathrm{e}^{(\mathrm{v_i}-\mathrm{u_i})}}{f(x_i;\beta)\mathrm{e}^{\mathrm{v_i}}} = e^{-u_i}$$

The most common methods to study technical efficiency are the parametric stochastic frontier analysis and the non-parametric data envelopment analysis. The major advantage of using a parametric approach such as the stochastic frontier method compared with data envelopment analysis is the inclusion of a composite error term comprising technical inefficiency and random error (Coelli et al. 2005). Data envelopment analysis measures technical inefficiency as a residual, which does not take account of statistical 'noise' and measurement error (Cullinane et al. 2006). The composite error term estimated in the stochastic frontier analysis approach allows for both a statistical error term, normally distributed with constant variance, and a non-negative technical inefficiency term. The error term $u_{it}$ captures vessel-specific technical inefficiency, and is specified by:

$$u_{it} = \delta z_{it} + w_{it}$$

Where:

$z_{it}$ = vector of explanatory variables, including major inputs (hooks, vessel length) and fleet size.

$w_{it}$ = normally distributed error term with zero mean and constant variance.

The condition of non-negativity of the technical inefficiency component of the error term ensures that no vessel is more than perfectly efficient, having accounted for exogenous factors not accounted for in the model. A vessel that is apparently more than perfectly efficient would mean that the production function has not been estimated correctly or has not accounted fully for statistical noise.

## Output index

Because the Eastern Tuna and Billfish Fishery is a multi-species fishery, a total gross catch quantity will not accurately reflect vessel output. In similar cases, analysts have used revenue as a measure of output, which essentially weights catch volume by price to account for the productive value of different qualities of fish. However, this methodology is not suitable for application to the Eastern Tuna and Billfish Fishery. A significant amount of vertical integration in the industry—that is, co-ownership of the fishing and processing operations—means a significant volume of catch is transferred within a single firm, rather than sold on the market. Therefore, it is hard to distinguish between the value of the fish as a raw product, which would contribute toward vessel revenue, and the value added in the manufacturing process, which would contribute to profit derived from the manufacturing process.

In order to create an output measure that accurately takes account of fish species of different values without relying on revenue data, a Fisher index with an Elteto-Koves-Szulc (EKS) extension was used to create a composite output quantity index (Elteto & Koves 1964; Szulc 1964). This overcomes the issue of several different fisheries products in the one fishery, and accounts for the difference in value of each of the products while minimising the effect of potentially volatile fish prices.

The output index comprises the five highest value fish species in the fishery (albacore tuna, big eye tuna, swordfish, striped marlin, yellowfin tuna), southern bluefin tuna and an ‘other’ category comprising the remaining catch. The prices used to weight the index are average production unit value for landed whole fish, calculated using catch volumes and estimates of the gross value of production. Implicit in use of such an index is the assumption of homogeneous fish quality, meaning there is no differentiation between high quality and poor quality product for each species. Each kilogram of each species is assigned the same industry-wide price. While in practice this may not be a realistic assumption, adjustments are not possible given the data available. However, the prices used are a reasonable representation of the average fish quality.

Inclusion or exclusion of southern bluefin tuna is not straightforward. From a management perspective, it is a different fishery which means it should not significantly influence management decisions in the Eastern Tuna and Billfish Fishery. However, southern bluefin tuna can account for some revenue of operators in the fishery, and has therefore been retained in the analysis, so long as the vessel operates in the Eastern Tuna and Billfish Fishery and not just the Southern Bluefin Tuna Fishery.

Given use of a multilateral Fisher index with an EKS extension in creating the output index, a brief outline of the method is included below with a discussion of its appropriateness.

First, bilateral Fisher index terms are calculated between all observations in the fishery. The Fisher index is composed of two other types of indexes: the Laspeyres index and the Paasche index.

The bilateral Laspeyres index is a measure of quantity difference weighted using base observation (A) prices:

$$1)\ Q_{AB}^{L}=\frac{\sum_{i=1}^{N}p_{iA}q_{iB}}{\sum_{i=1}^{N}p_{iA}q_{iA}}$$

where the base observation is denoted by A, compared with observation B, and i represents the different inputs to the index (in this case, fish species).

