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Abstract

We investigate the effects of incorporating a fixed input on equilibrium profits and biomass. We first set up a theoretical model with an input that is fixed in the short-run (vessel size) but that can be used with a variable input at sub-optimal capacity. We use this model to get predictions for the impact on profits of exogenous changes in biomass, output price and vessel size. These give us interesting theoretical insights into why it is important to incorporate fixed inputs into profit analysis. We subsequently conduct an empirical investigation to gain an understanding of the effects of these non-discretionary factors on profit efficiency. In particular, we apply a truncated regression with bootstrap methodology to data on individual firm profit efficiency from the South Australian Rock Lobster Fishery. We find empirical support for our predictions that increased biomass and smaller vessel length are associated with higher profits. An additional empirical result is that individual quota management is positively associated with profit efficiency.

JEL Classification: *Q2, Q22*

Key words: *biomass, non-discretionary factors, profit efficiency, truncated regression, bootstrap, rock lobster, ITQ*

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1 Introduction

Profit efficiency evaluation is valuable not only in identifying sources of inefficiency, but also of major interest to managers, firm owners and other stakeholders. Profit efficiency in itself is one of the major factors that can help explain firm survival and growth, as well as changes in industry structure. In fisheries a major interest to policy makers is the sustainability of the industry. This means that a critical evaluation of factors affecting profit efficiency in the industry is vital for sound policy formulation aimed at ensuring the industry's sustainability across time.

The main objectives of this paper are two-fold. The first is to provide a theoretical basis to justify the need to consider the importance of vessel capital when evaluating profit efficiency in fisheries. The second is to empirically identify factors beyond firms control which can significantly affect profit efficiency. Based on the heavy initial capital outlay, fixed cost is considered important in fisheries (Clark et al., 1979). For example, empirical evidence suggests that vessel size does matter in efficiency measures when quota system is introduced. Both large and smaller vessels are affected differently for various reasons (Grafton et al., 2006), underscoring the need to separate fixed costs, in this case the cost of fishing vessel, from other operating costs such as fuel, payment to crew and captains, and any such variable costs.[1] We develop a model that allows a firm to make a long-run decision about the optimal level of variable effort and to choose the size of vessel accordingly. Once the vessel-size decision has been made, however, the firm may choose to use a sub-optimal level of variable effort with the fixed input. This sub-optimal use comes at additional variable cost but, importantly, this cost is less than the (now sunk) fixed cost. We examine the impact on biomass of the inclusion of this sunk cost component. We then generate testable empirical predictions of the effect of exogenous changes in biomass, price and vessel length on profits.

[1] Grafton et al. (2006), find that while small vessels improved their short-run technical, labour and fuel allocative efficiency, large vessels realized significant improvements in short-run economic cost efficiency.

It has been pointed out in the literature that both biological and economic compositions of fisheries models are sometimes over simplified (Clark et al., 1979). It has thus become necessary to extend the biological or economic component, or both, in an attempt to show possible useful practical applications in fisheries. To do this we introduce fixed cost into the conventional profit function and modify the cost structure in the function. This enables us to carry out theoretical analysis of the full effect of firm profit maximization on fish stock. Studies on firm profits have been based on different assumptions. For example, Anderson et al. (2000) considered firm entry and exit decisions based on their profits in relation to fixed cost. Smith (1969) and Anderson (2000) also analyze firm entry and exit decisions assuming different management regimes. We, on the other hand, focus on the effect of profit maximization on stock levels across time, based on a modified version of the profit function that include a fixed input that can be used with a variable input at sub-optimal capacity, and relate the analysis to different management regimes at the same time.

The empirical analysis of non-discretionary factors affecting efficiency is conducted using truncated regression with bootstrap on data from the South Australian Rock Lobster Fishery.[2] To our knowledge there are no studies focusing on profit efficiency analysis of this fishery.[3] This paper is also the first to employ the bootstrap truncated regression approach to study the effect of non-discretionary variables on profit efficiency in the fishery. A major importance of this method is its ability to correct bias generated by the deterministic data envelopment analysis (DEA) technique that computes the efficiency scores, particularly in the face of small sample sizes.

The empirical part of the paper adopts a semi-parametric approach by first using

[2]We are extremely grateful to EconSearch, particularly Dr. Julian Morison (Director, EconSearch), for making this firm level data available to us. EconSearch is a research body established in 1995 to provide economic research and consulting services in agricultural and resource industries throughout Australia (EconSearch, 2011). EconSearch collects the confidential data and provides reports to the state fisheries regulator, PIRSA.

[3]There are studies of lobster fishery profits in the region including Sharp et al. (2004)'s study of the New Zealand Rock Lobster Fishery, Hamon et al. (2009)'s study of the Tasmanian Rock Lobster Fishery, and EconSearch's economic indicator reports on the South Australian Rock Lobster Fishery.

DEA efficiency scores calculated in the previous paper on variable input and regressing on non-discretionary inputs. We do this using a parametric truncated regression with bootstrap technique. We adopt this semi-parametric approach for two reasons. The dependent variable we use is pre-determined by a non-parametric DEA procedure. This non-parametric approach has been found to be serially correlated with some important underlying variables that may well explain efficiency performance. However, this is not established when DEA estimates alone are considered in efficiency analysis. Another reason is that these non-discretionary variables are fundamentally different from other input variables.[4] This means there is the need to employ other methods that can help gauge out the role of these variables in the determination of a firm's economic performance. Our objective here is to determine if indeed such factors have any impact on profit efficiency and, how such factors fit into the sustainability equation of the fishery under investigation. Using a parametric method to achieve this objective is consistent with the literature (for examples, see Simar and Wilson (2011) and Assaf and Matawie (2010)).

Our theoretical analysis suggests that although the effect of vessel size can be ambiguous, the closer effort is closer to optimal vessel usage, profits will rise. However, profits will fall if having a larger vessel exacerbates the sub-optimality of vessel use. The theoretical analysis further shows that as long as the cost associated with sub-optimal use of vessel size remains positive but lower than the sunk costs the equilibrium stock level is negatively affected. This is caused by the higher effort. This means vessel size may affect profitability via two channels. The first is the reduction in profit levels in direct relation to vessel size. The second is the indirect reduction in profitability in relation to reduced biomass levels. These offer a way to interpret the results obtained in our empirical analysis. We also show theoretically, that changes in prices have a direct and an indirect effect on profits. A rise in output price is good for profits, at least in the short-run. This confirms the negative price

[4]These factors are considered fundamentally different from other input variables in as far as their values cannot be altered either directly by the firm or within meaningful time frame. For example, a fishing firm cannot alter its assigned fishing quota, neither can it alter the length of its vessels, in any fishing period.

effect observed in our empirical results which can be attributed to the direct short-run negative effect resulting from unfavourable exchange rate shocks in the periods considered for the study. The indirect long-run effect of higher prices is negative through a reduction in biomass.

The empirical results suggest that increases in fish stocks are desirable for profit efficiency but only up to a point. This result is supported by our theoretical results, and consistent with the fisheries literature which indicates that incremental changes in the fish biomass though beneficial, is counter productive beyond certain point.[5] We also establish that for the South Australian Rock Lobster Fishery existing boat lengths are not commensurate with biomass and, therefore, impact profit efficiency negatively. Again this result is consistent with the fisheries literature.[6] Zone specific characteristics and the individual transferable quota (ITQ) management system are both found to impact profit efficiency positively. The ITQ effect is found to generally agree with existing literature on the benefits of the ITQ introduction in fisheries (see Grafton et al., 2000). Finally, we find evidence to to suggest that unfavourable exchange rate position of the rock lobster fishery with its major trading partners may explain some of the allocative (managerial) challenges that negatively impact profit efficiency in the fishery.

Efficiency studies in the literature generally use either the DEA or the free disposal hull (FDH) procedures to obtain efficiency measures in a first stage. In a second stage the efficiency measures obtained in the first stage are used as the independent variable and regressed on a number of non-discretionary variables, using methods such as ordinary least square (OLS), censored, or tobit regressions.[7] These methods, including quasi-maximum likelihood estimation (QMLE) methods are argued to perform equally well (McDonald, 2009). Simar and Wilson (2011), however, explain that

[5] see for example, Dupont et al. (2005); Grafton et al. (2007) and Kompas et al. (2010)

[6] See Tingley et al. (2005); Grafton et al. (2006); and Pascoe and Robinson (2008).

