Impact of skipper characteristics and technology on individual fisher technical efficiency

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Abstract: Differences in technical efficiency of fishing vessels are often attributed to skipper skill and differences in technology. While the later can be defined in terms of the technology employed, the former is more difficult to quantify. In this paper, the contribution of technology and skipper characteristics (e.g. level of education, experience, training) to technical efficiency are examined using a stochastic production frontier. Three types of fishing activities are examined: mobile gear (e.g. trawl), potters and netter-liners. The results suggest that technology and skipper characteristics can affect the level of efficiency, although these effects differ by gear type used. Traditional measures of labour skill (education and experience) are found to be less relevant when trying to measure skipper skill.

Keywords: Technical efficiency, stochastic production frontier, fisheries

1. INTRODUCTION

An assumption of input controls such as those imposed in the UK is that restricting input use indirectly leads to a target level of output being achieved. However, such controls are usually restricted to inputs that are readily measurable, such as boat size, engine power, gear use and days fished. When other factors affect the level of output, the usefulness of input controls in achieving target output levels may be limited (Pascoe and Coglan 2000). For example, when skipper or crew skill is a major factor determining the output of the vessels, controlling other inputs may be largely ineffective for many of the boats. Variations in skipper and crew skill are likely to contribute to the overall technical efficiency of the vessel, along with other potentially uncontrollable inputs. The contribution of these inputs to the production process will influence the potential success of management through input controls.

Relatively few studies have attempted to determine the factors affecting efficiency in fisheries. Pascoe, Andersen and de Wilde (2001) found that boat characteristics (e.g. vintage of engine and hull, crew number etc) as well as management changes can directly affect the efficiency of individual fishing vessels. Similarly, Eggert (2001) found that boat age, size and base location (i.e. home port) have a significant impact on the level of technical efficiency. Pascoe and Coglan (2002) found that differences in boat characteristics explained around one third of the variation in technical efficiency of English Channel trawlers, and attributed the remainder to unmeasureable characteristics such as skipper skill and differences in technology that could not be quantified. Other studies have also suggested that much of the difference in efficiency between vessels may be due to differences in skipper skill (e.g. see Squires and Kirkley 1999).

In this study, the efficiency of a number of key fleet segments operating in the English Channel was estimated using a stochastic production frontier. An inefficiency model is subsequently developed with the aim to determine the factors affecting efficiency. The model includes both skipper characteristics as well as differences in the level of technology employed in order to determine how these factors affect efficiency.

2. EFFICIENCY: SKILL OR TECHNOLOGY?

Most of the previous studies of efficiency in fisheries concluded that skipper skill was the primary factor affecting variation in efficiency of different vessels. However, few studies have attempted to quantify skipper skill and therefore directly measure its contribution to efficiency.

Traditional labour economics measures skill separately in terms of either education level or level of experience, although more recently composite indexes of skill and experience have been developed (Portela 2001). Education is generally assumed to be associated with increased efficiency. There is also recognition in the literature that education extends beyond formal schooling and includes participation in extension programmes (e.g. Ali, Parikh and Shah 1996) and vocational/on-the-job training (Ravn and Sørensen 1999).

Experience is often considered an alternative to education in the development of skills, the idea of learning-by-doing (Young 1991). The general assumption in such cases is that skill, and therefore productivity and efficiency, increases with experience (Portela 2001). Age is often used as a proxy for experience (e.g. Card and Lemieux 1996), although some studies suggest that skill may diminish with age in relative terms through reduced incentive to continue to develop and learn (Maurer 2001). Similarly, some empirical studies using years of experience as a measure of skill have found that efficiency decreases with experience, the explanation provided being that those in the industry longer are less willing to adapt (Wilson *et al* 1998).

Education and experience does not explain all differences in skill. Card and Lemieux (1996) found that as much as 40-50 per cent of the difference in wages (assumed to be an objective measure of skill) was not attributable to either of these measures. In the case of fisheries, Kirkley, Squires and Strand (1998) and Sharma and Leung (1999) attempted to include skipper characteristics through measures of experience and education. While these were found to be significant, differences in efficiency between boats with similar physical and skipper characteristics were still observed (Kirkley, Squires and Strand 1998).

