Catch, Efficiency and the Management of the Australian Northern Prawn Fishery*

Tom Kompas
National Centre for Development Studies
Australian National University
tom.kompas@anu.edu.au
and
Australian Bureau of Agricultural and Resource Economics
tom.kompas@abare.gov.au

Tuong Nhu Che
Australian Bureau of Agricultural and Resource Economics

Abstract

This paper is a study of the production technology and relative efficiency of vessels harvesting tiger prawns in the northern prawn fishery (NPF), one of Australia's largest and most lucrative fishing areas. It is based on a unbalanced panel data set of 228 observations among thirty-seven vessels for the years 1990 to 1996, and employs a technique which specifies a stochastic frontier production function in order to decompose the variation in the output due to unbounded random effects from those that result in differences in technical inefficiency among fishing vessels in the industry. Estimation of this output frontier provides key information on the relative importance of inputs in the harvest of tiger prawns, output elasticities, returns to scale and the economic performance of each fishing vessel, year to year. The level of technical inefficiency is shown to depend positively on gear headrope length and negatively on either A-units or fuel expenditures. The point is especially relevant since input controls in the form of A-unit restrictions over vessel size and engine power in the fishery during this period appear to have resulted in a substitution toward less efficient but unregulated inputs, decreasing overall efficiency in the NPF.

*Acknowledgments: Paper presented at the eleventh biannual International Institute of Fisheries Economics and Trade Conference, Wellington New Zealand, August 2002. The authors would like to thank Steve Beare, Janet Bishop, Debbie Brown, Peter Gooday and Bill Venables for helpful comments on this work and the nature of the Australian northern prawn fishery in general. Financial support from the Fisheries Resources Research Fund is gratefully acknowledged. The views expressed herein are those of the authors and do not necessarily reflect the views of ABARE.

JEL Classification: O13, Q22
Keywords: input controls, efficiency, tiger prawns, Australian northern prawn fishery

1. Introduction

The management of open or limited access fisheries is a difficult challenge. In many cases, the harvesting capacity of the fishing fleet exceeds the biological capacity of the resource to regenerate. As a result some type of control with the aim of reducing catch is usually necessary. Ideally, regulation should both enhance economic performance and guarantee the biological sustainability of fish stocks for future generations. Unfortunately, open or limited access fisheries are generally characterized by severe economic inefficiencies, often resulting in excess effort, over-capitalization (e.g., too many vessels and overly large boats, engines and net sizes) and quickly depleted stocks. In addition, some regulatory measures, partly designed to correct these problems, often generate unwanted effects, such as the substitution of regulated inputs for more inefficient but unconstrained inputs in order to maintain catch.

This paper is a study of the production technology and relative efficiency of vessels harvesting tiger prawns in the northern prawn fishery (NPF), one of Australia's largest and most lucrative fishing areas. It is based on a unbalanced panel data set of 228 observations among thirty-seven vessels for the years 1990 to 1996, and employs a technique which specifies a stochastic frontier production function in order to decompose the variation in the output of fish due to unbounded random effects from those that result in differences in technical inefficiency among fishing vessels in the industry. Estimation of this output frontier provides key information on the relative importance of inputs in the harvest of tiger prawns, output elasticities, returns to scale and the economic performance of each fishing vessel, year to year. The level of technical inefficiency is shown to depend positively on gear headrope length and negatively on either A-units or fuel expenditures. The point is especially relevant since input controls in the form of A-unit restrictions over vessel size and engine power in the fishery during this period appear to have resulted in a substitution toward less efficient but unregulated inputs, decreasing overall efficiency in the NPF.

Section 2 of the paper provides a summary of the theoretical framework for stochastic production frontiers. Section 3 briefly describes the Australian NPF and the tiger prawn fishery in particular. Section 4 describes the data set and the relevant variables used in the estimations. Section 5 provides the econometric specifications used in this study and summarizes overall results. Section 6 provides a further discussion. In particular, it details technical inefficiencies for each vessel in the fishery and discusses the factors which affect the level of inefficiency. Section 7 concludes.

2. Theoretical Framework

Stochastic production frontiers were first developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The specification allows for a non-negative random component in the error term to generate a measure of technical inefficiency, or the ratio of actual to expected maximum output, given inputs and the existing technology. The idea can be readily applied to panel data. Indexing firms by i, the specification can be expressed formally by

$$Y_{it} = f(X_{it}, \beta, t)e^{v_{it}-u_{it}} \tag{2.1}$$

for time t, Y_{it} output (or catch), X_{it} a vector of inputs and β a vector of parameters to be estimated. As usual, the error term v_{it} is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ and captures random variation in output due to factors beyond the control of firms, such as weather. The error term u_{it} captures technical inefficiency in production, assumed to be firm-specific, non-negative random variables, independently distributed as non-negative truncations (at zero) of the distribution $N(\mu_{it}, \sigma_u^2)$, where, following Battese and Coelli (1995),

$$\mu_{it} = \delta_0 + z_{it}\delta + \omega_{it} \tag{2.2}$$

defines an inefficiency distribution parameter for z_{it} a vector of firm-specific effects that determine technical inefficiency and δ is a vector of parameters to be estimated. Firm-specific effects for a fishery could include the size of vessel, length of gear, engine power, a hired skipper versus an owner-operator, skipper experience, and so on. Input variables may be included in both equations (2.1) and (2.2) as long as technical inefficiency effects are stochastic, say for random variable ω_{it} (see Battese and Coelli, 1995).