[7] Simar and Wilson (2007), find over 1,500 articles for the period between 2007 and 2010. They indicate the main methods used in the second stage are OLS or tobit regressions, and rely on conventional methods for inference.

the first stage measures are estimates of the unobserved true efficiency measures, and thus serially correlated in a complicated, unknown, way with the non-discretionary variables.[8] They show that the application of OLS, tobit, and conventional likelihood methods in the second stage may lead to estimation problems and therefore inappropriate. In other words, the dependency problem violates the second stage regression assumption that the error terms, are independent of the discretionary variables. In addition, other regression methods in the second stage are either invalid or do not describe the underlying data generating process (Simar and Wilson, 2011).

Another reason for the violation is attributed to the fact that the DEA scores are relative efficiency indexes and not absolute indexes (Barros and Assaf, 2009). To obtain statistical properties of the efficiency scores obtained from the DEA procedure, Simar and Wilson (1998; 1999; 2007), propose the bootstrap method in the second stage regression. Based on the original Efron (1979) re-sampling idea, Simar and Wilson (2007) extend their method to capture non-discretionary variables that may impact the efficiency scores other than technical or allocative inefficiencies. Specifically, Simar and Wilson (2007) propose a statistical model in which the form of the second stage regression equation is determined by the structure from which the DEA estimates are obtained in the first stage. The model is specified based on assumptions that lead to truncated regression in the second stage which can be consistently estimated using maximum likelihood (MLE) estimation.[9] They show the consistency of the second stage estimated results in a Monte Carlo experiment. Comparing truncated regression results with OLS results in the Banker and Natarajan (2008) model it is also emphasized that the bootstrap method provides the only feasible means for

[8] In the efficiency literature the computation of the DEA scores is considered a first stage. The second stage is the application of various parametric methods to determine the effect of other factors, not considered in the first stage, on the efficiency scores. In the past the two stages have been considered separately. Considering the two stages together is not a requirement though it is common to find the two stages together in one paper in recent times (Simar and Wilson, 2011). We consider the two in separate but related papers.

[9] Simar and Wilson (2007) show that these assumptions augment the standard non-parametric production model where DEA efficiency estimators are consistent to incorporate non-discretionary variables.

inference in the second stage (Simar and Wilson, 2011). This view is emphasized in a recent work by Lee and Worthington (2011).

The paper is structured as follows. Section 2 sets up the theoretical model, detailing the firm's long and short-run decisions. Management techniques and empirical predictions are also discussed in this Section. In Section 3 we provide theoretical exposition of the empirical method employed in the analysis, with Section 4 describing the data from the South Australian Rock Lobster Fishery. In Section 5 the empirical results regarding the impact of non-discretionary variables on profit efficiency are presented. Section 6 concludes that addressing the role of capital is important in studies of fisheries profitability and provides suggestions for future extensions.

2 Model

In the standard dynamic, single-species fisheries Gordon-Schaefer model (Gordon, 1954; and Schaefer, 1957) fishermen face a constant marginal cost of effort which is equal to average cost. We depart from this assumption by including two inputs in harvesting: one that is variable and one that is fixed in the short-run, the latter hence having some associated sunk costs. The decision on what size of the fixed input (say, vessel length) to purchase is made to correspond with maximum profits at the optimal, ex ante, level of effort. After this decision has taken effect, however, the fishermen may find it more profitable to use the vessel at a sub-optimal capacity (either too much or too little) and pay an additional cost for this.[10] We compare the equilibrium levels of effort under these different assumptions about cost and consider the impact of including fixed costs on short-run biomass and profit levels.

[10]Imagine a standard long-run average cost diagram. Suppose we are operating in the constant-returns-to-scale range so that the minimum of the short-run average cost for every vessel size is the same (γ) but that the short-run average cost curve associated with each vessel size is greater to the left and the right of the minimum than the long-run average cost curve.

2.1 Firm's long-run decision

We start by considering the fisherman's long-run decision where he chooses the level of the variable input effort (E_{it}) and the associated fixed input size (V_{it}) to maximize profit, taking the actions of others ($E_{jt},\ V_{jt},\ j \neq i$) and the natural growth of the fish stock as given.

$$\max_{E_{it}} \int_0^\infty e^{-\delta t} \left\{ (pqB_t - c)E_{it} - \gamma V_{it}) \right\} dt \tag{1}$$

subject to

$$\dot{B}_t = F(B_t) - qE_{it}B_t - \sum_{j \neq i} qE_{jt}B_t$$

$$F(B_t) = rB_t \left(1 - \frac{B_t}{K}\right)$$

As the optimal vessel size is chosen to minimize the costs of putting forth a particular level of effort, we let $V_{it} = E_{it}$ in this long-run decision, which implies

$$\max_{E_{it}} \int_0^\infty e^{-\delta t} \left\{ (pqB_t - c)E_{it} - \gamma E_{it}) \right\} dt$$

subject to

$$\dot{B}_t = rB_t \left(1 - \frac{B_t}{K}\right) - qE_{it}B_t - \sum_{j \neq i} qE_{jt}B_t$$

where profit depends on the output price (p), technical capability (q), effort level (E_{it}), vessel size (V_{it}), stock size (B_t), average and marginal cost of effort (c), and average cost of the vessel (γ). Growth of the fish stock is based on the logistic natural growth function, with an intrinsic growth rate (r), natural maximum stock size (K), and stock size (B_t), less the amount of harvesting done by all fishermen. Thus, the Hamiltonian for player i is:

$$\mathcal{H} = e^{-\delta t}\left[pqE_{it}B_t - (c+\gamma)E_{it}\right] + e^{-\delta t}\lambda_t\left[rB_t\left(1-\frac{B_t}{K}\right) - qE_{it}B_t - \sum_{j\neq i} qE_{jt}B_t\right] \tag{2}$$

Taking first-order conditions and assuming a symmetric equilibrium, the steady-state equilibrium stock level, $\tilde{B}$, equates the discount rate (δ) with the return from leaving another fish in the ocean:[11]

$$\delta = -\frac{r\tilde{B}}{K} + \frac{r}{n}\left(1-\frac{\tilde{B}}{K}\right)\frac{pq\tilde{B}}{pq\tilde{B}-(c+\gamma)} \tag{3}$$

Equation (3) is just the standard *modified golden rule* of fisheries except that there are two cost terms, c and γ. The equilibrium biomass implicitly defined by Equation (3) gives an associated equilibrium level of effort $\tilde{E} = \frac{r}{nq}(1-\frac{\tilde{B}}{K})$ and therefore the optimal vessel size ($\tilde{V}$).

2.2 Firm's short-run Decision

Now let us consider the decision for a fisherman who has already purchased a vessel of size $\tilde{V}$ and the cost of doing so is sunk. If there were no inefficiencies associated with using the "wrong" size of vessel[12] the short-run decision would lead to effort being determined by Equation (3) but with $\gamma = 0$. Suppose, however, that to use a vessel of size $\tilde{V}$ with effort $E \neq \tilde{E}$ involves some additional cost (say increased maintenance cost if $E > \tilde{E}$ or increased mooring costs if $E < \tilde{E}$):

$$\textit{Suboptimal Cost} = \frac{m}{2}(E_{it} - \tilde{V}_i)^2$$

then the Hamiltonian for the fisherman's short-run profit-maximizing decision is represented by:

$$\mathcal{H} = e^{-\delta t}\left[pqE_{it}B_t - cE_{it} - \frac{m}{2}(E_{it}-\tilde{V}_i)^2\right] + e^{-\delta t}\lambda_t\left[rB_t\left(1-\frac{B_t}{K}\right) - qE_{it}B_t - \sum_{j\neq i} qE_{jt}B_t\right] \tag{4}$$

[11] See Proof 1 in the Appendix

[12] That is, if the short-run average cost curve was the same shape as the long-run average cost curve (at least over some range).

Taking first-order conditions and assuming a symmetric equilibrium, the steady-state stock level, $\hat{B}$, is now implicitly determined by:[13]

$$\delta = -\frac{r\hat{B}}{K} + \frac{r}{n}\left(1 - \frac{\hat{B}}{K}\right)\frac{pq\hat{B}}{pq\hat{B} - c - m\left(\frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right) - \tilde{V}\right)} \tag{5}$$

Clearly if there were no costs associated with sub-optimal use ($m = 0$) we would have the standard *modified golden rule.* Under the assumption that these costs of sub-optimal use (that is, $m\left(\frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right) - \tilde{V}\right)$) are positive but less than the fixed costs, γ, (at least in a neighbourhood of $\tilde{V}$), the equilibrium stock level $\hat{B}$ is lower than $\tilde{B}$ and effort is higher. Choosing this higher level of variable input than is optimal for the vessel size will result in lower than anticipated profits but is in the fisherman's best short-run interests. What we would expect to observe in a fishery with fixed (and sunk) costs is lower profits and lower biomass.