The bilateral Paasche index is also a measure of quantity difference, weighted using prices of observation B:

$$2)\ Q_{AB}^{P}=\frac{\sum_{i=1}^{N}p_{iB}q_{iB}}{\sum_{i=1}^{N}p_{iB}q_{iA}}$$

The bilateral Fisher index is the geometric average of the Laspeyres and Paasche indexes:

$$3)\ Q_{AB}^{F}=\sqrt{Q_{AB}^{L}Q_{AB}^{P}}$$

Application of the bilateral Fisher index to cross sectional or panel data may lead to problems of intransitivity (Diewert 1988). Transitivity is best illustrated with the simple example of three firms: A, B and C. If the index of A is larger than that of B, and the index of B is larger than that of C, then in order to be transitive it must follow that the index of A must be larger than that of C. In addition, transitivity requires the value of the index to be independent of the base used. The use of a bilateral Fisher index has the potential to violate the transitivity condition, which necessitates use of the EKS extension.

The EKS index was named after Elteto and Koves (1964) and Szulc (1964), and ensures transitivity and base-observation invariance (that is, independence of the choice of base observation) (Gray et al. 2011). If there are N observations, an EKS index between observations A and B is denoted by:

4) $Q_{AB}^{EKS} = (\prod_{r=1}^{N} Q_{AC}^{F} Q_{CB}^{F})^{1/N}$

This creates an index of quantity that takes into account different species and their values, without relying on revenue estimates or unknown transfer prices.

An implicit assumption in use of such an index is that of radial expansion of all outputs, given an increase the set of inputs. This implies any increase in efficiency or random shock changes all outputs proportionally. Reports of substitution between species targeted in response to changing market conditions would not be fully captured with use of the index.

Some fisheries studies argue that, because of the nature of the longline fishing method, inputs are largely non-allocable. That is, effort (hooks) is unable to be effectively designated exclusively to a single species. Based on this it could be argued, as consistent with Pascoe et al. (2010), that the radial expansion assumption is reasonable in the case of a fishery, as the proportions of different species caught depend on stock availability (as opposed to stock abundance) and the types of technology used. Stock abundance and technology change slowly enough to be captured over a long time (Pascoe et al. 2010). However, it remains uncertain whether this is appropriate given the potential for significant variation in stock availability given variable migration patterns from year to year. The ability to target certain species using methods other than technology, such as area selection, may cast doubt on the assumption of non-allocability of effort.

## Input data

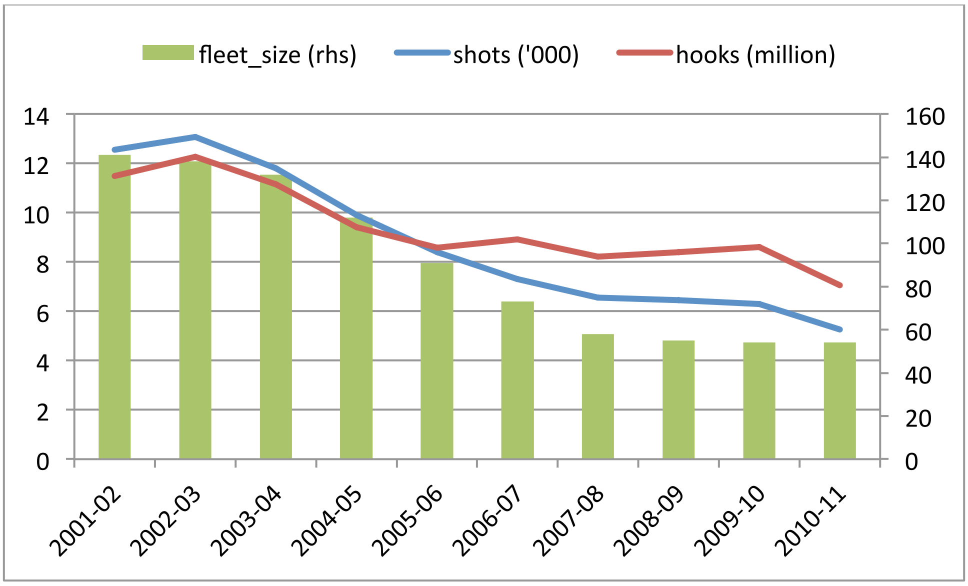
Assuming constant stocks and technology, output is determined by level of effort. For the purposes of analysis, three key variables are included.