It is often assumed that increases in technology raises efficiency levels, although these advantages may not be substantial For example, the adoption of improved search technology may give some skippers an advantage over those using less efficient technologies. Robins, Wang and Die (1998) found that boats operating in the Australian northern prawn fishery using GPS (Global Positioning Systems) had 4 per cent greater fishing powers than those boats who without GPS. The use of both a GPS and plotter was found to increase fishing powers by 7 per cent.

As the introduction of technology is often linked with both vocational training and the development of complementary skills to optimise its use, accessing the impact of technology alone can be difficult. In their study, Robins, Wang and Die (1998) identified a 'learning effect' of the new GPS technology, as fishing powers continued to increase by 2 to 3 per cent over the first three years of using the equipment.

3. METHODOLOGY

The level of efficiency of a particular firm is characterised by the relationship between observed production and some ideal or potential production (Greene 1993). The measurement of firm specific technical efficiency is based upon deviations of observed output from the best production or efficient production frontier. If a firm's actual production point lies on the frontier it is perfectly efficient. If it lies below the frontier then it is technically inefficient, with the ratio of the actual to potential production defining the level of efficiency of the individual firm

A general stochastic production frontier model can be given by:

$$\ln q_j = f(\ln \mathbf{x}) + v_j - u_j \quad (1)$$

where q_j is the output produced by firm j, $\boldsymbol{x}$ is a vector of factor inputs, v_j is the stochastic error term and u_j is the estimate of the technical inefficiency of firm j. Both v_j and u_j are assumed to be independently and identically distributed (iid) with variance σ_v^2 and σ_u^2 respectively.

In order to separate the stochastic and inefficiency effects in the model, a distributional assumption has to be made for $u_{j.}$ While a range of distributional assumptions are available, one approach is to define the inefficiency as a function of the firm specific factors such that:

$$\mathbf{u} = \mathbf{z}\ddot{\mathbf{a}} + \mathbf{w} \quad (2)$$

where $\mathbf{z}$ is the vector of firm-specific variables which may influence the firms efficiency, $\boldsymbol{\delta}$ is the associated matrix of coefficients and $\boldsymbol{w}$ is a matrix of iid random error terms. The parameters of the inefficiency model are estimated in a one-step procedure (Battese and Coelli 1995) along with the parameters of the production frontier.

4. THE FISHERIES OF THE ENGLISH CHANNEL

The English Channel contains a number of multi-species multi-gear fisheries dominated by high value fish and shellfish species such as sole, lobster and scallops. Around 4000 registered boats operate in the fishery ranging in size from 4m to over 30m, of which around half are based in the UK. The fleet consists primarily of UK and French boats, although a small number of Belgian beam trawlers operate part of the year in the Eastern Channel, and a small fleet from the Channel Islands operate in their adjacent inshore waters. Most of the UK boats are relatively small, owner-operated, multi-purpose vessels, using a range of different fishing gears over the year. Total employment in the UK component of the fishery was estimated to be about 4,300 excluding indirect employment in industries linked to the fishing industry.

A number of distinct fishing activities (termed métiers) in the Channel have been defined based on country of origin, fishing gear employed and area fished. The métiers are broadly based on seven main gear types: beam trawl, otter trawl, dredge, line, nets and pots. While fleets can also be broadly classified on the basis of their main gear type, they are largely multi-purpose, and operate in several different métiers over the year.

4.1 Production Data

The data set used in the analyses was comprised of both logbook and economic survey data. Monthly logbook revenues from all activities of the boats in the sample (i.e. over all gear types for multi-gear vessels) were aggregated into annual revenues over the period 1993-98, and combined with survey estimates of revenue for 1999 and 2000 (Cattermoul and Pascoe forthcoming). As the latter two years data represented the complete activity of the vessels, the annual revenues derived from the logbook data were aggregated over all fishing activities that the vessel participated in. The revenues in each year were inflated to 2000 values using a Fisher price index for the period 1993-98, and changes in the fish component of the retail price index in 1999 and 2000 to bring the revenues to 2000 values. Annual data were used as most of the factors assumed to affect efficiency did not vary over the year.

