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Measuring boat-level efficiency in Commonwealth fisheries

An example using the Commonwealth Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery

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Abstract

Australian Commonwealth fisheries are managed with the objective of maximising economic returns to the Australian community—an objective that may be served by increasing the efficiency of the fishing fleet. This paper presents a stochastic frontier analysis (SFA) of the Commonwealth Trawl Sector (CTS) of the Southern and Eastern Scalefish and Shark Fishery. ABARES used boat-level data to explore the potential of the SFA approach to determine the efficiency of the fleet and find reasons for any inefficiencies.

This preliminary work:

- indicates significant inefficiency in the CTS fleet
- provides some support for the hypothesis that a structural adjustment in 2006 resulted in less efficient boats leaving the fishery, which led to improved economic returns
- shows that interannual effects, such as stock availability, management changes and technical change, play a large role in the estimated frontier and must be disentangled from each other in further work to provide more information for managers.

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1 Introduction

The Commonwealth Fisheries Harvest Strategy Policy aims to maintain key commercial stocks at ecologically sustainable levels and maximise economic returns to the Australian community by targeting maximum economic yield (MEY) (DAFF 2007). To assess the performance of Commonwealth fisheries against MEY, fishery policymakers frequently rely on economic indicators for information about economic activities in the fishery. ABARES presents a range of such indicators in its *Australian fisheries economic indicators report* series*.* The economic indicators used to inform fishery management generally serve two main purposes: they inform management decisions against the economic objective and they monitor management performance against the economic objective.

Achieving maximum technical efficiency is an important aspect of increasing economic returns and achieving MEY. This paper uses the stochastic production frontier (SFA) approach to develop an indicator of fleet-level technical efficiency. The analysis presented here uses a combination of catch and effort data from the Commonwealth Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery and economic data from ABARES financial and economic surveys of the fishery to develop this indicator.

An indicator of technical efficiency is useful to fishery managers charged with maximising economic returns from the fishery. For example, this indicator is useful for better understanding the effect on efficiency from management changes (for instance gear restrictions, closures of areas to fishing or structural adjustment)—something not possible with total factor productivity analysis. The preliminary results presented here suggest that the Securing Our Fishing Future Structural Adjustment Package in 2006 increased average technical efficiency of the fleet operating in the Commonwealth Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery by prompting the exit of the least efficient vessels.

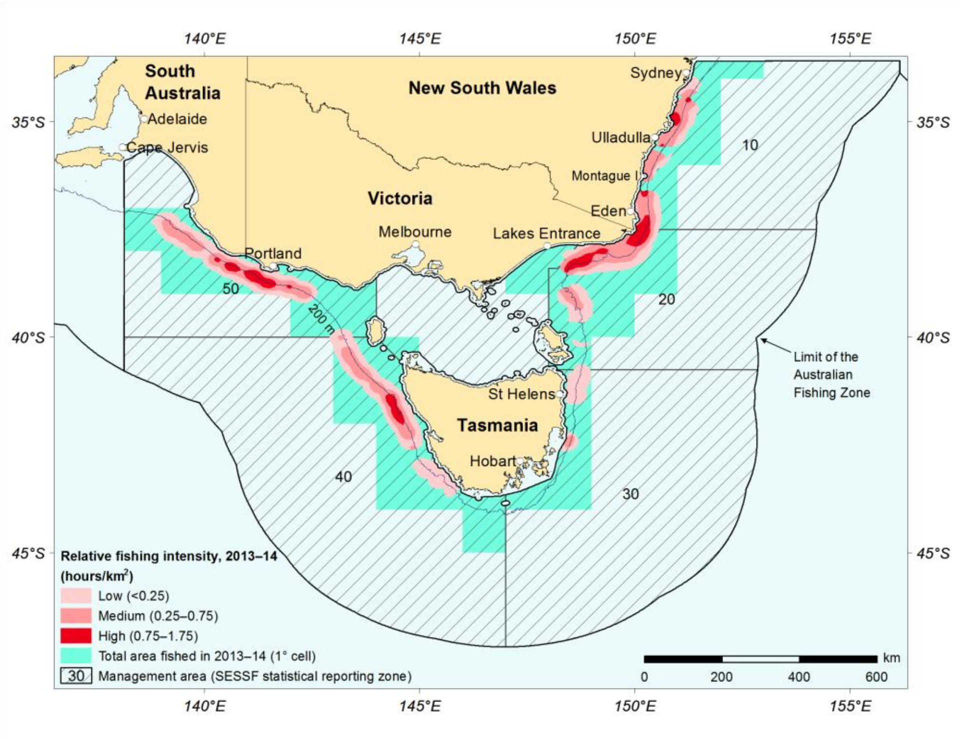
ABARES has presented prior SFA work on boat-level efficiency for the Eastern Tuna and Billfish Fishery in New (2012). The analysis presented in this paper extends that work by incorporating ABARES economic survey data. New (2012) used only logbook data to produce a method applicable to all fisheries, especially those too small to warrant dedicated bioeconomic models or financial surveys.