- Number of shots—total number of shots laid in a financial year, representing total effort in the fishery.
- Average hooks—the average number of hooks per shot during the financial year, representing an average gear size as a proxy for fishing capacity.
- Quadratic time trend—revealing trends in stock availability and productivity over time.

Vessel length was included in many other similar studies, as an important capital input and a proxy for crew size (Greenville et al. 2006; Kompas et al. 2004). This was not significant in various specifications tested, and the more limited model presented provides a better functional form for the data used in the analysis. A possible explanation for its insignificance is that vessel length is less important to fishers using the longline technique compared with, for example, trawl methods. More important is the ability of a vessel to have a large number of hooks in the water.

The trends in fleet size, number of shots set and hooks used over the period 2001–02 to 2010–11 is shown in Figure 7.

Figure 7 Major Eastern Tuna and Billfish Fishery inputs, 2001–02 to 2010–11



*Note*: Data presented excludes effort exclusively for southern bluefin tuna catch, as the effects are negligible on the trends presented.

## Determinants of technical inefficiency

A range of factors of interest may be included in the model of technical inefficiency. A key assessment is whether the permit buyback in 2006 had a significant effect on overall efficiency, and as such a fleet size variable was included. Total hooks was included as it is a primary input, and is of interest as it was the primary regulated input during the period of effort controls. To further analyse the effort control period, the variable hooks(e) is an interaction variable between a dummy variable for the years 2009–10 and 2010–11 and total hooks. Therefore, it takes the values of hooks for those two years, and otherwise takes a value of zero. Finally, vessel length has been included as a major unregulated input. The independent variables in the inefficiency model may include some of the same input variables in the stochastic frontier, provided the inefficiency effects are stochastic (Battese & Coelli 1995: 327).

The key determinants of technical inefficiency being studied are:

- Fleet size—the total number of vessels operating in the fishery during the period.
- Hooks—the total number of hooks used in a given financial year.
- Hooks(e)—takes the value of 'hooks' for the years 2009–10 and 2010–11, and otherwise takes the value of zero.
- Vessel length—the total length of the fishing vessel.

## Econometric specification

The analysis uses a translog functional form, having rejected the less general Cobb-Douglas functional form based on a joint significance test of the squared and interaction terms (Table 1, hypothesis test 2). The significance of $\gamma$, which is the proportion of the composite error term attributed to technical inefficiency, demonstrates that an ordinary least squares method is not suitable, and reaffirms use of the stochastic frontier model. Finally, the joint significance of the $\delta$

terms—the explanatory variables in the technical efficiency model—confirms use of the functional form of the model.

The relevant test statistics for these hypothesis tests are calculated using

$$LR = -2\left\{\ln\left[\frac{L(H_0)}{L(H_1)}\right]\right\} = -2\{\ln\,[L(H_0)] - \ln[L(H_1)]\}$$

with the critical values a mixed chi-squared distribution, taken from table 1 in Kodde and Palm (1986).

Table 2: Test for functional form based on a joint significance test of the squared and interaction terms

| **Null hypothesis (H₀)** | **Log likelihood** | | **LR test statistic** | **Critical value** | | **Decision** |
|---|---|---|---|---|---|---|
| | Null hypothesis | Alternative hypothesis | | | | |
| $\gamma = 0$ | –302.89 | –247.69 | 110.4177 | $\chi^2_{0.01(1)} =$ | 5.412 | H₀ rejected |
| $\beta_3 = \beta_4 = \beta_5 = 0$ (Cobb-Douglas) | –257.21 | –247.69 | 19.05148 | $\chi^2_{0.01(3)} =$ | 10.501 | H₀ rejected |
| $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$ | –266.59 | –247.69 | 37.81018 | $\chi^2_{0.01(4)} =$ | 12.483 | H₀ rejected |

Translog specifications, unlike Cobb-Douglas specifications, give non-constant output elasticities (percentage change in output from a 1 per cent increase in input). This is because the parameters depend not only on the value of a single parameter, but also on the levels of all explanatory variables because of the squared and interaction terms. Therefore, elasticity estimates presented are those calculated at the mean values of each parameter, calculated over the entire dataset.