2.3 Management techniques

Now let us consider the impact of different management techniques: limited entry; total allowable catch (TAC) limits; and individual quotas (IQs). Limited entry simply fixed the number of fishermen (n) and thus in our model we would observe the lower biomass and the associated lower profits in the presence of fixed costs. Management techniques in fisheries are often simply aimed at addressing the overcapacity problem, via reduction in labour and capital inputs to levels where marginal cost of an additional increase in effort equals the corresponding marginal revenue generated (Owers, 1975). In the absence of overcapacity control firms will expand effort to the point where economic rent is zero. The firm also makes its production decision on the resource stock but behaves as though the resource has a zero user cost (Gordon, 1954).

[13] See Proof 2 in the Appendix.

If the objective is to ensure sustainability of the biomass and controlling capacity is not enough, catch limits are frequently introduced. The TAC management system, for example, requires that the fishery is shut down when allowable harvest has been taken. The assumption is that TAC programme is perfectly enforceable, such that fishing is stopped whenever the set TAC level is reached. The perfect enforceability of TAC implies a biological equilibrium at stock sizes where growth equals the TAC (Anderson and Seijo, 2010). The literature, however, acknowledges that the introduction of TAC has not succeeded in solving the open access problem of over fishing. Instead TAC has made the over capacity problem more severe as a result of Olympic type of fishing and, consequently, dissipating resource rents in most cases (Asche et al., 2008). This manifests in our model where the TAC may be able to implement stock level $\hat{B}$ but each fisherman will then face incentives to pay at least the cost m and overuse his vessel in the race for the fish.

An individual quota system is one of the alternative techniques introduced in a number of fisheries to address the overcapacity problem. This management technique is expected to reduce effort, increase efficiency and ensure sustainability of the fisheries. The ITQ system is also thought to have the potential to reduce cost, and change revenues of fishing firms over both the short and long-run. Increased returns in Halibut fishing in Canada, for instance, is found to far exceed cost with the introduction of individual vessel quotas, IVQs (an IQ system) (Grafton et al., 2000). In our model, an IQ system may be able to not only implement $\tilde{B}$ (or, more, preferably the socially optimal level) but also to provide the incentive to use the vessel at its optimal capacity.

2.4 Empirical predictions

One purpose of conducting this theoretical analysis is to inform the empirical analysis in subsequent Sections. In the previous paper, profit inefficiency measures were calculated based on a long-run assumption where all inputs are variable. The theory here indicates that non-discretionary (in the short-run) components of profits - biomass, output price, and vessel size - may play an important role. To see this specifically, we can consider some simple comparative statics. Recall that in each period individual profits (excluding sunk costs) will be:

$$\hat{\pi} = pq\hat{E}\hat{B} - c\hat{E} - \frac{m}{2}(\hat{E} - \tilde{V})^2 \tag{6}$$

At the symmetric steady-state the growth rate equals the harvest so $\hat{E} = \frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right)$ so:

$$\hat{\pi} = (pq\hat{B} - c)\frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right) - \frac{m}{2}\left(\frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right) - \tilde{V}\right)^2, \tag{7}$$

and thus, the response of profits to an exogenous increase in biomass can be calculated as:

$$\frac{d\hat{\pi}}{d\hat{B}} = \frac{r}{nqK}\left[\left(pqK - c - m(\hat{E} - \tilde{V})\right) - 2\left(pq\hat{B} - c - m(\hat{E} - \tilde{V})\right)\right] \tag{8}$$

which is positive in the relevant range.[14] Note that Equation (8) is increasing in c: increasing biomass is more helpful (to increase profits) for higher cost firms. Note also that the relationship between profits and biomass is increasing at a decreasing rate.[15]

The response of profits to an exogenous increase in output price (through an appreciation of the Australian dollar for example) can be calculated as:

$$\frac{d\hat{\pi}}{dp} = \underbrace{q\hat{B}\frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right)}_{positive} + \underbrace{\frac{\partial\hat{\pi}}{\partial\hat{B}}}_{positive}\underbrace{\frac{d\hat{B}}{dp}}_{negative} \tag{9}$$

As can be seen from Equation (9), the effect of price on profits is made up of a short-run effect and a long-run effect via biomass. In the short-run, an increase in price is good for profits but in the long-run the effect is ambiguous because the higher price induces increased effort which negatively impacts the biomass and hence harvest will fall.[16] The overall impact of the price versus quantity effect is ambiguous. As the data we use in the analysis here is for four distinct time periods, and we will control

[14]See Proof 4 in the Appendix.
[15]See Proof 4 in the Appendix.
[16]Refer to Equation (5) and see Proof 5 in the Appendix.

directly for biomass, the short-run (positive) effect is what we would expect to observe in the data.

The response of profits to an exogenous increase in vessel size can be calculated as:

$$\frac{d\hat{\pi}}{d\tilde{V}} = \underbrace{m(\hat{E}-\tilde{V})}_{\gtreqless 0\, if\, \hat{E} \gtreqless \tilde{V}} + \underbrace{\frac{\partial\hat{\pi}}{\partial\hat{B}}}_{positive} \underbrace{\frac{d\hat{B}}{d\tilde{V}}}_{negative} \tag{10}$$

As can be seen from Equation (10), the effect of having a larger vessel is ambiguous in both the short- and long-run. The initial impact depends on whether effort is already above or below optimal for vessel size $\tilde{V}$: if having an exogenously larger vessel means the effort is closer to the optimal for that vessel size, profits will rise; or profits will fall if having a larger vessel exacerbates the sub-optimality of effort. The long-run impact, via the effect on biomass, is negative which may counteract or reinforce the initial impact.[17] In this theoretical characterization we have been looking for the steady-state, we have not looked at the dynamics of going from a initially unexploited fishery to a mature fishery.[18] If we think that the fishery considered in our empirical analysis is now mature and that vessels were purchased when the biomass was closer to its original size, we would expect that the vessels are larger than is now optimal and hence we would expect larger vessels to experience lower profits in both the short- and long-run.

3 Truncated Regression with Bootstrap

Simar and Wilson (2007) propose a bootstrap semi-parametric procedure for making valid inferences about the impact of non-discretionary factors on efficiency measures. The procedure is outlined in the form of algorithms, the first of which is referred to as algorithm 1. This algorithm details a single bootstrap procedure. A double boot-

[17]Refer to Equation (5) and see Proof 5 in the Appendix.

[18]Clark et al. (1979) show that if capital is at least partially malleable the steady-state will be the same but that the dynamics of getting to the steady-state will be different to the case of perfectly malleable capital.

strap procedure was later proposed (Simar and Wilson, 2007). However, they show that the single bootstrap and double bootstrap procedures produce similar results.[19] We adopt the single bootstrap procedure in this paper. In this approach we regress the profit efficiency scores obtained in our first study on non-discretionary factors using a truncated regression with bootstrap. In the next few paragraphs we give a brief description of the bootstrap concept, its importance in the second stage analysis and, give details of the bootstrap algorithm used in this paper. We also detail the application of the truncated regression method used in the next Section.

Bootstrapping is a re-sampling method which re-samples the data with replacement. The idea is to mimic the data generating process (DGP) characterizing the underlying *true* data generation. The procedure helps provide confidence intervals for the regression parameters. Details of this are discussed later in this Section. Since the DEA scores are simply measures of distance to a best practice frontier a number of questions arise.[20] Simar and Wilson (2011) emphasize that statistical inference is important, and meaningful inference require coherent, well-defined statistical model describing the DGP and providing probabilistic structure for inputs, outputs, and non-discretionary (environmental) variables. The bootstrapping method employed in this paper uses the single bootstrapping procedure.

The Farrell (1957) efficiency measure is assumed to take a functional form, $\psi(Z_i,\ \beta)$, of the non-discretionary co-variates, Z_i, and the parameters, β, together with an independently distributed error term, ε_i, assumed to represent the part of inefficiency unexplained by the co-variates (Simar and Wilson, 2007). Given that by definition the inefficiency measure is greater than or equal to unity, that is $\theta_i \geq 1$, Simar and Wilson (2004) make the assumption that the error term, ε_i, is independently and

[19] Olson and Vu (2009) confirm this in their study on economic efficiency in farm households, investigating factors explaining differences in economic efficiency.