2 Commonwealth Trawl Sector

Background of the sector

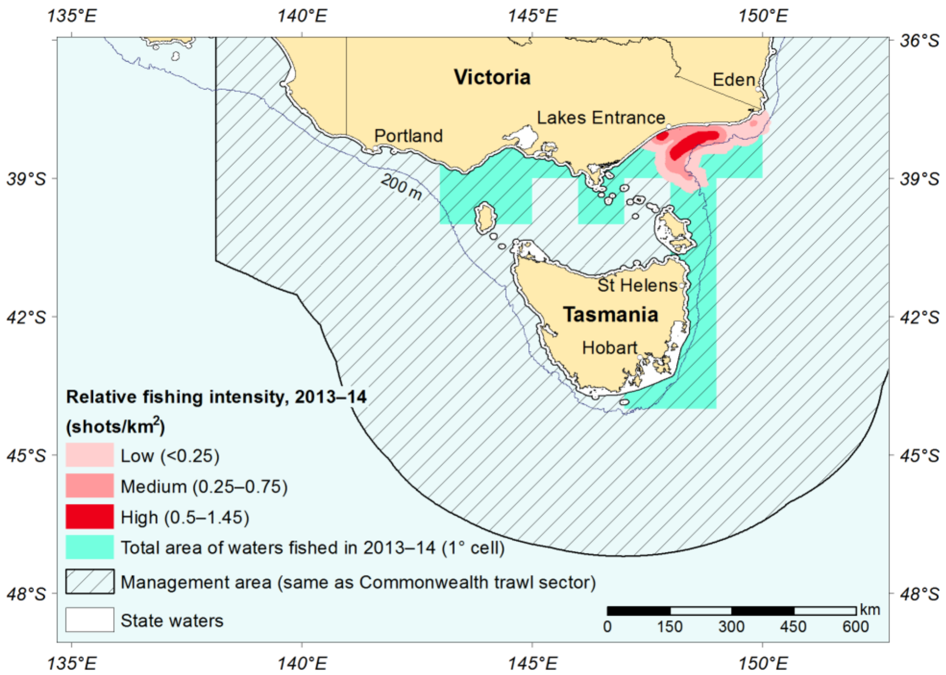
This paper evaluates the use of stochastic frontier analysis using ABARES survey data for the Commonwealth Trawl Sector (CTS) of the Southern and Eastern Scalefish and Shark Fishery (SESSF). In 2013–14 the CTS was the second largest Commonwealth fishery in terms of gross value of production (GVP), with landings valued at $40.2 million (Savage & Hobsbawn 2015). The CTS uses both otter trawl and Danish seine methods. In 2013–14, 33 trawlers reported around 47 057 hours of combined fishing effort and 14 Danish seine fishers reported 7 525 shots, concentrated off eastern Victoria. The CTS stretches from Sydney south around Tasmania to Cape Jervis in South Australia, where it abuts the Great Australian Bight Trawl Sector (Map 1 and Map 2). Key landing ports of the CTS are Ulladulla, Eden, Lakes Entrance, Hobart and Portland. Fishing effort is highly concentrated and the total area fished makes up a small proportion of the defined fishery.

Map 1 Area of the Commonwealth Trawl Sector—otter trawl



Source: Skirtun & Green 2015

Map 2 Area of the Commonwealth Trawl Sector—Danish seine



Source: Skirtun & Green 2015

Key economic trends

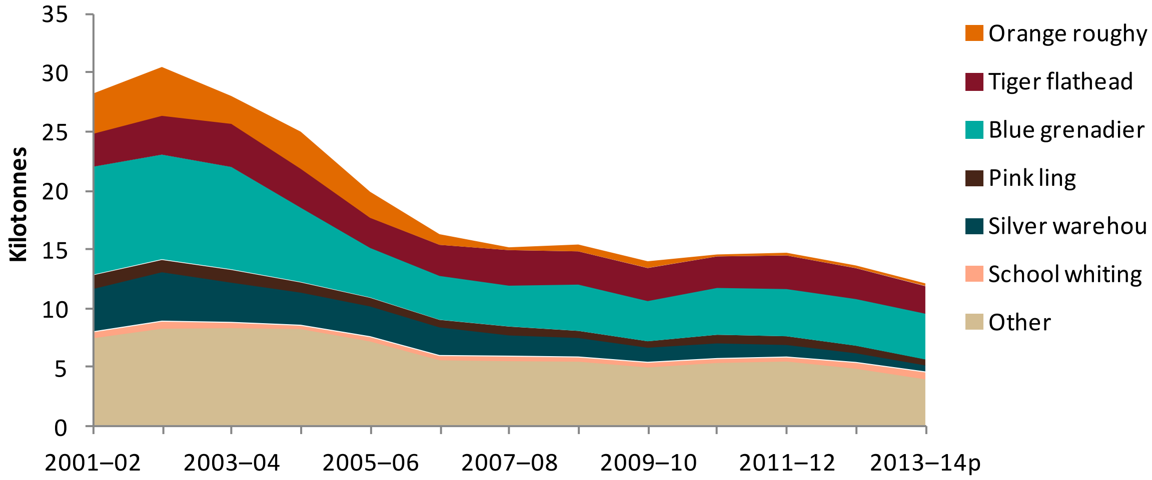
The CTS is a major source of Australian fresh fish for the Sydney and Melbourne markets. Key target species include tiger flathead, blue grenadier, pink ling, silver warehou and eastern school whiting. These five species collectively accounted for about 76 per cent of the landed catch and 66 per cent of the sector's GVP in 2013–14 (Georgeson et al. 2015). The catch for these key species declined sharply from 2001–02 to 2005–06. Between 2005–06 and 2013–14 the decline has continued at a slower rate (Figure 1).

In 2013–14 total catch for all species was 10 677 tonnes, well below the peak of 30 558 tonnes in 2002–03. The reduction from this peak was driven by a 4 858 tonne (57 per cent) reduction in blue grenadier catch and a 3 541 tonne (87 per cent) reduction in silver warehou catch. In addition, orange roughy, once a major component of the fishery, could not be commercially targeted outside the Cascade Plateau after 2006 and formed a negligible proportion of the catch in the survey years.

The real gross value of production in the CTS has declined sharply from 2001–02 to 2006–07 driven by falling catch, before declining at a more moderate pace to 2012–13 (Figure 2). GVP in 2012–13 was $57.9 million, down from $97.2 million in 2001–02 (2013–14 dollars). This was despite increases in the prices of tiger flathead (51 per cent) and blue grenadier (4 per cent). In 2013–14 GVP fell to $40.2 million as a result of reductions in catch, as total allowable catch limits (TACs) declined, and lower fish prices, including flathead, ling and blue grenadier.