# 4 Eastern Tuna and Billfish Fishery technical efficiency trends

## Data and variables

The data used for this analysis are taken from a variety of sources. Catch and effort (hooks, shots) data are sourced from logbook data. Other variables, such as fish prices and consumer price index, are sourced from various ABARES publications, including *Australian Commodity Statistics* (ABARES 2011a) and *Australian Fisheries Statistics* (ABARES 2011b). Crucially, this study does not rely on any commercially sensitive financial information of any operators, which is a key part of the method's wider applicability to 'data poor' fisheries.

The results were calculated using the Frontier 4.1 software (Coelli 1996) and are presented in tables 3 to 5.

### Table 3: Production frontier model estimates

| | coefficient | standard-error | t-ratio | p-value | |
|---|---|---|---|---|---|
| constant | −10.7686 | 1.1616 | −9.2704 | 0.0000 | *** |
| ln(shots) | 1.2158 | 0.2262 | 5.3753 | 0.0000 | *** |
| ln(av_hooks) | 1.2504 | 0.3870 | 3.2313 | 0.0013 | *** |
| ln(shots)^2 | −0.0359 | 0.0108 | −3.3139 | 0.0010 | *** |
| ln(av_hooks)^2 | −0.0354 | 0.0356 | −0.9950 | 0.3200 | |
| ln(shots)*ln(av_hooks) | −0.0035 | 0.0357 | −0.0989 | 0.9212 | |
| t | −0.0802 | 0.0208 | −3.8520 | 0.0001 | *** |
| $t^2$ | 0.0061 | 0.0019 | 3.2240 | 0.0013 | *** |
| $\sigma^2$ | 0.4017 | 0.0715 | 5.6149 | 0.0000 | *** |
| $\gamma$ | 0.8679 | 0.0285 | 30.4837 | 0.0000 | *** |

*** represents statistical significance at the 1 per cent level of significance

### Table 4: Calculated elasticity estimates

| | elasticity | standard error | t-ratio | p-value | |
|---|---|---|---|---|---|
| ln(shots) | 1.0375 | 0.0409 | 25.3965 | 0.0000 | *** |
| ln(av_hooks) | 0.9909 | 0.2021 | 4.9026 | 0.0000 | *** |

*** represents statistical significance at the 1 per cent level of significance

Elasticity measures were derived, using the mean input levels, following methods in Kalirajan and Tse (1989):

$$\eta_i = \frac{\partial y}{\partial x_i} . \frac{x_i}{y} = \frac{\partial lny}{\partial lnx_i} = \beta_i + \sum_j \beta_{ij} lnx_j$$

Standard errors are calculated in the following way:

$$Var(\eta_i) = Var(\beta_i) + \sum (lnx_j)^2 . Var(\beta_{ij}) + 2 \sum lnx_j . cov(\beta_i, \beta_{ij}) + 2 \sum lnx_j lnx_k cov(\beta_{ij}, \beta_{ik})$$

### Table 5: Technical inefficiency model estimates

| | coefficient | standard-error | t-ratio | p-value | |
|---|---|---|---|---|---|
| constant | 0.4225 | 0.3081 | 1.3713 | 0.1707 | |
| fleet size | 0.0029 | 0.0020 | 1.4672 | 0.1427 | |
| hooks | −0.0096 | 0.0007 | −13.4582 | 0.0000 | *** |
| Hooks(e) | 0.0031 | 0.0013 | 2.3919 | 0.0170 | ** |
| vessel_length | −0.0346 | 0.0116 | −2.9772 | 0.0030 | *** |
| **Mean technical efficiency 0.77** | | | | | |