[20] Simar and Wilson (2011), for example, identify questions such as: how far might a new firm lie beyond the best practice frontier, if such a possibility exists; by how much are observed firms able to improve their performance, if they are able to do so; or by how much can firms on the best practice frontier able to improve their performance, assuming they are able to do so.

normally distributed random variable with mean 0, and unknown variance σ_ε^2, i.e., $\varepsilon_i \sim N(0,\, \sigma_\varepsilon^2)$, with left truncation at $1 - \psi(Z_i,\ \beta)$. These assumptions imply the following equation:

$$\theta_i = \psi(Z_i,\ \beta) + \varepsilon_i \geq 1 \tag{11}$$

Equation (11) is understood to be the first-order approximation of the unknown *true* relationship (Simar and Wilson, 2004). Here θ_i can be considered as the *true* estimate of the unobserved true efficiency measure, and ψ a smooth continuous function. Equation (13) can also be re-arranged to yield $\varepsilon_i \geq 1 - \psi(Z_i,\ \beta)$. This explains why the error term, ε_i, is truncated on the left at $1 - \psi(Z_i,\ \beta)$.[21] Ramalho et al. (2010) note that given the interpretation of the DEA scores, the scores can be treated like any other dependent variable in the regression analysis. This implies that the parametric estimation and inference in the regression analysis can be carried out using standard procedure.[22]

The single bootstrapping procedure essentially requires regressing the DEA efficiency scores on non-discretionary variables using truncated regression of the form:

$$\hat{\theta}_i = Z_i\beta + \varepsilon_i \geq 1 \tag{12}$$

The variables, parameters and error terms are as explained in Equation (11). The left hand side dependent variable, $\hat{\theta}_i$, is the computed efficiency scores replacing the *true* unobserved efficiency measures in Equation (11). Simar and Wilson (2007) explain that $\hat{\theta}_i$ is an estimate of the unobserved *true* efficiency measure, θ_i, and thus serially correlated in a complicated, unknown way with the non-discretionary variables. Fur-

[21] The assumptions imply a separability condition, where separability here is used to mean that the support of the output variables does not depend on the non-discretionary variables, Z. The functional form, $\psi(Z_i,\ \beta)$, is also assumed to be linear. The linearity assumption is made to correspond with what is typically observed in the literature. For details see Simar and Wilson (2007). Though different parametric forms, for example logistic regression, can be assumed, we follow the convention in the literature and assume linear form.

[22] McDonald, 2009; and Romalho et al., 2010, interpret the DEA scores as descriptive measures and, therefore, the frontier can be viewed as observed best-practice construct within the selected sample (Simar and Wilson, 2011).

ther to that, under the assumption that the DEA efficiency estimates obtained are consistent, the maximum likelihood (ML) estimation of Equation (12) yields consistent estimates of β. However, given that the estimates have just replaced the *true* unobserved efficiency measure θ_i, inference from Equation (12) is problematic. This is so because while $\hat{\theta}_i$ estimates θ_i consistently, DEA estimators have a slow convergence rate and are biased (Simar and Wilson, 2007). The single bootstrap procedure is therefore proposed to help overcome these problems. The bootstrap procedure for the truncated regression incorporates information on the parametric structure of Equation (12), and the distributional assumption on the error term.

Now we provide details of the algorithmic procedure of the Simar and Wilson (2007) single bootstrap method. The algorithm follows the following steps. The first step involves the computation of the efficiency scores. As mentioned before, this paper uses efficiency scores computed in a separate paper. This was done using the non-parametric DEA approach.[23] The second step involves estimation of the parameters, $\hat{\beta}$ and $\hat{\varepsilon}_i$, of Equation (12). This is done using the ML method to estimate Equation (12) as a truncated regression. The next step computes $\boldsymbol{B}$ bootstrap estimates of $\hat{\beta}$ and $\hat{\sigma}_\varepsilon$ as follows: (i) for each observation $i = 1, \ldots, n$, ε_i is drawn from a normal distribution with variance $\hat{\sigma}_\varepsilon^2$ (i.e., $N(0,\, \hat{\sigma}_\varepsilon^2)$) with left truncation at $(1 - Z_i\hat{\beta})$ and $\theta_i^* = Z_i\hat{\beta} + \hat{\varepsilon}_i$ is computed; (ii) a truncated regression of θ_i^* on Z_i is then estimated using ML method to give the bootstrap bias corrected estimates, $\hat{\beta}^*, \hat{\sigma}_\varepsilon^*$. The procedure also constructs the confidence intervals for the parameters together with the associated p-values (Afonso and St Aubyn, 2005). The following Section describes the data used in the analysis.

[23] Mean distributions of these efficiency scores are provided in Table 1. These are mean scores for the Northern and Southern Zone Rock lobster Fisheries of South Australia, covering the periods; 1997/98, 2000/01, 2004/05, and 2007/08.

4 Data Description

Data on the South Australian Northern and Southern Zone Rock Lobster Fisheries were obtained from EconSearch and SARDI.[24] EconSearch collects confidential survey data from fishing operators in the Northern and Southern Zone fisheries for the estimation of various economic indicators. The data are cross-sectional, covering the fishing periods 1997/98, 2000/01, 2004/05, and 2007/08.[25] The surveys are voluntary, and due to legal reasons no identifiers are used. It is therefore not possible to track individual vessels over time. For each of these time periods the data are grouped separately into Northern (NZ) and Southern (SZ) Zones. The data is further grouped into discretionary (direct variable, quasi-fixed and fixed costs) and non-discretionary categories. In this paper we focus on the non-discretionary variables.

The non-discretionary variables include; estimated biomass levels, boat length, boat age, engine age, and electronic equipment age.[26] Mean values of these variables, including their standard deviations, minimum and maximum variables, for all the periods under investigation are provided in Table 1. The biomass mean values are significantly higher in the Southern Zone than in the Northern Zone, in all peri-

[24]As earlier mentioned EconSearch collects the confidential data and provides reports to the state fisheries regulator, PIRSA. We are grateful to EconSearch, particularly Dr. Julian Morison, for making the data available to us. In addition to the aforementioned thanks to EconSearch, we are also grateful to Dr. Adrian Linnane of SARDI, for making the biomass data, as published in Linnane et al. (2012), available to us. SARDI is the South Australian Government's principal research institute. SARDI conducts biological and ecological research on South Australian fisheries, including estimating biomass for NZRL and SZRL.

[25]The fishing periods correspond with the fishing seasons in these fisheries. The Northern and Southern Zone fishing seasons fall within the financial year calender. However, the fisheries are closed for about six months in each lunar year. The seasonal closures coincide with the breeding seasons of the fisheries. In the Northern Zone fishery is closed from the 31st of May to the 1st of November, each year. In the Southern Zone the closure is from the 31st of May to the 1st of October, each year. Source: PIRSA (2012). We are most grateful to Stacey Paterson of EconSearch for providing us with this additional information.

[26]In the context of fisheries these variables are considered fundamentally different from other input variables in as far as the values cannot be altered either directly by the firm or within meaningful time frame. For example, a fishing firm cannot alter its fishing quota assigned in any given period, nor can it alter the length of its fishing vessel within a single fishing period. Note: quotas are assigned based on TAC which is in turn determined by the biomass level in each period.

ods. Observe that though mean biomass is higher in the Southern Zone, there is greater variability in the Southern Zone biomass levels, compared to the North. It is important to note that though there was consistent decline in the Northern Zone biomass throughout the periods, the fall was sharpest in the 2004/05 fishing period. The Southern Zone, on the other hand, experienced a significant increase in biomass levels in 2000/01 and thereafter registered its first decline in 2004/05. The fall in the Southern Zone, however, was steeper in the 2007/08 period.
For the 1997/98 and 2000/01 periods the mean boat age in the Southern Zone is higher than in the North. The opposite is the case for the 2004/05 and 2007/08 periods. On the other hand, mean engine age is generally higher in the Southern Zone, except for the 2004/05 period. A similar picture is observed for electrical equipment age, where the mean age is higher in the Southern Zone for all periods except for the 2007/08 period. Mean boat length is higher in the Southern Zone for all periods. The mean values of other non-discretionary variables in the 1997/98 period for the Northern Zone are also generally lower compared to those of its Southern counterpart. The differences in the mean distributions across the zones are assumed to account for regional differences, and therefore used as non-discretionary variables in the truncation regression analysis carried out in this paper. In Table 1 are also statistics of the efficiency scores used as dependent variables. Recall from Section 3 of this paper that by definition the inefficiency measure is greater than or equal to one. Note that the efficiency scores obtained in paper 2 are between 0 and 1, so we specify $\hat{\theta}$ (see Section 3) as their inverse. This is further explained in Section 5 where the truncated regression model is specified. We point out in paper 2 that these are zone specific inefficiency scores and so we do not compare across zones. However, notice that variabilities within zones differ.