For the purposes of the analysis, the boats were aggregated into three groups – boats using mobile gear (beam and otter trawlers and scallop dredges), potters and netter-liners. In the case of the latter group, most boats operated using both gear types. For the mobile gear group, most boats used at least two of the three gear types covered by the grouping. Potters were kept separate largely due to the existence of sufficient observations and also because the target species (crab and lobster) differ substantially to those of the other groups. A summary of the key characteristics of the fleet segments is given in Table 1. As can be seen, there is considerable variation in the data both in inputs and output.

Table 1. Average output and boat characteristics

	Mobile gear		Potters		Netter-liners	
	Mean	C.V.	Mean	C.V.	Mean	C.V.
No. boats	18		26		24	
Revenue (£)	144,613	87%	39,101	111%	53,635	111%
Days fished	171	41%	116	78%	120	72%
Engine power (kW)	217	67%	72	81%	113	71%
Length (m)	14	42%	8	27%	10	26%

A key input into standard fisheries production functions is the level of stock. In multi-species fisheries such as the Channel, deriving a composite stock index is not straightforward. While some studies have developed an approach based on revenue shares for aggregating the stocks into a single measure (e.g. Pascoe, Andersen and de Wilde 2001), this requires an index of all key stocks. In the Channel, most species are not regularly subject to a stock assessment, so independent stock estimates are not available.

The method developed by Herrero and Pascoe (2001) was used to determine the stock effect. This produces an estimate of the effects of changes in stock size on the level of output at the individual observation level (thereby allowing for differing effects due to differing characteristics of the vessel). The output measures were adjusted based on this stock effect. An additional feature of the stock effect measure in this case was that it would also correct for any systematic differences between the survey and logbook revenue estimates. A small number of observations with particularly large stock effects were exclude. As not all catch is recorded, it was assumed that a large adjustment to these data probably reflects an underestimate of the original value and hence it (and the adjusted estimate) may not be reliable.

4.2 Skipper and technology data

A difficulty identified in the previous study of English Channel trawlers (Pascoe and Coglan, 2002) was that information on skipper characteristics and levels and use of onboard technology was not available. A survey of vessels operating in the English Channel was undertaken in order to obtain these characteristics for a subset of the fleet (Cattermoul and Pascoe forthcoming). Information collected included skipper characteristics such as age, number of years fishing experience and the number of generations of family fishing history (Table 2), as well as education levels and vocational training. Information on use of on-board technology was also collected, including equipment used (Table 3) and the number of years that the skipper had been using it.

Table 2 Skipper details by main gear type, 2000

	No.	Age (years)		Experience (years fished)		History[a]	
	Observations	Mean	RSE	Mean	RSE	Mean	RSE
Beam Trawl	4	31	2.2	16	6	3.0	0.0
Otter Trawl	13	43	6.9	23	10	0.8	37.5
Dredge	2	50	7.1	30	2	0.5	100.0
Pots	27	49	4.7	30	9	1.2	19.6
Line	4	56	5.6	29	11	1.0	70.7
Nets	20	46	5.0	27	9	1.4	22.3

[a]Values for family fishing history as follows: 0 = no history 1 = father/uncles and close family 2=father and grandfather 3 = more than three generations. Source: Cattermoul and Pascoe (forthcoming).

Table 3: Proportion of sample using electronic technology by main gear type, (%) 2000.

	Beam	Otter	Dredge	Line	Nets	Pots
VHF	100	100	100	100	95	96
MF	100	15	0	0	15	0
GPS	100	100	50	50	55	74
GPS Plotter	100	85	50	50	80	37
Echo sounder	75	100	50	100	80	81
Sonar	0	15	0	25	0	4
Radar	100	100	50	50	70	48
Auto pilot	75	69	50	50	35	41

Source: Cattermoul and Pascoe (forthcoming)