The condition that $u_{it} \geqq 0$ in equation (2.1) guarantees that all observations lie on or beneath the stochastic production frontier. A trend can also be included in equation (2.2) to capture time-variant effects.[1] Following Battese and Corra (1977) and Battese and Coelli (1993), variance terms are parameterized by replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$. For the basic case, the technical efficiency (TE) of the i-th firm in the t-th period can be defined as

$$TE_{it} = \frac{E(Y_{it} \mid u_{it}, X_{it})}{E(Y_{it} \mid u_{it} = 0, X_{it})} = e^{-u_{it}} \tag{2.3}$$

for E the usual expectations operator. The measure of technical efficiency is thus based on the conditional expectation given by equation (2.3), given the values of $v_{it} - u_{it}$ evaluated at the maximum likelihood estimates of the parameters in the model, where the expected maximum value of Y_{it} is conditional on $u_{it} = 0$ (see Battese and Coelli, 1988). The measure TE_{it} clearly must have a value between

[1] For the specification in section 5, likelihood ratio tests reject a time trend (not reported) in the technical inefficiency model, so the effect is ignored here.

zero and one. If $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2) = 0$ the expected value of TE is one since there are no deviations due to technical inefficiency, or $\sigma_u^2 = 0$. If $\gamma = 1$ deviations in output are due entirely to technical inefficiency effects or σ_u^2. Thus, for $0 < \gamma < 1$, output deviations are characterized by the presence of both technical inefficiency and a random (stochastic) error.

3. The Australian Northern Prawn Fishery

The northern prawn fishery (extending from Cape Londonderry in Western Australia to Cape York in Queensland) is the largest and one of Australia's most valuable fisheries. First established in the late 1960's, more than fifty species of prawn inhabit the fishery, but brown and grooved tiger prawns and white banana prawns currently account for over 80 per cent of the commercial landings (ABARE, 2001). The gross value of prawn production in the NPF in 1999–2000 is estimated to be A$107 million with a total harvest of about 5,600 tons (AFMA, 2001). Nearly 90 per cent of all prawn output is exported to Japan and Asia.

In 2000, 115 vessels actively participated in the NPF. All vessels are purpose built twin gear otter trawls and generally range in size from 14 to 29 meters, with the most common boat size between 18 and 25 meters (AFMA, 2001). Most boats operate between 80 and 90 percent of the time available for fishing, with breakdowns and unloadings (to mother-ships) accounting for much of the remaining time. The fleet is technologically advanced, employing modern packing and freezing capabilities and sophisticated fishing aids such as echo sounders and satellite global positioning systems and plotters. Average annual catches of all tiger prawns range from 3,300 to 5,300 tonnes per fishing season, with a maximum sustainable yield estimated to be around 4,000 tonnes (ABARE, 2001). Recent stock assessments suggest that tiger prawn stocks are overfished with falls in landings over the past decade and recent tiger prawn catches (2,694 tonnes in 1997 and 3,250 tonnes in 1998) well below estimated maximum sustainable yield, and continue so to the end of 2000 (Dichmont, 2001).

Over the years the NPF as a whole has been subject to policy management, based on granted units over entry and inputs defined by a Statutory Fishing Right (SFR), to address concerns over the level of fishing effort and the biological sustainability of stocks. The fishery is managed by the Australian Fisheries Management Authority (AFMA). A number of measures to control effort have been used, including mid-seasonal and area closures (since 1987), gear restrictions (twin gear only, since 1987) and most recently gear headrope length restrictions (ABARE, 2001). Of particular concern for the period of this study (1990–1996) are the presence of restrictions on vessel size and engine power (defined A-units). A-unit controls have been in place in this fishery since 1987, with an aggressive target for reductions set to occur by 1993 through an enhanced buy-back scheme designed to literally surrender A-units. Since the target was not met in 1993 an additional compulsory pro rata surrender of A-units across remaining boat operators came into effect in April 1993, forcing the number of units to the target level (see Dann and Pasco, 1994).