We also include the Australian/Hong Kong exchange rates (AUD/HKD) as a non-discretionary variable, for the period under consideration. The inclusion of this variable in our data set is important. According to EconSearch annual reports, unfavourable exchange rate position of the Australian dollar (AUD) in relation to the Hong Kong (HKD) dollar negatively impacts profits in the fisheries since products

Table 1: Period by period means, standard deviations, and spread of efficiency and non-discretionary variables

Period	Zone	Ineff. measure ($\hat{\theta}$)	Biomass	Boat age	Boat length	Engine age	Elect. Equip. age	HKD/AUD Exch. rate
1997/98	NZ	1.32	2912.04	11.78	10.27	6.56	4.47	5.28
		(0.26)	*(75.81)*	*(6.05)*	*(0.66)*	*(4.54)*	*(2.24)*	*(0.34)*
		[1.02, 1.83]	[2858.43, 2965.64]	[3.00, 23.00]	[8.42, 11.36]	[1.00, 15.00]	[2.00, 11.00]	[4.53, 5.85]
	SZ	1.30	2911.72	12.82	11.94	7.28	4.54	
		(0.34)	*(337.00)*	*(6.97)*	*(0.90)*	*(7.08)*	*(1.26)*	
		[1.02, 2.70]	[2673.43, 3150.01]	[3.00, 30.00]	[9.90, 13.24]	[1.00, 30.00]	[3.00, 7.00]	
2000/01	NZ	1.42	2351.06	10.38	10.24	5.13	5.25	4.20
		(0.22)	*(214.29)*	*(6.14)*	*(0.78)*	*(2.82)*	*(1.89)*	*(0.22)*
		[1.03, 1.82]	[2199.53, 2502.58]	[2.00, 30.00]	[7.54, 11.09]	[1.00, 10.00]	[2.00, 10.00]	[3.77, 4.69]
	SZ	1.42	4510.75	14.42	11.89	5.22	4.62	
		(0.25)	*(342.01)*	*(8.42)*	*(1.16)*	*(4.93)*	*(3.71)*	
		[1.00, 2.08]	[4268.91, 4752.58]	[1.00, 40.00]	[8.53, 13.96]	[1.00, 19.00]	[1.00, 15.00]	
2004/05	NZ	1.83	1716.14	19.50	10.19	10.19	5.95	5.86
		(0.52)	*(30.31)*	*(12.35)*	*(0.91)*	*(4.09)*	*(2.54)*	*(0.23)*
		[1.00, 2.77]	[1694.70, 1737.57]	[3.00, 56.00]	[7.28, 11.59]	[5.00, 20.00]	[2.00, 12.00]	[5.37, 6.22]
	SZ	2.07	4466.00	14.17	11.77	5.79	6.13	
		(0.64)	*(366.73)*	*(10.21)*	*(1.48)*	*(4.02)*	*(3.90)*	
		[1.10, 3.97]	[4206.68, 4725.32]	[2.00, 65.00]	[3.06, 15.14]	[1.00, 24.00]	[1.00, 24.00]	
2007/08	NZ	1.53	1475.04	21.83	10.16	6.26	3.09	6.99
		(0.58)	*(83.49)*	*(12.03)*	*(0.94)*	*(8.00)*	*(3.67)*	*(0.31)*
		[1.01, 3.74]	[1416.28, 1534.35]	[6.00, 50.00]	[8.7, 11.88]	[2.00, 25]	[1.00, 13.00]	[6.10, 7.52]
	SZ	1.73	2534.33	16.67	11.83	6.73	4.04	
		(0.83)	*(704.14)*	*(10.97)*	*(1.26)*	*(5.16)*	*(3.44)*	
		[1.00, 4.92]	[2036.43, 3032.23]	[5.00, 66.00]	[8.10, 13.56]	[1.00, 26.00]	[1.00, 14.00]	

Notes: Biomass is in tonnes; Boat age, Engine age, and Electrical equipment age, are all in years; and Boat length, in meters. Ineff. measure ($\hat{\theta}$), refers to profit inefficiency measures. Period, refers to fishing periods considered for the study, with days referring to trading days in each financial year.

Data sources: EconSearch (2011), and Reserve Bank of Australia (2013).

from these fisheries are mainly for the export market.[27] A careful observation of the statistics in Table 1 shows an appreciation of about 20% of the HKD against the AUD, between the 1997/98 and 2000/01 periods, but thereafter fell sharply by about 40% in value against the AUD in the 2004/05. This depreciation of the HKD against the AUD continued into the 2007/08 period. The fall in value between the 2004/05 and 2007/08, however, was about 19%.

The appreciation of the AUD against the HKD meant that products from the fisheries had become relatively costly, with the shock in the 2004/05 period being more severe. The appreciations of the AUD against the HKD are much higher when the maximum values are considered. In a competitive world market, this shock is more than likely to have negative impact on demand for the products from these fisheries and hence profits. In the next Section we detail the empirical procedure and present the results together with the analysis. Having detailed the theoretical background of the analysis and described the data used, the next task is to describe the empirical application and analyse the results obtained. We do these in the next Section.

5 Empirical Application, Results and Analysis

To investigate the possible effects of non-discretionary variables on profit efficiency of the fishing firms in the South Australian Rock lobster Fishery, we specify a truncated regression model based on Equation (12). Reasons for using the truncated regression approach are well elaborated in the introduction to this paper so the details are not repeated here. However, a brief reminder of why we use the truncated regression model is in order. OLS and other methods have been shown to bias the results since the explanatory variable, the DEA efficiency scores, is likely to be correlated with the

[27] Hong Kong is the major export destination of products from these fisheries, accounting for over 80% of total trade volume (EconSearch, 2011). The exchange rate data was obtained from the official website of the Reserve Bank of Australia (www.rba.gov.au/statistics/hist-exchange-rates/). These were daily trading rates from which we calculated annual (financial year; 1st of July to 30th of June) averages, together with other statistics, for the periods covered in our analysis.

error term. This bias is avoided by running the truncated regression based on MLE. We begin this section by describing the application procedure, show the results, and provide detailed analysis of these results.

5.1 Application

The non-parametric DEA technique was used in a separate but related paper to obtain profit efficiency scores for sampled fishing firms from the Northern and Southern Zones of the South Australian Rock lobster Fishery.[28] The firms were sampled for the 1997/98, 2000/01, 2004/05, and 2007/08 fishing periods. For the regression analysis we pool the efficiency scores for the four periods together. The efficiency scores are between 0 and 1 so we specify $\hat{\theta}_i$ as their inverse, yielding values greater than or equal to 1, i.e. $\hat{\theta}_i \geq 1$. We use pooled data in order to increase the sample size and also to be able to pick up changes across different fishing periods, if any. Using $\hat{\theta}_i$ as the regressand, we specify the truncated model for the Northern and Southern Zone fisheries, in the form of Equation (12), in Equation (15) as follows:

$$\begin{aligned} Profit\,Efficiency_{izt} \;=\;& \psi(Biomass_{zt},\, Biomass^2_{zt},\, Boat\,Age_{izt},\, Boat\,Length_{izt}, \\ & Zone\,Dummy_{zt},\, Management\,(ITQ)_{zt}, \\ & Period\,Dummy,\, Engine\,Age_{izt}, \\ & Electrical\,Equipt.\,Age_{izt},\, AUD/HKD_t) + \varepsilon_i \end{aligned} \tag{13}$$

The dependent (explained) variable is the efficiency score of firm i in zone z in period t. Recall that these are inefficiency measures truncated at 1 from below (left truncation). This means that a negative coefficient on the explanatory variables indicates decrease in inefficiency hence improvement in efficiency. The opposite is true for a

[28] Table 1, provides summary statistics of the efficiency scores used in this paper as the dependent variable ($\hat{\theta}_i$).

positive coefficient; that is, a worsening of inefficiency. The time subscript t represents specific fishing periods and not continuous time. We specify four models using the above explanatory variables. In model (1), our base model, we include biomass, biomass^2, boat age, boat length, Zone dummy, Management (ITQ) dummy, and Period(2004/05) dummy. We include biomass^2 in order to observe the effect of marginal changes in the stock level. To capture zone specific characteristics we also include zone dummy to estimate the zone fixed effect. In this sense the zone dummies are used as proxies for geographical, environmental, and ecological characteristics considered fixed for each zone. The individual transferable quota system was introduced in the Northern Zone fishery in the 2003/04 fishing period, exactly ten years after its introduction in the Southern Zone. We believe it is important to investigate any possible impact this management policy could have on profit efficiency and so include the management (ITQ) dummy variable to carry out this investigation. For reasons explained in detail later, we also include a dummy for the 2004/05, specifically.