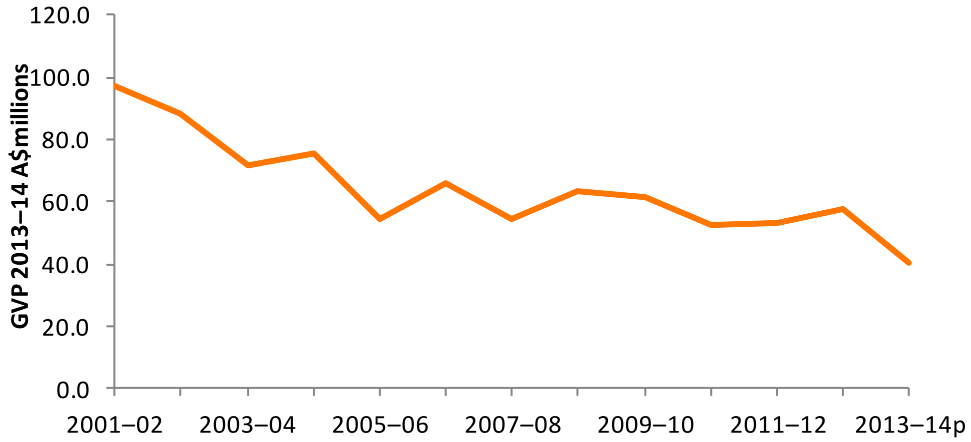
Net economic return (NER) in the CTS has fallen since a peak of $7.3 million in 2010–11, to $4.2 million in 2012–13, and was projected to fall to $1.4 million in 2013–14 (Figure 3) driven by lower GVP. NER was negative until 2005–06 (Skirtun & Green 2015).

Figure 1 Landed catch, Commonwealth Trawl Sector, 2001–02 to 2013–14



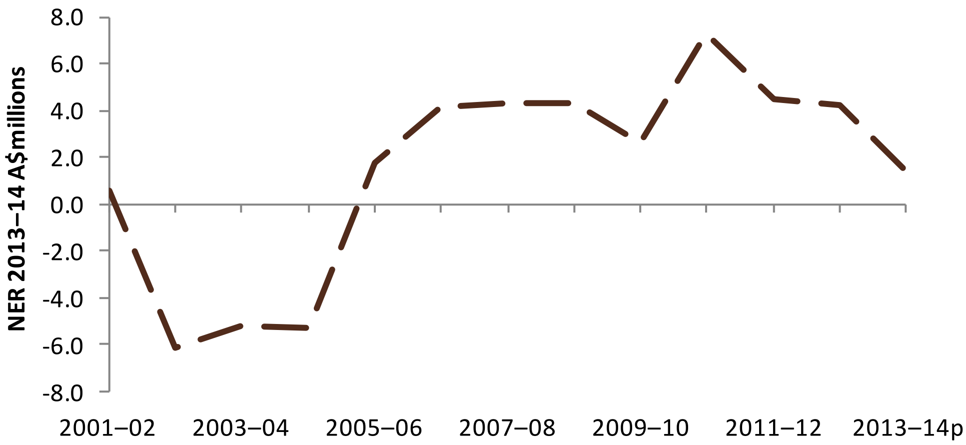
p Preliminary estimate.
Source: Skirtun & Green 2015

Figure 2 Real gross value of production, Commonwealth Trawl Sector, 2001–02 to 2013–14



p Preliminary estimate.
Source: Skirtun & Green 2015

Figure 3 Net economic return, Commonwealth Trawl Sector, 2001–02 to 2013–14



p Preliminary estimate.
Note: Time series of financial and economic performance tables are available on the ABARES website.
Source: Skirtun & Green 2015

Current management arrangements

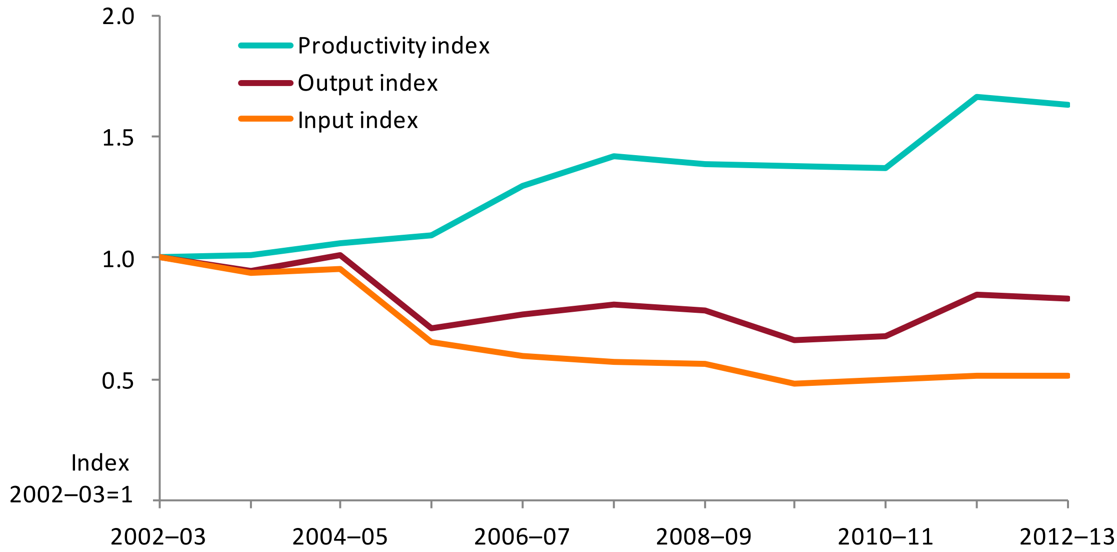
The key commercial species in the CTS are managed under TACs, set to target MEY from the fishery. TACs are set for quota species for each fishing season and allocated to quota holders through individual transferable quotas. In 2006 the Securing Our Fishing Future Structural Adjustment Package resulted in removal of half of the 118 concessions originally available in the sector and reduced the number of active vessels (Vieira et al. 2010). Results suggest that the average technical efficiency in the fishery was improved as less efficient vessels left the fishery.

All species groups under quota are managed under the SESSF harvest strategy framework (Georgeson et al. 2015). The harvest strategies target B_{MEY}, a biomass associated with MEY. For the key species in the CTS this has generally been through a proxy target reference point of $0.48B_0$ or 48 per cent of virgin biomass (estimated biomass prior to commercial fishing).

Trends in total factor productivity

The total factor productivity (TFP) analysis presented in Skirtun & Green (2015) and other ABARES economic indicator reports demonstrates aggregate inputs have fallen at a greater rate than aggregate outputs over the surveyed period (Figure 4). As a result, the TFP index has increased, especially after the structural adjustment in 2006, and has likely played a large role in improved NER (Skirtun & Green 2015).