5. FACTORS AFFECTING EFFICIENCY

5.1 Production function specifications

A translog frontier production function was specified, given as

$$\ln V_{j,t} = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} + \frac{1}{2}\sum_i \sum_k \beta_{i,k} \ln X_{j,i,t} \ln X_{j,k,t} - u_{j,t} + v_{j,t} \quad (3)$$

where $V_{j,t}$ is the output measure in period t and $X_{j,i,t}$ and $X_{j,k,t}$ are the inputs (i, k) to the production process. As noted above, the error term is separated into two components, where $v_{j,t}$ is the stochastic error term and $u_{j,t}$ is the estimate of the technical inefficiency. The output used in the model was the average real revenue, adjusted for the stock effects following the method of Herrero and Pascoe (2001). The inputs used in the model were days fished, engine power (kW) and overall length (OL). As the data were pooled, gear specific dummy variables were also incorporated to test the effect of specific gear types on the model.

5.2 Inefficiency model

A number of boat characteristic variables were derived from the data for use in the inefficiency model. The level of activity varies substantially in the fishery, and it might be expected that this would reflect the relative efficiency of the skippers. To examine this, an index of fishing activity was derived based on the average number of days fished each year over the period of the data. The number of crew per metre overall length was also included as a variable, as more crew on the boat would enable the catch to be sorted faster and the nets or pots to be reset faster. The vintage of the boat was also assumed to affect efficiency, as older designs were presumable less efficient than modern vessels built with modern materials. Incorporating a larger engine was also thought to affect efficiency as the boat would be able to reach the fishing grounds faster as well as tow the gear faster. While engine power was a variable in the production function, the ratio of engine power to boat size was incorporated into the inefficiency model to test the effects of this on efficiency.

The information collected on technology use was too detailed to use in its entirety due to degrees of freedom problems. The technology was aggregated into three categories – navigational aids (GPS, radar), auto-pilots and fish finding aids (sonar, sounders). Communication technology was not included as nearly all boats had some form of communication device for safety purposes. While this could also affect efficiency (through skippers working together and passing on information about catch rates in different areas), identifying how the technology was used was not possible. Information was collected as to when the skipper adopted the technology, and dummy variables were used to represent the use of these technologies.

Skipper characteristics incorporated into the analyses included age in 2000[1], the number of years experience, the number of generations of family fishing history, formal education ("O" levels or above), vocational education (e.g. training in navigation, use of radar, VHF etc) and boat handling training (e.g. skipper ticket, crew hand, etc). For the education and training variables, dummy variables were used with a value of 1 if training had taken place and 0 if it had not. Roughly 40 to 50 per cent of the boats in the sample had undertaken some form of formal education above "O" levels, a similar proportion had undertaken some form of vocational training and around 30 per cent had undertaken some form of boat handling training (Cattermoul and Pascoe forthcoming).

6. RESULTS

The model was estimated using FRONTIER 4.1 (Coelli 1996). The estimated parameters of the production frontiers and inefficiency models are given in Table 4. In all cases, engine power and boat size were highly correlated, resulting in multicollinearity in the production frontier. This affects the derived individual elasticity estimates, not the 'predictive' power of the production frontier. Exclusion of one of the correlated variables resulted in a significant change in the log-likelihood value, so such restrictions could not be used to overcome this problem. Consequently, the derived elasticity estimates are unreliable and are therefore not presented.

The model results presented in Table 4 relate to the most appropriate specification based on a series of tests, conducted in order to test the specification of the models (Table 5). These are tested through imposing restrictions on the model and using the generalised likelihood ratio statistic (λ) to determine the significance of the restriction. The generalised likelihood ratio statistic is given by

$$\lambda = -2\left[\ln\{L(H_0)\} - \ln\{L(H_1)\}\right] \tag{4}$$

where $\ln\{L(H_o)\}$ and $\ln\{L(H_1)\}$ are the values of the log-likelihood function under the null (H_o) and alternative (H_1) hypotheses. The restrictions form the basis of the null hypothesis, with the unrestricted model being the alternative hypothesis. The value of λ has a χ^2 distribution with the number of degrees of freedom given by the number of restrictions imposed.