Recall that our dependent variable is from pooled observations. This, however, often has the non-identical distribution problem. This occurs because the underlying population of pooled cross-sectional observations may have different distributions in different time periods (Wooldridge, 2009). The literature indicates that the problem can be solved by allowing the intercept to differ across periods. To do this we introduced period dummies for three of the four periods, omitting one period at a time as the base period. Possible variabilities among firms in the fisheries ideally require that firm specific characteristics (firm fixed effect) are controlled for. However, we are unable to do this for a couple of reasons. It was earlier mentioned that due to confidentiality reasons the observations in our data set do not have unique identifiers, and so was impossible to identify individual firms across different time periods. This limitation of the data made it impossible to include firm fixed effects in our models. A possible way of going around the problem was to try creating cohorts among the observations using some specific, relatively time invariant, variable such as boat length. This also proved difficult to do as boat lengths could not be tracked across different time periods.

As robustness check we specify three other models; that is, models (2), (3), and (4). In model (2) we control for engine age and electrical equipment age. We drop these variables in model (3) and include the Australian/Hong Kong exchange rate variable. We include all ten variables in model (4). As earlier explained the Australian/Hong Kong exchange rate variable was included to capture any allocative inefficiencies arising from possible management challenges caused by the exchange rate changes on the fisheries' export markets.[29] We run all the models using 2000 bootstrap replications, on Stata. This number of replications is enough to provide adequate coverage of the confidence intervals (Simar and Wilson, 2004). In the Section that follows we present results of the models together with their analysis.

5.2 Results and analysis

Table 2 below presents results of the various models estimated. All four models show that increases in current levels of the fish stock, in the fisheries, are desirable. The biomass is significant across all four models at the 10% level and in the anticipated direction; increases in biomass levels significantly increase profit efficiency levels (decreases profit inefficiency) in the fisheries. The biomass^2, on the other hand, shows that marginal increases in the biomass, after a certain point, is counter productive to profit efficiency in the fisheries. This explanatory variable is significant at the 10% level across all four models, except for model (2), though the magnitude of the coefficient are quite close to each other.

The direction of both the biomass and the biomass^2 is consistent with the fisheries literature; monotonic increases in the biomass is desirable only up to a point (Dupont et al., 2005; Grafton et al., 2007; and Kompas et al., 2010), beyond which any incremental changes in the biomass is counter productive. This is supported by our theoretical analysis that the response of profits to an exogenous increase in biomass is

[29] Products from these fisheries are mainly for the export market (EconSearch, 2011).

positive in a given range. Boat age is not significant across all four models, however, the direction and size of the coefficient is worth mentioning. The coefficient suggests that an increase in the age of boats in the fisheries, by one additional year, is likely to reduce profit inefficiency (increase profit efficiency). A possible interpretation of this is that boat age is possibly a proxy for crew experience, which comes with the number of years the crew remains in the fisheries. In other words, if a boat is operated by the same core crew, then it is expected to gain more operational (technical) experience with each additional year, which is beneficial for efficiency. We find evidence in the literature to support this view (see Pascoe and Coglan, 2002).

Table 2: Truncated Bootstrap Regressions

	(1)	(2)	(3)	(4)
	Dependent variable: Nerlovian Efficiency Scores			
Biomass	-7.720*	-7.705*	-7.462*	-7.447*
	(4.554)	*(4.639)*	*(4.494)*	*(4.277)*
Biomass^2	1.069*	1.067	1.082*	1.080*
	(0.645)	*(0.654)*	*(0.658)*	*(0.628)*
Boat Age	-0.240	-0.268	-0.239	-0.267
	(0.217)	*(0.219)*	*(0.216)*	*(0.214)*
Boat Length	2.776*	2.699*	2.708*	2.634
	(1.673)	*(1.592)*	*(1.597)*	*(1.622)*
Zone dummy	-3.791*	-3.777*	-3.154*	-3.139*
	(2.035)	*(2.127)*	*(1.899)*	*(1.799)*
Management (ITQ)	-2.977*	-2.968	-3.261	-3.252*
	(1.781)	*(1.820)*	*(2.060)*	*(1.926)*
Period(2004/05)	3.027**	3.024**	2.700**	2.696***
	(1.174)	*(1.211)*	*(1.098)*	*(1.019)*
Engine Age		0.091		0.092
		(0.270)		*(0.251)*
Electrical Equipt. Age		-0.010		-0.010
		(0.244)		*(0.236)*
AUD/HKD			0.508	0.509
			(0.461)	*(0.441)*
Constant	12.450	12.441	8.909	8.889
	(8.368)	*(8.633)*	*(7.572)*	*(7.459)*
σ	1.036***	1.035***	1.025***	1.024***
	(0.226)	*(0.226)*	*(0.222)*	*(0.214)*
AIC	290.139	293.882	290.314	294.043
BIC	322.492	333.424	326.261	337.179
Log Likelihood	-136.070	-135.941	-135.157	-135.021
Obs.	269	269	269	269

*Note: Bootstrap standard errors in parentheses, *** p<0.01, ** p<0.05, * P<0.10*
AUD/HKD: Australian/Hong Kong dollar exchange rate. Bootstrap replications: 2000
Source: Authors' calculations

Boat length is significant at the 10% level in all but one model, model (4), with the magnitude and direction of the coefficient being similar across all the models. The direction of the coefficient is as expected and consistent with the literature. The coefficient on this variable shows that any additional increase in boat length is not beneficial to the profit efficiency. It was earlier noted that differing vessel sizes may have different impacts for various reasons (see for example, Tingley et al., 2005; Grafton et al., 2006; and Pascoe and Robinson, 2008). Recall from Table 1 that the biomass in the two fisheries declined consistently over the period, with the Northern Zone experiencing sharper declines. The implication is that the average boat length, of boats in the fisheries, was not commensurate with the biomass level and, therefore, impacted profit efficiency negatively.

Results in Table 2 also show that holding all else constant zone characteristics affect profit efficiency positively; that is, zone characteristics increase profit efficiency (decrease inefficiency) significantly, at the 10% level in all four models. Results from models (1) and (4) show that the introduction of the ITQ management system had a positive effect on profit efficiency in the fisheries, and this was significant at the 10% level. Though not statistically significant in the other models, the direction is the same across all models, with relatively small differences in magnitude. This seems to confirm studies in the literature that point to the benefits of the introduction of the ITQ system in fisheries across the globe. Next we analyze the period variable.

The above analysis is supported by our theoretical analysis in Subsection 2.4. The analysis suggests that though the effect of vessel size can be ambiguous, if effort is closer to optimal vessel size profits will rise. However, profits will fall if having a larger vessel exacerbates the sub-optimality of vessel use. The theoretical analysis further shows that as long as the cost associated with sub-optimal use of vessel size remains positive the equilibrium stock level is negatively affected. This is so given that effort is higher in that case. This means vessel size may affect profitability via two channels. The first is the reduction in profit levels in direct relation to vessel size. The second is the reduction in profitability in relation to reduced biomass levels caused indirectly by positive cost associated with sub-optimal use of vessel size.

These offer further explanation to results obtained in our empirical analysis.