Figure 4 Productivity indexes, Commonwealth Trawl Sector, 2002–03 to 2012–13



Source: Skirtun & Green 2015

The undecomposed TFP index is unable to identify the source of changes in productivity. Management factors that could influence TFP include:

- changes in the composition of the fleet—for instance, less efficient vessels exiting as a result of structural adjustment
- greater stock abundance relative to fleet numbers following the exit of many vessels
- adoption of the Commonwealth Fisheries Harvest Strategy Policy, including the MEY objective
- changes in gear and spatial restrictions.

To evaluate their actions, managers must be able to distinguish the management factors from each other and from non-management effects such as:

- stock variation between years due to natural factors
- technical change over time
- improved technical efficiency by fishers.

The preliminary work in this paper indicates that changes in composition of the fleet have improved efficiency, and that fishers may further improve efficiency and net economic returns. It also suggests methods for isolating other effects in future work.

3 Data

Sources

This study uses two primary sources of data to create unbalanced panel data from 2002–2003 to 2012–13.

Australian Fisheries Management Authority logbook and registration data

All fishers in Commonwealth fisheries are required to record catch and effort data for the Australian Fisheries Management Authority (AFMA). These data are shared with ABARES for specific purposes, including for the *Fishery status reports* series and *Australian fisheries economic indicators report* series.

Data are available at a boat level for all boats in a fishery and include:

- landed catch per species—combined with price data from ABARES GVP determination work to calculate the output index described in the methodology section
- effort data—recorded differently depending on the sector, but includes hours trawled for trawling operations, shots for Danish seines and number of hooks for hook fishing. This study makes use of days fished.

Data on boat length and engine power are also available but have not been used here. Previous ABARES SFA analysis in New (2012) relied entirely on these data using effort as input variables.

ABARES survey data

ABARES has undertaken economic surveys of selected Commonwealth fisheries since the early 1980s. These have been done on a regular basis for particular fisheries since 1992. The current fisheries survey program involves surveying major Commonwealth fisheries every two years; smaller fisheries (in terms of GVP) are surveyed on an ad hoc basis, such as when a fishery is undergoing major changes and monitoring is particularly important. ABARES aims to develop a consistent time series of economic information for each fishery. Such information, in conjunction with scientific assessments of each fishery, is vital for assessing fisheries' economic performance.

ABARES survey reports are made publicly available along with aggregated data products.

The primary fisheries surveyed are:

- Commonwealth Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery
- Gillnet, Hook and Trap Sector of the Southern and Eastern Scalefish and Shark Fishery
- Eastern Tuna and Billfish Fishery
- Northern Prawn Fishery
- Torres Strait Prawn Fishery.

Other fisheries are included on an irregular basis.

ABARES surveys are designed and samples selected on the basis of information provided by AFMA. This information includes data on the volume of catch, fishing effort and boat characteristics.

Between February and August, an ABARES officer visits the owner of each boat selected in the sample. The officer interviews the boat owner to obtain physical and financial details of the fishing business for the survey years. When necessary the skipper of the boat is also interviewed. Further information is subsequently obtained from accountants, selling agents and marketing organisations on the signed authority of survey respondents.

Information obtained from various sources is reconciled to produce the most accurate description possible of the financial characteristics of each sample boat in the survey.

For the purposes of this study, these data provide information on the value of boat capital, labour inputs and fuel inputs. Other data are available on less important inputs (for instance freight), on boat year of manufacture and, in selected other fisheries, skipper characteristics. These data may potentially be used in further extensions of this work.

The use of these input variables distinguishes this work from New (2012) and may provide better indicators of how economic returns have changed and can be improved.

ABARES fisheries survey data have many similarities with ABARES farm survey data, which have been used in prior SFA studies including Hughes et al. (2011), Coelli and Sanders (2013) and Morey (2013). However, a major difference is that fisheries survey data are collected at a boat level rather than firm level, leaving major inputs and technologies (the boat characteristics) largely fixed.

Panel data

The result of combing these datasets is a single unbalanced panel dataset from 2003 to 2013 comprising 188 observations of 45 vessels (Table 1). Boats have been in the sample between 1 and 11 years in the sample, with an average tenure of 4 years.

Because ABARES survey data are based on financial years (in accordance with bookkeeping practice) panel data are necessarily split by financial years. This potentially causes some complications in the analysis as the fishing season (beginning on 1 May) is not concurrent with the financial year. This is notable for the period of the exit of vessels following the 2006 fishing season, which reported data in the 2007 financial year for the period of overlap.

An important caveat is that panel data include both trawl vessels and Danish seine vessels, but make no attempt to distinguish between the two technologies. This distinction might be desirable in future work.

Fixed technologies

These panel data are at a boat level rather than firm level. This means that a major input—the boat—can neither be scaled up nor down. The length of the boat is a fixed input, although features of the boat, for instance engine power, can be altered between years. This is different to conventional uses of SFA on firms, where the only necessarily fixed feature is the registered business or continuing manager.

Boat-level data can complicate things, especially for a fishery like the CTS that has periodic entry of large factory vessels into the fishery. These vessels are longer, have much larger crews and greater fuel use, catch much more fish but often fish for shorter seasons. Entry of a factory vessel can shift the production possibility frontier significantly.

Table 1 Panel data—number of vessels

Financial year ending	Panel observations	Fishery population
2003	18	105
2004	22	102
2005	25	97
2006	20	89
2007	18	81
2008	13	53
2009	14	53
2010	15	51
2011	15	50
2012	14	50
2013	14	50
Total	**188**	**781**

Source: AFMA and ABARES

4 Methodology

Economic efficiency is an important area of study, especially for highly regulated parts of the economy such as fisheries. Such studies can help policymakers create market structures that can maximise economic returns.

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. Economic efficiency requires that both technical and allocative efficiency is achieved.

Measuring technical inefficiency is the focus in this paper. In part this means that the results provide a measure that should not be confused with a profit maximising level of production. To determine if boats are operating in the most profitable manner possible, one requires an estimate of allocative efficiency.

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.

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 cannot be attributed to measured factors that are likely of interest to managers.

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

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 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 means the production function has not been estimated correctly or has not accounted fully for statistical noise.