In all cases, the model was original specified as a translog production frontier. The hypothesis that the correct functional form of the model is Cobb-Douglas can be imposed by removing the squared and cross product terms from the translog production function (i.e. H_o: $\beta_{i,k}=0$) and re-estimating the model. This was rejected at the 1 per cent level of significance for the mobile gear vessels (Table 5). For the potters, the λ value was almost significant at the 5 per cent level, and most of the cross product and squared terms were significant, so the translog functional form was kept. For the net-liners, a Cobb-Douglas functional form was accepted (Table 4) as the restrictions could not be rejected.

A key test is the one-sided generalised likelihood ratio-test for the existence of a frontier (i.e. H_o: $\gamma=0$). As the alternative hypothesis is that $0<\gamma<1$, the test has an asymptotic distribution, the critical values of which are given by Kodde and Palm (1986). If the hypothesis is accepted, then there is no evidence of technical inefficiency in the data and the production frontier is identical to a standard production function. In this case, the presence of inefficiency (i.e. the existence of a frontier) was confirmed for all three gear types (Table 5).

A final test was that the terms of the inefficiency model were jointly insignificant (i.e. $\delta_1=\delta_2=\ldots=\delta_n=0$). In all cases, this was rejected at the 1 per cent level, although for the case of the net-liners, the skipper characteristics could be excluded without significant effect on the model. In the initial estimation with all variables included, all of the skipper characteristics (i.e. δ_7 to δ_{14}) were found to be non-significant. While other boat characteristics

[1] This was held constant for all observations for the vessel. Allowing age to vary resulted in problems due to correlation with experience, which was allowed to vary over time in the analyses.

(including technology employed) were also not significant, these were not excluded as some variables in each of these categories were significantly different from zero.

Table 4. Production frontier and inefficiency model results

	Mobile gear		Potters		Net-line	
	coefficient	t-ratio	coefficient	t-ratio	coefficient	t-ratio
Constant	12.13	10.28 ***	-0.76	-0.79	-3.33	-3.55 ***
lndays	2.21	2.85 ***	2.48	2.95 ***	1.50	10.83 ***
lnkW	-7.04	-8.31 ***	2.03	2.73 ***	0.87	2.23 **
lnOL	3.57	1.75 *	-2.39	-1.34	1.37	1.53
$\ln^2$days	-0.06	-0.76	-0.23	-3.17 ***		
Ln^2kw	0.09	0.42	0.69	4.12 ***		
$\ln^2$OL	-0.05	-0.05	3.75	3.20 ***		
lnday*lnkW	0.82	4.15 ***	-0.15	-0.72		
lnday*lnOL	-1.68	-3.66 ***	0.34	0.57		
lnkW*lnOL	1.20	1.68 *	-3.15	-4.54 ***		
Beam dummy	-2.59	-7.07 ***				
Dredge dummy	0.11	0.52				
Pelagic dummy	1.67	5.84 ***				
Line dummy					-0.25	-0.95
Intercept	-0.07	-0.06	2.24	2.13 **	-0.03	-0.04
lnactivity	1.49	4.42 ***	1.66	2.90 ***	1.62	4.56 ***
ln(Crew/m OL)	-0.54	-2.42 **	1.90	1.97 *	-0.55	-1.37
ln(boat vintage)	-1.33	-3.30 ***	1.52	2.31 **	-0.16	-0.57
ln(kW/m OL)	0.47	2.10 **	-1.79	-3.46 ***	0.63	1.76 *
Nav. Aid	-0.01	-0.06	-3.21	-3.48 ***	-1.05	-3.38 ***
Sounder/ sonar	-0.20	-0.83	0.21	0.35	-0.43	-1.15
Auto-pilot	-1.95	-4.56 ***	-0.31	-0.56	0.11	0.25
ln(Skipper age)	0.72	1.92 *	1.41	2.09 **		
ln(Experience)	1.16	3.60 ***	-2.01	-3.21 ***		
History	-0.21	-3.56 ***	0.13	0.55		
Formal Ed.	0.44	1.69 *	2.39	2.56 **		
Vocational ed.	-1.29	-2.54 **	-0.20	-0.20		
Boat Handling	0.36	1.51	1.97	2.19 **		
σ^2	0.06	4.83 ***	1.24	4.23 ***	0.39	4.69 ***
γ	0.63	7.18 ***	0.90	19.79 ***	0.08	4.01 ***
log likelihood	10.308		-70.103		-75.33	

*** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level

Table 5. Specification tests

	$L(H_0)$	$L(H_1)$	λ	Significance
Mobile gears				
$\beta_{i,i}=\beta_{j,j}=\ldots=\beta_{i,j}=0$	-26.221	10.308	73.058	0.00%
$\gamma=0$	-29.564	10.308	79.744	<1%[a]
$\delta_1=\delta_2=\ldots=\delta_n=0$	-24.266	10.308	69.148	0.00%
Potters				
$\beta_{i,i}=\beta_{j,j}=\ldots=\beta_{i,j}=0$	-76.270	-70.103	12.334	5.49%
$\gamma=0$	-88.683	-70.103	37.159	<1%[a]
$\delta_1=\delta_2=\ldots=\delta_n=0$	-88.683	-70.103	37.159	0.02%
Net-line boats				
$\beta_{i,i}=\beta_{j,j}=\ldots=\beta_{i,j}=0$	-72.23	-64.09	16.29	18%
$\gamma=0$	-93.88	-72.23	43.29	<1%[a]
$\delta_1=\delta_2=\ldots=\delta_n=0$	-93.62	-72.23	42.76	0%
$\delta_7=\delta_8=\ldots=\delta_{14}=0$	-75.33	-72.23	6.20	62%

a. based on the critical value determined by Kodde and Palm (1986)

6.1 Impact of technology and training on efficiency

From Table 4, increasing the level of activity was generally associated with a reduction in efficiency in all gear types[2]. This may be due to diminishing returns to effort. However, it is more likely that there is no causality between activity and efficiency, but that the least efficient vessels on average fish more than more efficient vessels (possibly even because they are inefficient).

For the mobile gear boats, older boats were found to be more efficient than newer boats, while the reverse was true for potters. For the potters, the results conform to *a priori* expectations with regard to the vessel vintage, as older boats were presumably designed differently to newer boats.

A number of results were likely to be representative of a direct productivity effect rather than efficiency effect *per se*. Increasing the number of crew relative to the boat size increases the efficiency of the mobile gear vessels. More crew enables the catch to be sorted faster, and the net to be back in the water quicker, increasing the potential catch rate per day. Similarly, increasing the engine power relative to the boat size increased efficiency for potters, but decreased it for the trawlers. For potters, larger engines allow the boat to move between strings of pots faster, allowing more pots to be worked per day. In contrast, increasing engine power without increasing boat size does not provide any advantages for the trawlers.

The impact of technology on efficiency varied by gear type. For the static gear boats (potters and net-liners), navigational aids increased efficiency, while for the trawlers the use of an auto-pilot was significant. For the static gear boats, being able to quickly find the pots or nets is a major factor affecting their output, as time spent searching for the gear is not productive. The instances of lost gear are also likely to decrease. For the trawlers, the use of an auto-pilot effectively frees up the time of the skipper to assist the crew in sorting the catch while still moving between fishing areas, effectively increasing the crew number on board.

The skipper characteristics also had differing impacts on efficiency. For the net-line vessels, no skipper characteristics were found to be significant in explaining variations in efficiency. For the potters, efficiency decreased with skipper age. Given efficiency decreased also with boat age, it could be assumed that the two effects are related (i.e. older skippers had older boats), but a small negative correlation between these variables was found (r=-0.25), suggesting that older skippers do not necessarily run the older boats. The skipper 'age' effect is compensated to some degree by the effect of experience (years fished), which was associated with an increase in efficiency for the potters. Education and training were associated with lower levels of efficiency, contrary to a priori expectations. Given this, it is likely that experience rather than education is a more important determinant of efficiency in this fleet segment.

In contrast, efficiency decreased with experience for the mobile gear boats. However, efficiency increased with vocational training (primarily in the use of boat electronics) and with the history of the family in the fishing industry. Experience of the earlier generations in such cases is likely to be passed down, which may be more valuable training than education and direct experience in the fishery. The addition of vocational training to this inherited experience allows more effective use of the more recent technologies, further increasing efficiency.