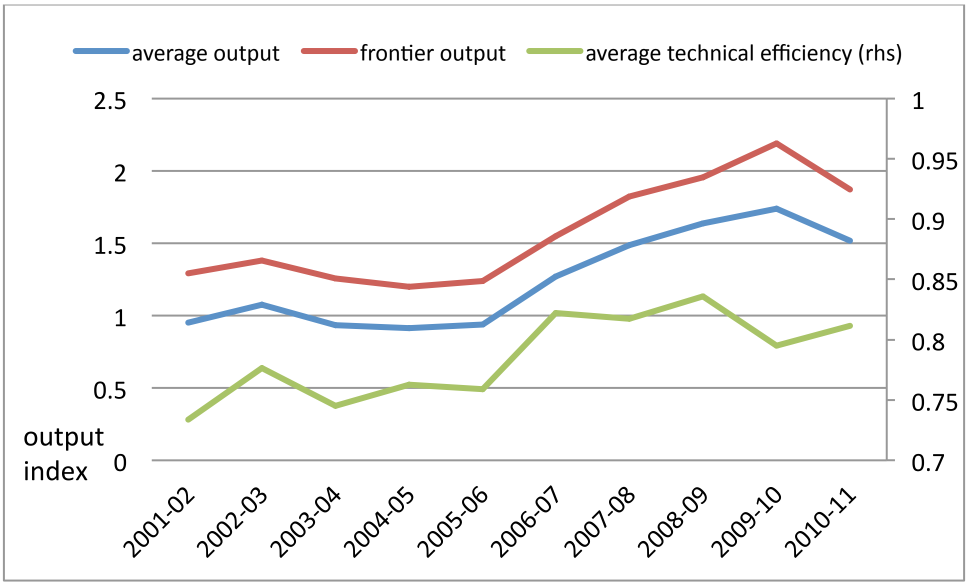
*** and ** represent statistical significance at the 1 per cent and 5 per cent level of significance, respectively

Both elasticity estimates presented in Table 2 are calculated from parameters in the production frontier model (at mean values) and are significant and have signs corresponding with expectations. An increase in either the number of shots or the average number of hooks used corresponds to an increase in output.

Similarly, the negative parameter on the linear time trend suggests that the aggregate effect of stock and productivity changes on technical efficiency has declined since 2002, which would decrease catch per unit effort if all else is held constant. This is consistent with a trend of generally declining catch volumes since 2000–01 (Figure 3). The squared time trend term suggests that the pace of decline of the combination of stock and productivity change has slowed over the period of analysis.

The main focus of this paper—the level of technical efficiency in the fishery—is elicited from the technical efficiency model. The existence of technical inefficiency is confirmed by the significance of $\gamma$ (0.87) term in the production frontier model, which is the proportion of the composite error term attributable to technical inefficiency. This aligns with the estimate of mean technical efficiency (0.77) from the technical inefficiency model; a further indication that technical inefficiency exists in the industry. The level of technical inefficiency in the industry represents the gap between frontier output and actual average output. Average output and the determined frontier output from the model have exhibited a positive trend over the 10 years to 2010–11, reflecting a combination of increase in average technical efficiency and an increase in vessel-level technical efficiency (Figure 8).

Figure 8 Average annual output, frontier output and average technical efficiency



## Fleet size

A trend toward a smaller fleet size was evident over the past decade. Therefore, the reduction in fleet size cannot be entirely attributed to the structural adjustment package. Rather, the structural adjustment package appears to have reinforced and possibly hastened an already existing trend.

The primary aims of the structural adjustment package were to secure the sustainability of Commonwealth fish stocks (including in the Eastern Tuna and Billfish Fishery) that were subject to overfishing or were at significant risk of overfishing in the future and to ensure a profitable future for the fishing industry (AFMA 2005; Vieira et al. 2010). The main aim of the study of technical efficiency in relation to the structural adjustment package was, therefore, to ensure no adverse effects on technical efficiency, or that adverse effects were minimised.