Output index

Because the Commonwealth Trawl Sector (CTS) 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 weights catch volume by price to account for the productive value of different qualities of fish. However, this methodology is not suitable for applying to the CTS. Significant 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. This makes it hard to distinguish between the value of the fish at the boat level, which would contribute toward vessel revenue, and the value added in the manufacturing process, which would contribute to profit derived from the manufacturing process.

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 approach is adapted from New (2012) who applied it to the Eastern Tuna and Billfish Fishery. This overcomes the issue of several different fisheries products in the one fishery and accounts for the difference in value of each product while minimising the effect of changing fish prices, whether highly volatile or subject to low-term trends as consumer preferences change—as occurred with silver warehou.

The output index comprises four major targeted fish species in the fishery (tiger flathead, blue grenadier, pink ling and silver warehou), as well as a number of other species both targeted and non-targeted. 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. In practice this may not be a realistic assumption but adjustments are not possible given the data available. However, the prices used are a reasonable representation of the average fish quality.

Nine species (blue grenadier, blue eye trevalla, school whiting, jackass morwong, mirror dory, orange roughy, pink ling, silver warehou and tiger flathead) are included in the index, as well as a composite 'other species' variable for the remainder of the catch.

Inclusion of non-targeted or incidental species (such as orange roughy) is not straightforward. Fishers do not explicitly decide to try to catch these species and may be prohibited from doing so. However, the fish can still be sold on the market and provide an economic return to fishers.

A multilateral Fisher index with an EKS extension is used to create the output index and is described in this section with a discussion of its appropriateness. The alternative Tornqvist index was not used because frequent zero values for particular species would have made calculation problematic.

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 using a 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 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. Use of a bilateral Fisher index could 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

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

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 in 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 trawl and others fishing methods, inputs are largely non-allocable. That is, effort (for example, hooks, trawling and shots), fuel and labour are unable to be effectively designated exclusively to a single species. Based on this it could be argued, that the radial expansion assumption is reasonable in a fisheries context, 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. However, it is uncertain whether the assumption is appropriate given the potential for significant variation in stock availability because of changing migration patterns from year to year. The ability to target certain species using methods other than technology, such as area selection, may mean assumption of non-allocability of effort is less reliable. There are indications in the data and anecdotally that a small number of vessels in the fishery are able to specialise in particular species.

Using a Fisher output index in the SFA framework may impose assumptions about the optimality of fishers' output mixes. It also may assume that fishers are price takers and are not choosing output levels to influence market prices.

Future work may use total catch indexed to a Fisher price index. This should yield the same substantive results but provide coefficients that are easier to interpret, particularly for policy audiences.

Input data

The model uses these variables:

- quantity of fuel used—derived by dividing total expenditure on fuel from ABARES survey data by the average diesel price for that year
- quantity of labour—derived by multiplying usual total crew data from the ABARES survey by total days fished from logbook data
- total days fished—used as an indicator of boat capital use (with all boats implicitly quantified as 1). Future work may incorporate characteristics such as length or engine power
- year proxies for 2004 to 2013—used to capture changing stock availability between years. This also implicitly captures technical change and management changes (including gear restrictions and closures) and some part of changing sample composition. A quadratic time trend was considered, but rejected based on a log-likelihood test. Inclusion of more variables in future work may mean a quadratic time trend is more appropriate
- factory vessel proxy—1 if the vessel is a freezer factory vessel and 0 otherwise, reflecting the different technologies used.

Determinants of technical inefficiency

The model presented here has a single determinant of technical inefficiency—total value of boat capital, which is from ABARES survey data and logged to normalise.

Vessel length was tested but was rejected based on a log-likelihood test and was insignificant when combined with the value of boat capital (of which it is likely a component) along with other characteristics such as engine power. Future work may consider length and engine power (available in registration data) as separate variables.

Year of manufacture is present in survey data but was not used. Other fisheries survey data include skipper characteristics such as age and years of fishing experience in a given fishery but these are not available for the CTS.

New (2012) uses fleet size as an explanatory variable to assess the effects of the Securing Our Fishing Future structural adjustment. This can distinguish the effects of greater stock per vessel on efficiency as distinct from the changing composition of the fleet—that is, the exit of less efficient vessels. The model presented in this paper has not attempted this but may incorporate it in future.

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. 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 both on the value of a single parameter and 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.

5 Issues, results and implications

Analysis was undertaken using the 'R software environment for statistical computing and graphics' (R Development Core Team 2012) with the frontier package (Coelli & Henningsen 2009).

Issues

For accurate estimates of efficiency, estimated frontiers should monotonically increase for all outputs (Henningsen & Henning 2009). Otherwise, boats producing the same output but with more inputs would seem to be more efficient because the frontier estimates negative returns to scale. After estimating the model, tests revealed that the translog function monotonically increased for fuel, labour and days fished in 90.4 per cent of observations. This violation of monotonicity is a common issue in SFA analysis and was expected in this study given the nature of a boat-level dataset and considerable heterogeneity in the fleet. This work uses the method of Henningsen and Henning (2009) to impose monotonicity restrictions on the model to produce more reliable estimates of technical efficiency.

The unrestricted and restricted (where monotonicity assumptions are violated) frontier models are presented in Table 2 and the technical efficiency models in Table 3. Notable differences in coefficients between the unrestricted and restricted models occur for the year proxies—for example, contracting the frontier in the restricted model for the year 2009. As such, the efficiency estimates differ between the restricted and unrestricted model across the years considered in the analysis. In the restricted model estimated efficiencies—discussed in a following section—for the 2009 example are mainly higher than in the unrestricted model (Figure 5). This highlights the major role year proxies play in the sensitivity of the model. These year proxies likely incorporate a number of distinct effects, including:

- stock variability
- management changes—including closures, gear restrictions and introduction of the Harvest Strategy Policy
- technical changes
- changes in composition of the surveyed fleet.

Inclusion of more variables may capture these separately and reduce the complications associated with monotonicity.

The frontier tends to shift from year to year, further highlighting the importance of disentangling year effects in the analysis. Figure 6 shows how contributions of the year proxies to the frontier vary over time.