6.2 Contribution of efficiency to production

The relative contribution of the inputs, fisher efficiency and random variation to the production of the vessels can be estimated from the results of the analysis. The value of σ^2 represents the total estimated variation of the combined error term (i.e. $\sigma^2 = \sigma_u^2 + \sigma_v^2$). The percentage of variation explained by the production function can be estimated as $R^2 = 1 - \sigma^2 / \sigma_V^2$, where σ_V^2 is the estimated variance of the (logged) output measure.

Similarly, the proportion of the combined error term can be derived from the estimated value of γ ($= \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$). The estimate of γ provided in the MLE results is only an approximation of the contribution of inefficiency to total variance as the true variance of u_i is proportional but not exactly equal to σ_u^2 (Coelli, Rao and Battese 1998). The corrected relative contribution of inefficiency is given by $\gamma^*=\gamma/[\gamma+(1-\gamma)\pi/(\pi-2)]$ (Coelli 1995).

[2] The direction of effect on efficiency is the opposite of the sign in the inefficiency model in Table 4.

The derived contribution of the inputs, fisher efficiency and random variation to total output are illustrated in Figure 1. For the mobile gear and netter-liners, variations in individual fisher efficiency had only a small contribution to total variation in output, accounting for less than 2 per cent in both instances. As a result, increasing fisher efficiency may have only a relatively small impact on total output.

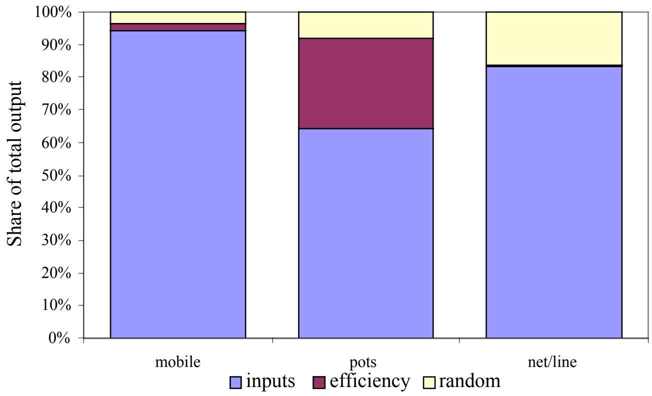

Figure 1. Contribution of inputs, efficiency and random error to total output

In contrast, efficiency accounted for 28 per cent of the variation in the output of the potting boats, and 77 per cent of the variation in output not due to the level of inputs employed. Only a few factors were found to positively affect efficiency for these boats, with the use of larger engines, navigational aids and experience being the main factors that could increase efficiency. However, as around three quarters of the fleet currently use navigational aids, and engine power increases are restricted through a unitisation system, the magnitude of the increase may be limited. Further, it is not possible to derive from the MLE estimation the proportion of efficiency (or inefficiency) explained by the inefficiency model. As an indication only of the potential contribution of these factors, the logged TE scores were regressed against the variables in the inefficiency model using OLS. The resultant model was found to explain less than 10 per cent of the variation in efficiency, indicating that individual fisher skill is largely determined by factors other than those indicated in the study.

7. DISCUSSION AND CONCLUSIONS

Little attention in the above results was given to the derived production functions as these were effectively intermediate steps to the estimation of the inefficiency model. However, as the derived implicit inefficiency scores are based on the variation in output not explained by the production function, some consideration needs to be given. The use of days fished as an input has a potential problems for the estimation process, as the number of days fished may be endogenous. For example, profit maximizing fishers may expend more time in the fishery when the value per unit of effort is higher, and hence direct estimation of the translog production frontier may result in simultaneity bias. Kirkley, Squires and Strand (1998) argue that given the stochastic nature of the output (e.g. due to weather conditions and the "luck" component of fishing), the choice of inputs based on expected profits will be subject to errors that are uncorrelated with the error terms in the production function. In such a case, direct estimation of the function results in consistent parameter estimates (Bjørndal 1989, Campbell 1991).