Several factors relating to fleet size could result in a change in technical efficiency. A change in the fleet composition where, for example, the least efficient vessels exited the fishery would result in an increase in average technical efficiency. A smaller fleet size also has a potential effect on vessel-level technical efficiency; positively by fewer ‘crowding’ effects resulting in more fish or fishing areas available to each vessel, or negatively by reducing the amount of shared information available from other vessels in the same fishery where, for example, identification of localised stock aggregations is important. The size of the fleet consistently decreased over the decade under analysis, encouraged in part by the structural adjustment package implemented in 2006. The parameter on fleet size is positive but insignificant, suggesting that the change in fleet size did not have a significant effect on vessel-level technical efficiency. However, an increase in average technical efficiency may be partly a result of a change in fleet composition.

## Effort creep

Effort creep is the substitution of regulated inputs for unregulated inputs as a means to increase overall effort when under effort controls.

Various tools—broadly classified as input and output controls—are available to the Australian Fisheries Management Authority to limit catch. While input controls, such as limited entry, hook limits or gear size restrictions are generally relatively easy to implement and enforce, the potential for effort creep still exists. By substituting regulated inputs (such as hooks) for unregulated inputs (engine size, vessel size), operators are able to increase effective effort, resulting in a tendency toward the common property equilibrium, where stocks are lower and fishery rents are dissipated. For example, if the fleet consists of fewer boats, individual boats may overcapitalise to increase overall fishery effort to undesirably high levels. Equally, if the number of hooks used is restricted, effort may increase through an increase in vessel length or engine size. This also results in distorted input mixes with overinvestment in unregulated inputs and underinvestment in regulated inputs. The result of this is generally lower technical efficiency (Grafton et al. 2006).

The extent to which conclusions about the occurrence of effort creep can be made is limited, as effort controls were only in place for 16 months (ending in February 2011). So only two financial years—2009–10 and 2010–11—may have been affected by effort controls and neither is completely representative of a period exclusively under effort controls. Despite this, if the occurrence was prevalent enough, it is likely to show up in the data for those two periods.

The hooks variable—the total number of hooks used during the year for each vessel spanning the entire time period—is significant and negative. As with all input variables, inputs that have a positive effect on the inefficiency term are over-utilised, while inputs that have a negative effect on the inefficiency term are under-utilised (Greenville et al. 2006). The negative parameter on the hooks variable suggests underutilisation of hooks as an input.

The dummy interaction variable hooks(e) includes the same hook data for the years 2009–10 and 2010–11, and otherwise has a value of zero. An initial test of the effect of effort controls on hooks (as the regulated input) is whether this is significantly different from the hooks variable. The parameters were shown to be statistically different at the 1 per cent level of significance, suggesting that the efficiency of the use of hooks was different during 2009–10 and 2010–11 compared with previous years in the sample.

Effort creep is characterised by under-utilisation of the regulated input during the period of effort controls, and over-utilisation of unregulated inputs. The positive and significant parameter on hooks(e) suggests this was not the case. Conversely, it suggests that hooks were over-utilised during 2009–10 and 2010–11, but under-utilised over the whole of the sample period.

Based on the conclusion of no under-utilisation of hooks during the two financial years in which effort controls were in place, the evidence for the occurrence of effort creep is limited. The non-occurrence could plausibly be the result of one or more of the following explanations.

Limits on the number of hooks are only effective if operators wish to use more hooks than are available under the limit. If the optimal number of hooks that would be used in the absence of effort controls is less than the total allowable number of hooks, operators will optimise their mix of inputs, and latent effort will exist in the fishery. However, latent effort may also reflect introduction of a new management regime and gradual uptake of entitlement trade.

Effort creep would not be possible if the regulated input was not able to be substituted effectively for other inputs. The vast majority of commercial fishing in the fishery uses the longline technique, which means the number of hooks may not be effectively substituted for other inputs, such as vessel length or engine size. Vessels may, therefore, have no practicable way to increase effort when the total number of hooks is limited.