Table 2 Frontier estimation

Dependent variable—ln(Fisher EKS output index)											
Variable	**coefficient**	**standard –error**	**t–ratio**	**p–value**	**Significance**	**adjusted coefficients**	**difference**	**difference/standard error**	**t–ratio**	**p–value**	**Significance**
constant	–6.3058	0.6723	–9.3802	0.0000	***	–9.5985	–3.2927	–4.8977	na	na	na
ln(fuel)	–0.4	0.396	–1.0099	0.3126	_	0.9131	1.3131	3.3159	na	na	na
ln(labour)	0.2865	0.3359	0.8529	0.3937	_	1.7224	1.4359	4.2748	na	na	na
ln(days fished)	2.2783	0.2405	9.475	0.0000	***	0.3467	–1.9316	–8.0316	na	na	na
ln(fuel)^2	–0.1052	0.081	–1.2984	0.1942	_	–0.1186	–0.0134	–0.1654	na	na	na
ln(fuel) * ln(labour)	0.316	0.0679	4.6527	0.0000	***	0.0122	–0.3038	–4.4742	na	na	na
ln(fuel) * ln(days fished)	–0.1385	0.0503	–2.7553	0.0059	**	0.0061	0.1446	2.8748	na	na	na
ln(labour)^2	–0.5973	0.0512	–11.661	0.0000	***	–0.2124	0.3849	7.5176	na	na	na
ln(labour) * ln(days fished)	0.3362	0.0487	6.9007	0.0000	***	–0.039	–0.3752	–7.7043	na	na	na
ln(days fished)^2	–0.6361	0.1123	–5.6666	0	***	–0.0226	0.6135	5.463	na	na	na
Year = 2004	0.083	0.0222	3.7422	0.0002	***	0.1644	0.0814	3.6667	na	na	na
Year = 2005	0.1927	0.0131	14.75	0	***	0.1924	–0.0003	–0.0229	na	na	na
Year = 2006	0.0967	0.0497	1.9471	0.0515	.	0.0893	–0.0074	–0.1489	na	na	na
Year = 2007	0.2974	0.0099	29.972	0.0000	***	0.2573	–0.0401	–4.0505	na	na	na
Year = 2008	0.3996	0.0603	6.6283	0.0000	***	0.39	–0.0096	–0.1592	na	na	na
Year = 2009	0.732	0.0907	8.0742	0.0000	***	0.5045	–0.2275	–2.5083	na	na	na
Year = 2010	0.3165	0.0414	7.6496	0.0000	***	0.2361	–0.0804	–1.942	na	na	na
Year = 2011	0.1944	0.0252	7.7143	0.0000	***	0.1441	–0.0503	–1.996	na	na	na
Year = 2012	0.3683	0.0249	14.817	0.0000	***	0.2675	–0.1008	–4.0482	na	na	na
Year = 2013	0.28	0.0294	9.5279	0.0000	***	0.2558	–0.0242	–0.8231	na	na	na
factory vessel proxy	2.6875	0.121	22.214	0.0000	***	1.8195	–0.868	–7.1736	na	na	na
σ^2	0.3671	0.0482	7.6206	0.0000	***	0.4504	0.0833	1.7282	5.0971	0	***
γ	1	0	1.52E+07	0.0000	***	1	0	na	2263.97	0	***

na Not applicable.

Note: Significance codes are 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘_’.

Table 3 Technical inefficiency model

	Unrestricted					Restricted				
variable	**Coefficient**	**Standard–error**	**t–ratio**	**p–value**	**Sig.**	**Coefficient**	**Difference**	**t–ratio**	**p–value**	**Sig.**
intercept	11.975	1.0838	11.05	0.0000	***	10.5738	–1.4012	7.1574	0.0000	***
ln(total boat capital)	–0.8608	0.0794	–10.838	0.0000	***	–0.7524	0.1084	–7.1387	0.0000	***
mean technical efficiency (unrestricted) 0.67						**mean technical efficiency (restricted) 0.63**				

Sig Significance.
Note: Significance codes are 0 '***', 0.001 '**', 0.01 '*', 0.05 '.', 0.1 '_'.