To account for possible variations in the distribution of the observations in the underlying population across different time periods we tried to incorporate the four periods into our models, as earlier explained. In all the options investigated, that is including all the periods in various ways as discussed earlier, only the versions with the 2004/05 period showed consistency and with significance at the 5% level.[30] Another reason for keeping the 2004/05 period dummy was the peculiarity of this time period in terms of the efficiency levels and biomass changes observed in this period across the two fisheries.[31] For example, the Southern Zone witnessed its first and sharp fall in biomass levels in the 2004/05 period, after a series of increases in previous periods. For the Northern Zone though decline in the biomass was consistent, the first significant decline was registered in this time period. The efficiency estimates also suggest that the 2004/05 period presented the worst efficiency scores, relative to other periods. These factors meant that the 2004/05 needed a more rigorous investigation. Indeed results from all four models show that, relative to all other periods, the 2004/05 period negatively impacted profit efficiency, and this negative impact was significant at the 5% level. Other non-discretionary variables in the fisheries included in models (2 and 4), such as engine age and electrical equipment age

[30] We also tried to incorporate time trend in the models in order to eliminate any possibility of spurious regression between profit efficiency and some of the explanatory variables such as boat age, engine age, electrical equipment age, etc. Spurious regression refers to a regression that shows significant results due to the presence of unit root in the variables. Allowing for time trend explicitly considers the possibility of changes in profit efficiency (i.e., either increases or decreases) over time for various reasons essentially unrelated to the other variables in the regression analysis (see-Wooldridge, 2009). A possible reason for not picking the time trend effect when we introduce time in the models is that biomass changes may not necessarily correspond with time, and that other factors besides time are more important. In fact, in reality, as far as the fisheries under investigation are concerned, factors such as weather, ocean currents, ecological conditions, and others, may play more important role in biomass changes. Again, in order to verify if the effect of the biomass (our key dependent variable) showed significant changes over specific periods, we tried to incorporate biomass and period interaction terms. Again in all the cases, only the interaction with the 2004/05 period turned out to be significant. Results of the versions described here are not included in Table 2.

[31] Refer to mean efficiency estimates for the two fisheries across all four periods under discussion in Table 1

were, individually and jointly, neither statistically nor economically significant.

As earlier mentioned the variable AUD/HKD was included in the analysis to help capture any other possible causes of allocative inefficiency in the fisheries over the period under investigation. Though this variable turned to be statistically not significant it provides reasonable economic insight. The coefficients of this variable in models (3) and (4) show that unfavourable changes in exchange rate position of the Australian dollar against that of a major trading partner such as Hong Kong does indeed negatively impact profit efficiency. In other words, the unfavourable exchange rate situation increased profit inefficiency in the fisheries. This helps answer some of the allocative (managerial) challenges in the fisheries. This observation is confirmed in EconSearch annual reports. Further to that, we show in our theoretical analysis that instantaneous changes in prices do have instantaneous effect on profits. In other words, instantaneous rise in output price is good for profits, at least in the short-run. The negative price effect observed in our empirical results can be attributed to instantaneous negative effect resulting from unfavourable exchange rate shocks in the periods considered for the study. In model (4) we include all ten variables but our results do not show any significant changes compared to others, with the exception of the 2004/05 dummy variable which becomes statistically stronger at the 1% level. In fact, the AIC measures shows that this model is worst among all four. Further to that our base model, model (1), tends to be robust with the best AIC measure.

6 Conclusion

Profit efficiency is one of the major factors that can help explain firm survival and growth, as well as changes in the industry structure. In fisheries where sustainability is of major interest to policy makers, critical evaluation of factors affecting profit efficiency is of vital importance to sound policy formulation aimed at ensuring industry sustainability across time. The main objectives of this paper were two-fold. The first was to provide a theoretical basis to justify the need to consider the importance of vessel capital when evaluating profit efficiency in fisheries. The second was to empirically identify factors beyond firms control which can significantly affect profit efficiency in fisheries. The empirical analysis was conducted using a truncated regression with bootstrap on profit efficiency measures from the South Australian Rock Lobster Fishery.

This paper used a modified version of the cost structure to theoretically analyse the effect on profits and fish stocks. We did this by introducing a fixed input, as well as a variable input, into a conventional fisheries profit function and carried out the analysis under both the short- and long-run firm decisions. In an industry where fixed costs are considered non-malleable, the examination provides interesting theoretical insights into the significance of such costs in profit analysis in both the short- and long-runs.

Our theoretical analysis suggests that though the effect of vessel size can be ambiguous, if effort is closer to optimal vessel size profits will rise. However, profits will fall if having a larger vessel exacerbates the sub-optimality of effort use. The theoretical analysis further shows that as long as the cost associated with sub-optimal use of vessel size remains positive but less than fixed costs the equilibrium stock level is negatively affected. This is from the higher effort in that case. This means vessel size may affect profitability via two channels. The first is the reduction in profit levels in direct relation to vessel size. The second is the reduction in profitability in relation to reduced biomass levels caused indirectly by positive cost associated with sub-optimal use of vessel size. These offer further explanation to results obtained in our empirical analysis: that for the South Australian Rock Lobster Fishery existing boat lengths are not commensurate with biomass and, therefore, impact profit efficiency negatively.

We also show, theoretically, that increases in prices are good for profits in the short-run, but there is an offsetting indirect, long-run negative effect via biomass. This confirms the negative price effect observed in our empirical results which can be attributed to a short-run negative effect resulting from unfavourable exchange rate shocks in the periods considered for the study. We find evidence to suggest that unfavourable exchange rate position of the rock lobster fishery with its major trading partners may explain some of the allocative (managerial) challenges that negatively impact profit efficiency in the fishery. The theoretical model also allows us to examine the effect of an exogenous increase in biomass. We find, as with the larger fisheries literature, that greater biomass will increase profits. We also find that increasing biomass has a positive effect on profits, but at a decreasing rate. Our empirical results support this theoretical observation. Empirically we also examined the impact of having an ITQ management system and found that it had a positive impact on profit efficiency. The ITQ effect is found to generally agree with existing literature on the benefits of the ITQ introduction in fisheries.

Based on Clark et al. (1979) and other assertions on the importance of vessel size in the literature, we argued that there is an overarching need to clearly separate cost of fishing vessels from other operating costs when analysing profits of fishing firms. We have also argued that this separation enables the effect of such costs on both the biomass and sustainability of the industry to be explicitly assessed. In the past some studies have examined firm profits in both fisheries (Smith, 1969; Anderson, 2000) and residential real estate (Anderson et al., 2000), under different assumptions. However, we are yet to identify studies that analyse the impact of firm profit maximizing behaviour on fish stocks, in both the short and long runs, using a modified version of the fisheries profit function. We consider our attempt in this direction a significant contribution to the literature.

Previous studies demonstrate that the dependency problem associated with computed efficiency scores violates the regression assumptions of independence between the error term and the discretionary variables. It is also established that as a result a number of estimation methods employed in the regression analysis are either invalid or inappropriate (Simar and Wilson, 2007; Barros and Assaf, 2009). Following the recent developments in the literature that address these estimation challenges (see Simar and Wilson, 2011) we have applied the truncated regression method with bootstrap in the investigation of the South Australian Rock Lobster Fishery. The uniqueness of this approach is that the regression equation is determined by the structure from which the DEA efficiency scores are obtained as well as ensuring consistent estimation using the maximum likelihood method. In addition, the bootstrap method is known to provide the only feasible means for inference. Furthermore, this method is relatively new in the fisheries context and, as far as we are aware, this is the first study to apply the method to the South Australian Rock Lobster Fishery.

The methods discussed in this paper have been applied to small sample cross-sectional data. Future work will extend the analysis to a balanced panel data to help elicit possible efficiency changes over time. Finally, using zone (regional) specific environmental characteristics (for example, distance to fishing grounds, crew travel time, tidal strength at different times of the fishing season, seasonal water temperatures) to help capture their significance in profit efficiency of any fisheries, including the South Australian Fishery, will be an interesting extension.