4. Data and Variables

4.1. Data set

The unbalanced panel data set used in this paper consists of thirty-seven vessels over the period 1990 to 1996, or 228 observations with thirty-one missing values.[2] The original database was drawn from surveys and statistics for the NPF fleet carried out and compiled by ABARE surveys and the CSIRO. The raw database includes measures of output by species (banana, brown and grooved prawn), crew size, revenue, boat variable costs (not available by species), capital costs and gear. Fishing logbook data obtained from the CSIRO includes data for all fishing firms for the period 1988–97, including the number of fishing days (effort). The CSIRO also holds data on vessel size and characteristics and skipper employment and experience. Of the roughly 130 vessels operating in the NPF during the sample period, the thirty-seven vessels in the unbalanced panel data representing almost 40 per cent of the total catch of prawns each year.

Since vessel trawling capacity is an important determinant of catch, headrope gear length is used as a proxy for trawling capacity throughout. Average gear length in the panel is measured at 27 meters, with a slightly smaller standard deviation for tiger prawns. Input expenditures average $47,522 per year, indexed by fuel prices in base year 1989, and include fuel, oil, and grease. Among these, fuel expenditures are clearly the most important and serve as a reasonable proxy for engine power and size.[3] Average fuel expenditures are much higher for tiger prawns, or $150,803 per year. Finally, the value of A-units, as a sum of one A-unit for every cubic meter of hull volume and one A-unit for each kilowatt of engine power, is used as a rough measure of fishing capacity. A-units averaged 508 in the panel data set.

5. Empirical Results

Generalized likelihood ratio tests are used to help confirm the functional form and specification. The correct critical values for the test statistic from a mixed χ-squared distribution (at the 5% level of significance) are drawn from Kodde and Palm (1986). As a pre-test, the null hypothesis of a Cobb-Douglas form of the

[2] Additional data is available for the years 1997-1999, but not for all of variables used in the econometric specification in this paper.

[3] See NPFAMP (2000). To some extent, fuel is also related to the size of vessel. In the data set, boat fuel expenditures are available only as an aggregate over tiger and banana prawn output. The measure of fuel used for banana prawns is thus obtained by multiplying total fuel expenditures by effort days in banana prawn production as a fraction of total effort days in banana and tiger prawn production.

production function was tested against a general translog specification by setting the relevant parameters for squared and interaction terms in the translog form equal to zero. The resulting test statistic was $\chi^2_{10} = 12.4$ compared to a critical value of 19.7. A Cobb-Douglas functional form was thus selected and equation (2.1) for the unbalanced panel data set (1990–1996) for tiger prawns is specified by a production function in log-linear form, or

$$\ln Y_{it} = \beta_0 + \beta_1 \ln \text{effort}_{it} + \beta_2 \ln \text{fuel}_{it} + \beta_3 \ln \text{stock}_{it} + v_{it} - u_{it} \tag{5.1}$$

where Y_{it} is the output of tiger prawns, effort is the average number of fishing days, fuel represents all input expenditures (fuel, oil, and grease) and stock is the measure of stock abundance or recruitment to the fishery.

The firm-specific factors used in the technical inefficiency model, or equation (2.2), are fuel expenditures, gear length, skipper experience (years) and the binary variable skipper, so that

$$u_{it} = \delta_0 + \delta_1 \text{fuel} + \delta_2 \text{gear} + \delta_3 \text{skipexp} + \delta_4 \text{skipper} + \omega_{it} \tag{5.2}$$

where the absence of a skipper (one) designates an owner-operator (zero). Although there is no apparent evidence in the data, fuel expenditures rather than A-units were used at this point to allay possible concerns over the false, under-reporting of A-unit capacity in logbooks. As mentioned, (real) fuel expenditures are highly correlated with engine power and hull size. They must also be reported to the Australian tax office so there is presumably less (if any) false reporting. In any case, the use of A-units rather than real fuel expenditures in the technical inefficiency model for tiger prawns gives similar estimates.

Additional log-likelihood tests indicate that the null hypothesis of no time trend in equations (5.1) and (5.2) is rejected. The null hypothesis that technical inefficiency effects are absent ($\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) and that vessel-specific effects do not influence technical inefficiencies ($\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) in equation (5.2) are both rejected, as is $\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$. Finally, the null hypothesis that $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2) = 0$, or that inefficiency effects are not stochastic, is also strongly rejected. All results again indicate the stochastic effects and technical inefficiency matter and thus that traditional OLS estimates are not appropriate in this study.