Figure 5 Unrestricted and restricted efficiency estimates

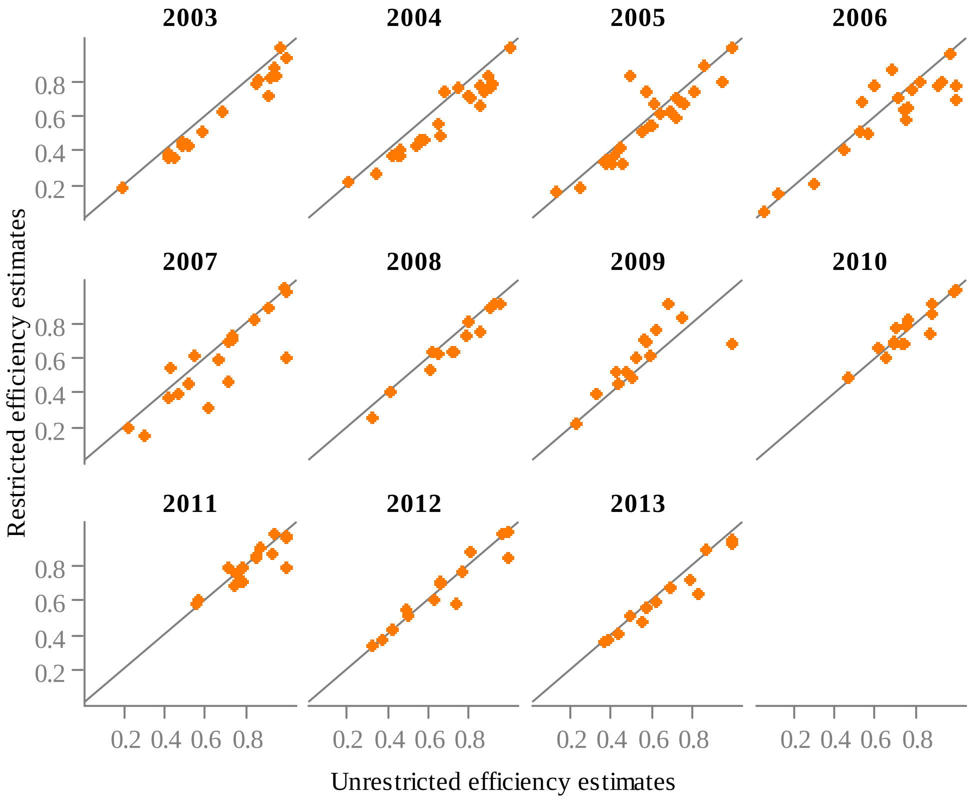
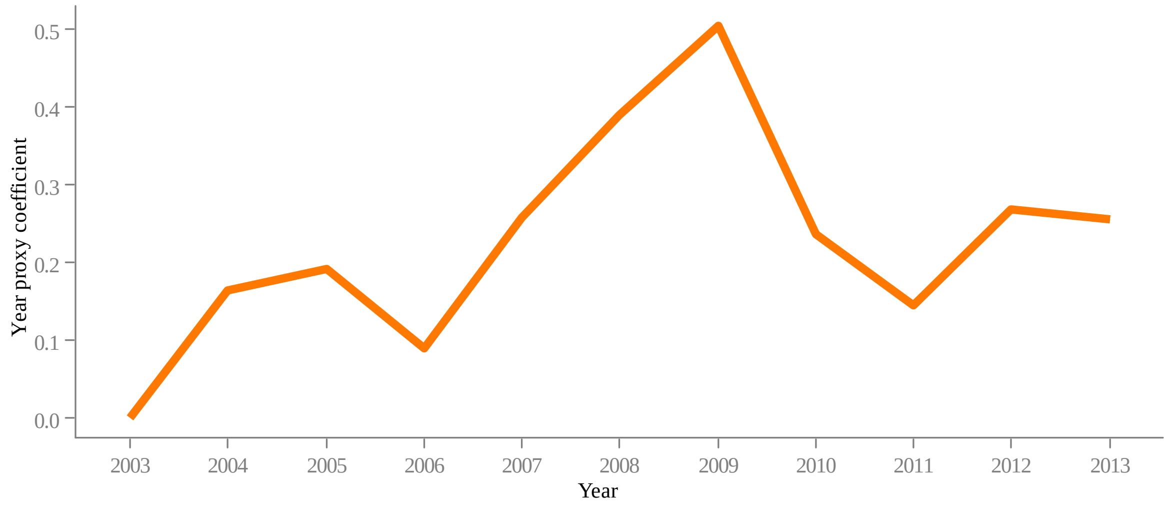


Figure 6 Year proxy coefficients



Results

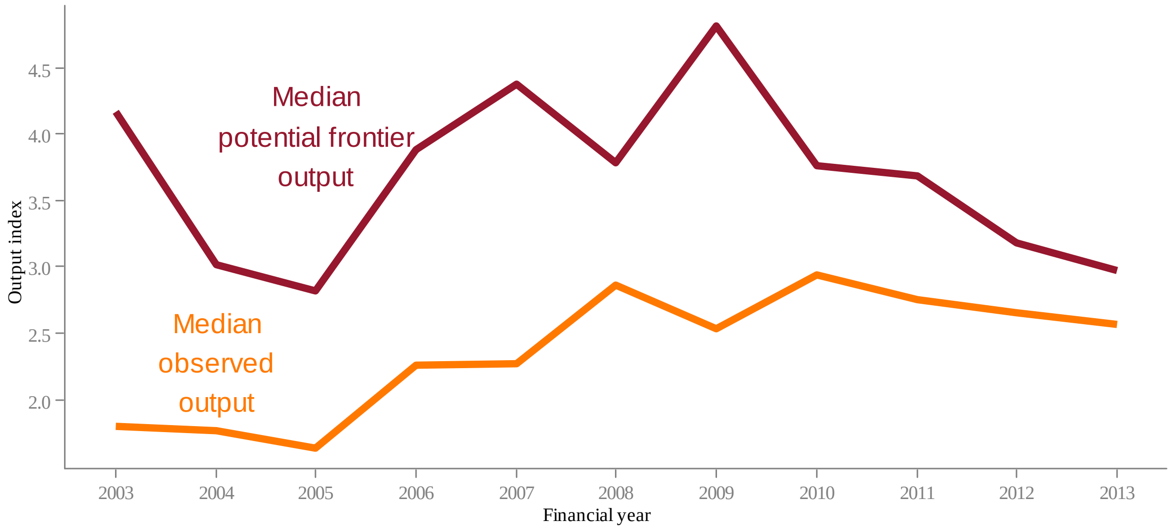
Inefficiency

The restricted model estimates that there is inefficiency (with a high level of statistical significance) in the Commonwealth Trawl Sector, with a mean estimate of 63 per cent efficiency over the 11 year period (2002–03 to 2012–13)). The distribution of estimates ranges from 0.04 to 0.999 and is skewed positively, with a median estimate of 67 per cent. This implies a significant gap between the observed output of the fleet and the estimated potential output of the fleet (at 100 per cent efficiency) for a given level of inputs (Figure 7). The presence of seemingly implausible efficiency estimates (such as 0.04) may also indicate model misspecification or a need to restrict the sample further.

The inefficiency model shows the total value of boat capital is negatively correlated with inefficiency. This implies that fishers may be able to improve efficiency by investing in their boats. Further work is needed to determine whether this is best achieved through newer boats, more powerful engines or larger boats.