A number of common features appeared in the analyses of factors that affect efficiency. Higher levels of fishing activity were generally associated with lower levels of technical efficiency. This is at odds with the previous study of beam and otter trawlers in the fishery that found that efficiency was positively correlated with activity (Pascoe and Coglan 2002). This result may be an artefact of the effort measure used – days at sea. A boat leaving late one evening and returning the next morning would register two days at sea, but may only fish for as long as a boat that sets out and returns on the same day, registering only one day at sea. As a result, the apparent inefficiency is most likely a result of imprecise effort data. In the previous study (Pascoe and Coglan 2002), the unit of effort used was hours actually fished (i.e. nets in the water). This measure was not available for all gear types and all years on a consistent basis, so was not used in this study.

Technology, although all types widely adopted, had varying impact on efficiency depending on the main gear types employed. For the mobile gear vessels, only the auto-pilot was found to significantly increase efficiency. From the coefficient in the inefficiency model, vessels using an auto-pilot were, on average, seven times (i.e. $e^{1.95}$) more efficient than an equivalent vessel and skipper not using an auto-pilot (i.e. ceteris paribus). Navigational aids were found to be significant for the static gear boats (potters and the net-line vessels). This is as expected as the effectiveness of these gears relies on the fisher finding them again. Navigational aids such as GPS enable the skipper to find the gear faster, resulting in more gear being able to be worked per day, and less loss of gear (and associated catch).

Education and training was generally associated with lower levels of efficiency. Formal education in particular was generally negatively related to efficiency. From the model results, potter skippers with formal education were roughly 10 per cent (i.e. $e^{-2.56}$) as efficient as their uneducated counterparts, *ceteris paribus*. However, this may be offset to some extent by their lower ages (correlation between education and skipper age = -0.36) and use of newer boats (correlation between education and vessel age = 0.2). This is at odds with most studies of efficiency that use formal education as a proxy for skill. Education is generally assumed to be associated with increased efficiency as it broadens the producers' minds and enables them to acquire and process relevant information (Ali, Parikh and Shah 1996). In the case of potting, where the stock is fairly immobile and sites can generally be revisited once found, there is little need to second guess where the animals may be, and perhaps too much thought can be an impediment as indicated in the results. Experience in this case is more relevant than education, as indicated in the results.

In contrast, use of mobile gear requires an understanding as to how the resource moves with changes in seasonal and climatic conditions, so requires greater skipper input. While formal education appeared to impede efficiency even of this group (but only at the 10 per cent level of significance), education can take many forms. Vocational education and family history (which can impart an education on to the skipper based on inherited knowledge) were found to be significant in affecting the efficiency of the mobile gear.

For the potters, skipper age was also generally found to be negatively correlated with efficiency. A possible explanation for this is that the younger skippers are more willing to change their fishing patterns in response to catch rates or prices, whereas older skippers may be more set in their ways. This is consistent with the arguments of Maurer (2001), that the incentives to learn and develop decrease with age. However, an alternative hypothesis is that older skippers are physically less fit than younger skippers. Most of the potting boats were small, with often only one (or in many cases no) additional crew member. The skipper plays an integral role in raising the pots and sorting the catch. Older skippers may not be sufficiently fit to do this at the same rate as younger skippers, resulting in fewer pots being worked per day. This is less of a problem for trawlers and even the netter-liners, which tend to have larger crews, reducing the reliance on the physical strength of the skipper.

From the study, while there exists the potential to reduce the gap in efficiency differential through training and technology, at least for the mobile gear vessels, there are still a number of factors that affect efficiency beyond those that can be readily quantified. It is likely that there is an individualistic element to skill that is independent of education, training or technology employed. This was more than evident for the potting fleet, where over 90 percent of the variation in efficiency was not due to the quantifiable factors. This may represent the unobserved ability suggested by Card and Lemieux (1996) but generally ignored in studies of labour skill. In most industries, some participants are naturally pre-disposed to certain skills and abilities that give them a productive edge. While training and technology may improve the productivity of those individuals that are not naturally skilled in fishing, there is likely to remain a large portion of efficiency differentials that cannot be explained though measureable inputs.

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