Results for the model (maximum likelihood estimates) are reported in the attached table. All input variables in the stochastic frontier production function are significant, and by order of importance for tiger prawn output are stock (0.43), effort (0.30) and fuel (0.26). Input share coefficients sum to 0.99 and a Wald test (not reported) confirms that constant returns to scale cannot be rejected. All variables in the technical inefficiency model test as significant. Gear headrope length has a significant (8.14) positive effect on technical inefficiency (hence a negative effect on technical efficiency), whereas fuel, skipper experience and the presence of a skipper have a positive effect on technical efficiency. Finally, the value of $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$ is 0.95 and highly significant. A good measure of the residual variation is thus due to inefficiency effects, although variance in v_{it} still clearly matters. The negative sign on the coefficient for skipper experience is not surprising. Unlike banana prawns in the NPF, which aggregate in clusters, called 'boils', and are thus easily spotted from the air and raked from the sea, tiger prawns are much more difficult to locate. They do not cluster and must be fished at night (by regulation), implying that experience in this fishery is essential in locating tiger prawns. However, the negative coefficient on hired skipper (as opposed to an owner-operator) is a surprise. Since, like many other fisheries, payments to the skipper in the NPF are incentive-based (depending on the total value of catch), a distinction between owner-operator and hired skipper should make little difference to the outcome. Nevertheless, in this sample a hired skipper tested as much more efficient than an owner-operator.

6. Discussion

Using the measure contained in section 2, the predicted technical efficiencies for vessels in this study range considerably from 0.31 to 0.96, with a mean technical efficiency of 0.773 for tiger prawns. The majority of vessels range from 0.81 to 0.90.[4] The value of mean technical efficiency does not vary by much over the sample period, but there is a significant difference between pre-1993 and the 1993–1996 measures, with a fall from 83 per cent in 1992 to 76 per cent in 1996. Given the estimated results for technical inefficiency in table 5 (negative for either A-units or real fuel expenditures and positive for gear length), the fall clearly appears to be the result of policy measures designed to decrease the number of A-units in this fishery (with a target of 54,000 class A-units by 1993) and the corresponding increase in gear length as vessels substituted toward the relatively inefficient but unregulated input, gear. Average vessel values generally confirm the result. A-units and real fuel expenditures fall through most of the sample period, but particularly so before 1993.[5] However, headrope gear length increases steadily from 1993, with average values of 26.91, 27.17, 27.30 and 27.72 meters.[6] Average technical inefficiency between the two periods thus decreases as the proportion of gear length to A-units (real fuel expenditures) rises.

[4]Comparable cross-sectional measures for 122 Hawaiian longline vessels, given by Sharma and Leung (1999), are 42% with a technical efficiency index of 0.9 or above, 34% within the range of 0.8 to 0.9, 12% from 0.7 to 0.8, 7% from 0.6 to 0.7, 3.3% from 0.5 to 0.6 and 2.2% percent of the boats have an index of less than 0.5. The mean in this study is 0.84. Kirkley, Squires and Strand (1995) obtain a mean value of 0.75 in the mid-Atlantic sea scallop fishery, across ten vessels.

[5]For example, A-units in 1990 are 27.45 and in 1993, 26.12. The vessel buy-back scheme designed to surrender A-units does not apply in this study only in the sense that the same thirty-seven vessels appear in the panel data set from 1990–1996. A-unit reduction in the sample was thus achieved through physical limits on engine power and speed.

[6]In the unbalanced panel data set the value for gear length rises for each of the thirty-seven vessels, for all observed values.

7. Concluding Remarks

This paper represents a study of the production technology and relative efficiency of firms producing tiger prawns in the northern prawn fishery, one of Australia's largest and most lucrative fishing areas. Results are based on a unbalanced panel data set of 228 observations among thirty-seven vessels for the years 1990–1996. On average, vessels in this panel study are shown to be reasonably technically efficient, but with considerable variance. The level of technical inefficiency is shown to depend positively on gear headrope length and negatively on either A-units or real fuel expenditures. The point is especially relevant since A-unit restrictions over vessel size and engine power in the fishery during this period appear to have resulted in a substitution toward less efficient but unregulated inputs, such as gear length. Overall efficiency declines in the fishery through time.

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Table: Parameter estimates of the stochastic production frontier and technical inefficiency models, tiger prawns (equations 5.1 and 5.2)

	Maximum Likelihood Estimate	
	Coefficient	Asymptotic T ratio
Stochastic production frontier		
Constant	2.06 *(1.97)*	1.04
Effort	0.30*** *(0.12)*	2.49
Fuel	0.26* *(0.14)*	1.81
Stock	0.43*** *(0.16)*	2.65
Technical inefficiency model		
Constant	3.13*** *(1.21)*	2.58
Fuel expenditures	-3.03* *(1.68)*	1.80
Head rope length of gear	8.14** *(4.29)*	1.90
Skipper experience	-0.15** *(0.08)*	1.96
Skipper	-3.95* *(2.51)*	1.57
Sigma-squared	2.63* *(1.67)*	1.57
Gamma	0.95*** *(0.03)*	29.26
Ln (likelihood)	140.17	
Mean Technical Efficiency	0.773	

Notes: **, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively. Numbers in parentheses are asymptotic standard errors.*