The fact that effort controls were in place for a predefined finite period may have played a significant role in a vessel's decision to alter input mix. A vessel will undertake costly substitution if discounted expected future benefits outweigh the costs of transition to an alternative input mix. For a 16-month period, after which a costly transition back to optimal input mix (in the absence of input regulation) would take place, it is possible that the expected benefits of additional catch at vessel level would not have outweighed the expected cost.

This is an important consideration in the decision between implementing input and output controls. In this specific case, effort controls did not have a significant effect on technical efficiency. However, because of the potential importance of the finite, predefined period of implementation, it is difficult to determine how fishers would react when faced with an indefinite period of effort controls. It is possible over an undefined period, the expected benefit of transferring to an alternative input mix may outweigh the expected costs, resulting in effort creep and erosion of fishery rents.

## Vessel length

The negative parameter on vessel length is significant at the 1 per cent level, indicating that a larger vessel size has a negative effect on inefficiency (positive effect on efficiency). This aligns with an expectation of larger vessels being able to operate more efficiently. If effort creep had occurred, vessel length could have been used as an unregulated input to increase effort. However, given the limited evidence for the occurrence of effort creep, it is not an expectation that vessel length would have been overcapitalised under effort controls.

## Efficiency of output controls with transferrable quota

Output controls are preferable from a management perspective as it negates the potential for effort creep; fishers are able to choose a combination of inputs that result in the most efficient operation to be allocatively efficient. When combined with a system of individual transferrable quotas, those fishers that most value fishing rights (based on expected profit) are able to purchase them from those that value them least, resulting in the most efficient operators remaining in the fishery.

Output controls were introduced in early 2011 and as a result the data used in the analysis extend only to the end of the year in which they were introduced. Therefore, the analysis does not include a full year where output controls were the primary management instrument. A more complete examination of the effect of output controls on technical efficiency, while controlling aggregate fishery catch to a predetermined target, must include at least one full year of data post implementation. This is a worthwhile topic of research to revisit once more data become available.

# 5 Conclusions

The main objective of this analysis was to investigate the level of vessel-level technical efficiency in the Eastern Tuna and Billfish Fishery, and the effects of management changes on technical efficiency. Two key management changes were studied: the structural adjustment package, which contributed to a continued reduction in fleet size, and introduction of effort controls for a 16-month period ending in February 2011.

Fleet size was shown to have little effect on the technical efficiency of individual vessels. An increase in the average technical efficiency may have been partly a result of a change in fleet composition, with the least efficient vessels exiting the industry. However, the aggregate effect of a reduction in crowding and in shared information was shown to have not been a significant indicator of changes in vessel-level technical efficiency over the past decade. Based on this, it can be concluded that the structural adjustment package did not adversely affect the technical efficiency of individual vessels. It is possible that the management action contributed to an increase in average technical efficiency as a result of a change in fleet composition; however, this was not tested in the model developed for this paper.

A limit on the total number of hooks used in the fishery, with tradeable rights, had the potential to result in effort creep. Effort creep is characterised by an over-utilisation of unregulated inputs and under-utilisation of regulated inputs, which will generally result in reduced technical efficiency. The model suggested that effort creep did not occur, which could plausibly be the result of a non-binding effort limit, the limited substitutability of hooks as an input to production and/or the brief, pre-determined time period in which effort controls were in place.

A valuable area of future research would be to study the effect of the recent introduction of a total allowable commercial catch with individual transferrable quotas. As this management change took effect in March 2011, data collected so far were insufficient. At least one complete financial year of data would be needed to reach any meaningful conclusions.

A key result of the analysis is that a level of technical inefficiency exists in the fishery. Continued monitoring of the technical efficiency effects of management changes is vitally important for successful fisheries management. In achieving a catch target consistent with fisheries management objectives, maximising technical efficiency is important in achieving one of the primary objectives of the Harvest Strategy Policy: 'to maximise the net economic returns [of fisheries] to the Australian community' (AFMA 2011), particularly in a fishery where domestic management actions have a limited effect on stocks.

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