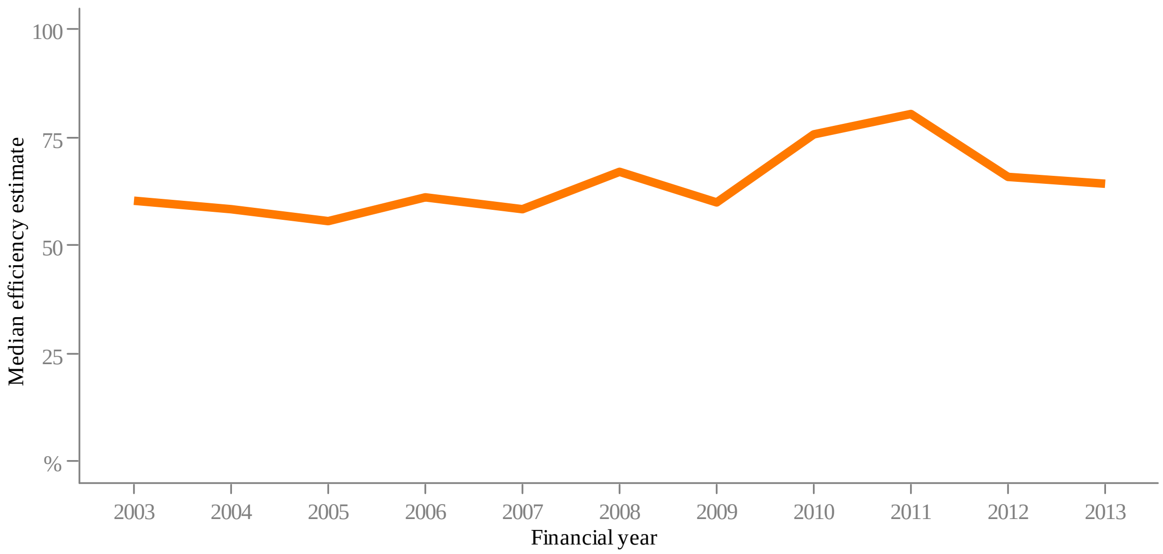
Figure 8 shows the median observed efficiency estimate has increased over time, including an upward trend after many boats exited the fishery during the 2006–07 financial year (discussed in the next section), but fell from 2011 to 2013. The peak of efficiency in 2009 and subsequent decline may have played a role in the decline in estimated economic returns in the same period, as shown in Figure 3.

Figure 7 Median restricted model output and frontier output for observed levels of inputs



Note: Medians are used because means would indicate if a factory vessel (with much higher frontier output) is present or absent in a given year, violating ABARES confidentiality commitments.

Figure 8 Median restricted model efficiency estimates over time



Effects of the structural adjustment

The efficiency estimates were used to test the inference drawn in Skirtun and Green (2015) and Vieira et al. 2010 that the Securing Our Fishing Future adjustment package following the 2006 season increased average efficiency (and thus net economic returns) by prompting the exit of less efficient boats from the fleet. The results support the inference.

Figure 9 shows boat-level efficiency estimates (from the restricted model) from 2003 to 2013. Vessels not present in logbook data after financial year 2007, which overlaps with the final months of fishing season 2006, are assumed to have exited the fishery. However, some of these boats may have been temporary entrants who would not have remained anyway. The figure shows that exiting boats appear to have been, on average, less efficient for each of the four years preceding the structural adjustment.

Figure 9 Boat-level restricted model efficiency estimates, highlighting exited and remaining vessels

Table 4 shows a test of the hypothesis that boats that exited the fishery had a lower average mean using the Welch two sample t-test. The samples are restricted to the 2003 to 2006 financial years as the 2007 season only captured a few months of activity by exiting boats, although this does not materially change the results. The results indicate the difference is significantly greater at the 0.001 significance level and that the minimum difference at the 95 per cent confidence level is 0.09. It is reasonable to conclude the adjustment package did lead to less efficient fishers exiting, which may have been responsible for improved NER as described in Skirtun & Green (2015). This finding is robust over all model specifications assessed.

Table 4 Comparison of exiting and remaining boats estimates, 2003 to 2006 only

Mean efficiency estimate (restricted model)			
Exiting boats			0.48
Remaining boats			0.65
Welch two sample t-test—alternative hypothesis that difference in mean is less than 0			
t-value	**Degrees of freedom**	**p-value**	**Lower bound difference at 95 per cent confidence interval**
–3.738	69.531	0.0002	–0.0937

Structural adjustment may have allowed greater efficiency for remaining boats by making stock more abundant relative to fleet numbers and, therefore, less costly to 'chase fish'. This outcome is consistent with the objectives of the concurrently introduced Harvest Strategy Policy and one suggested by the upward trend in Figure 8. Table 5 shows the outcomes of a t-test comparison before and after the structural adjustment (including the overlap year of 2007) observations for boats who were still active in the fishery between 2007 and 2013.

The results are not significant at the 0.05 threshold, implying that the observed increases in efficiency after the structural adjustment were due mainly to changes in the composition of the fleet rather than improved efficiency by fishers. However, any effects of greater stock abundance per vessel would likely be captured in the year proxies in the frontier model (along with technical change, interannual stock availability and other management changes) rather than being incorporated into efficiency estimates. The restricted model coefficients for the year proxies range between –0.08 and 0.71 prior to adjustment and between 0.09 and 0.50 afterwards. Determining what proportion of this variation is a result of a reduction in fleet numbers and what is resulting from other factors requires future work.

Table 5 Comparison of boats operating after 2006, before and after structural adjustment

Mean efficiency estimate (restricted model)			
Before 2007			0.65
2007 to 2013			0.69
Welch two sample t-test—alternative hypothesis that difference in mean is less than 0			
t-value	**Degrees of freedom**	**p-value**	**Lower bound difference at 95 per cent confidence interval**
–1.4268	135.23	0.078	–0.0077

6 Further work

The preliminary work described in this paper shows potential for SFA to be applied to boat-level survey data and to provide economic indicators useful to fisheries managers. It appears to support the established hypothesis that structural adjustment led to the exit of less efficient fishers, improving average efficiency and net economic returns.

To be more useful to managers the technique may be refined to:

- distinguish between various management changes, for instance gear restrictions, effort controls (as discussed in New 2012, spatial closures and biomass targeting strategies, including the Harvest Strategy Policy
- incorporate stock levels, for instance variables used by Stephan and Vieira (2013)
- indicate sources of inefficiency by incorporating variables such as skipper characteristics (for example, age and experience) and vessel characteristics (for example, length, engine power and year of manufacture). This may indicate the optimal level of investment in Australian fishing fleets.

Other issues are unresolved, including:

- the effects of applying SFA to boat-level data where many features of boat capital and technology are fixed
- why negative coefficients for fuel use are found in most model specifications. This may be an artefact of stock availability or bad luck, whereby boats that expend more fuel are those searching for, and failing to find, fish. A better model specification may be required
- how best to incorporate different fishing technologies, such as trawl and Danish seining, and different magnitudes (such as factory vessels) when subsamples of such populations are small and where managers desire sector-wide estimates. Logbook data include effort such as hours trawled and number of shots that are distinct for each technology.

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