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Appendix

Proof 1
The Long-run decision.
We re-state the Hamiltonian (2) as follows, and consider the necessary, first order, conditions.

$$\mathcal{H} = e^{-\delta t}\left(pqE_{it}B_t - c - \gamma\right)E_{it} + e^{-\delta t}\lambda_t\left[rB_t\left(1 - \frac{B_t}{K}\right) - qE_{it}B_t - (n-1)qE_{jt}B_t\right]$$

The necessary conditions of the Hamiltonian are

$$e^{-\delta t}\left(pqB_t - c - \gamma\right) - e^{-\delta t}\lambda_t qB_t = 0$$

and

$$e^{-\delta t}pqE_{it} + e^{-\delta t}\lambda_t\left[r - \frac{2r}{K}B_t - qE_{it} - (n-1)qE_{jt}\right] = -e^{-\delta t}[\dot{\lambda} - \delta\lambda_t],$$

which reduce to

$$\left(pqB_t - c - \gamma\right) - \lambda_t qB_t = 0 \tag{14}$$

and

$$pqE_{it} + \lambda_t\left[r - \frac{2r}{K}B_t - qE_{it} - (n-1)qE_{jt}\right] = -[\dot{\lambda} - \delta\lambda_t] \tag{15}$$

We consider the symmetric steady-state equilibrium. We thus focus on the steady-state, where $\dot{B}_t = 0 = \dot{\lambda}$. Steady-state variables are marked with tilda. Then $\tilde{B}$ and $\tilde{E}$ satisfy

$$r\left(1 - \frac{\tilde{B}}{K}\right) - nq\tilde{E} = 0$$

implying

$$\tilde{E} = \frac{r}{nq}\left(1 - \frac{\tilde{B}}{K}\right). \tag{16}$$

The steady-state assumption implies

$$\tilde{\lambda} = \frac{pq\tilde{B} - c - \gamma}{q\tilde{B}} \tag{17}$$

By symmetric steady-state it implies

$$\delta = \frac{pq\tilde{E}}{\tilde{\lambda}} + \left[r - \frac{2r}{K}\tilde{B} - nq\tilde{E} \right]$$

Substituting for $\tilde{\lambda}$ from (25) yields

$$\delta = \frac{pq^2\tilde{B}}{pq\tilde{B} - c - \gamma}\tilde{E} + \left[r - \frac{2r}{K}\tilde{B} - nq\tilde{E} \right] \tag{18}$$

Finally we substitute for $\tilde{E}$ in (26) from (24), and make the necessary algebraic re-arrangements to get

$$\delta = \frac{r}{n}\left(1 - \frac{\tilde{B}}{K}\right)\frac{pq\tilde{B}}{pq\tilde{B} - (c+\gamma)} - \frac{r\tilde{B}}{K}.$$

Further re-arrangement of this gives the modified golden rule (MGR) in the form

$$\delta = -\frac{r\tilde{B}}{K} + \frac{r}{n}\left(1 - \frac{\tilde{B}}{K}\right)\frac{pq\tilde{B}}{pq\tilde{B} - (c+\gamma)}$$

which the MGR in Equation (3).
This is the usual MGR except that instead of c, there is $c + \gamma$. □

Proof 2
The short-run decision.
We re-state the Hamiltonian of Equation (4) below and give the necessary conditions

$$\mathcal{H} = e^{-\delta t}\left[pqE_{it}B_t - cE_{it} - \frac{m}{2}(E_{it} - \tilde{V}_i)^2\right] + e^{-\delta t}\lambda_t\left[rB_t\left(1 - \frac{B_t}{K}\right) - qE_{it}B_t - \sum_{j\neq i} qE_{jt}B_t\right]$$

The necessary conditions of this Hamiltonian are

$$pqB_t - c - m\left(E_{it} - \tilde{V}\right) - \lambda_t qB_t = 0 \tag{19}$$

and

$$pqE_{it} + \lambda_t\left[r\left(1 - \frac{2B_t}{K}\right) - qE_{it} - (n-1)qE_{jt}\right] = -[\dot{\lambda} - \delta\lambda_t] \tag{20}$$

As before we consider the symmetric steady-state equilibrium, and focus on the steady-state, where $\dot{B}_t = 0 = \dot{\lambda}$. Steady-state variables are marked with hat. Then $\hat{B}$ and $\hat{E}$ satisfy

$$r\left(1 - \frac{\hat{B}}{K}\right) - nq\hat{E} = 0$$

which implies

$$\hat{E} = \frac{r}{nq}\left(1 - \frac{\hat{B}}{K}\right). \tag{21}$$

From the above the steady-state assumption it implies

$$\hat{\lambda} = \frac{pq\hat{B} - c - m\hat{E} + m\tilde{V}}{q\hat{B}} \tag{22}$$

and

$$\delta = \frac{pq\hat{E}}{\hat{\lambda}} + \left[r - \frac{2r}{K}\hat{B} - nq\hat{E} \right].$$

Substituting for $\hat{\lambda}$ from (30) gives

$$\delta = \frac{pq^2\hat{B}}{pq\hat{B} - c - m\hat{E} + m\tilde{V}}\hat{E} + r\left(1 - \frac{2\hat{B}}{K}\right) - nq\hat{E}. \tag{23}$$

We substitute for $\hat{E}$ in (31) from (29), and make the necessary re-arrangements to get the modified golden rule (MGR) in the form

$$\delta = -\frac{r\hat{B}}{K} + \frac{r}{n}\left(1 - \frac{\hat{B}}{K}\right) \frac{pq\hat{B}}{pq\hat{B} - c + m\tilde{V} - \frac{mr}{nq}\left(1 - \frac{\hat{B}}{K}\right)} \tag{24}$$

which the MGR in Equation (4). $\square$

Proof 3
Total derivative of Equation (3) with respect to $\tilde{B}$ and γ is

$$\begin{aligned} 0 &= \left\{ -\frac{r}{K} - \frac{r}{nK}\frac{pq\tilde{B}}{pq\tilde{B}-(c+\gamma)} + \frac{r}{n}\left(1-\frac{\tilde{B}}{K}\right)\frac{pq\left[pq\tilde{B}-(c+\gamma)\right]-pq\tilde{B}pq}{\left[pq\tilde{B}-(c+\gamma)\right]^2} \right\} d\tilde{B} \\ &+ \left\{ \frac{r}{n}\left(1-\frac{\tilde{B}}{K}\right)\frac{pq\tilde{B}}{\left[pq\tilde{B}-(c+\gamma)\right]^2} \right\} d\gamma, \end{aligned}$$

which implies

$$\frac{d\hat{B}}{d\gamma} = \frac{-\frac{r}{n}\left(1-\frac{\tilde{B}}{K}\right)\frac{pq\tilde{B}}{\left[pq\tilde{B}-(c+\gamma)\right]^2}}{-\frac{r}{K} - \frac{r}{nK}\frac{pq\tilde{B}}{pq\tilde{B}-(c+\gamma)} - \frac{r}{n}\left(1-\frac{\tilde{B}}{K}\right)\frac{pq\tilde{B}(c+\gamma)}{\left[pq\tilde{B}-(c+\gamma)\right]^2}} > 0$$

,

for $\gamma > 0$, $\pi > 0$, and $F(B) > 0$. So for costs lower than γ, if γ falls (to zero even), B goes down (i.e., will be lower than $\tilde{B}$). □

Proof 4

The derivative of Equation (7) with respect to $\hat{B}$ is

$$\frac{d\hat{\pi}}{d\hat{B}} = pq\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right) - (pq\hat{B}-c)\frac{r}{nqK} + m\left(\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right)-\tilde{V}\right)\frac{r}{nqK}$$

which, after rearranging and substituting in $\hat{E} = \frac{r}{nq}(1-\frac{\hat{B}}{K})$ gives Equation (8).
For Equation (8) to be positive we require

$$pqK - c - m(\hat{E}-\tilde{V}) - 2\left[pq\hat{B} - c - m(\hat{E}-\tilde{V})\right] > 0 \tag{25}$$

The lowest steady-state level of profit occurs at the bionomic level of biomass, that is, where $pq\hat{B} - c - m(\hat{E} - \tilde{V}) = 0$. At this biomass, (25) will certainly be true. The highest steady-state level of profit occurs when the discount rate is zero. In this case we can solve the modified golden rule (5) for $\hat{B}$ explicitly and subsequently $\hat{E}$

$$\begin{aligned}\hat{B} &= \frac{pq^2K + ncq - nmq\tilde{V} + mr}{(n+1)pq^2 + \frac{mr}{K}} \\ \hat{E} &= \frac{r}{nqK}\frac{npq^2K - ncq + nmq\tilde{V}}{(n+1)pq^2 + \frac{mr}{K}}\end{aligned}$$

Substituting these into (25) and rearranging we get

$$\frac{(n-1)pq^2}{(n+1)pq^2 + \frac{mr}{K}}\left(pqK - c + m\tilde{V}\right) > 0$$

As (25) is true for both highest and lowest steady-state profits, it must be true for other levels of profit. □

Proof 5
The total derivative of Equation (5) with respect to $\hat{B}$, p and $\tilde{V}$ is

$$
\begin{aligned}
0 \quad = \quad & -\left\{\frac{r}{K} + \frac{r}{nK}\frac{pq\hat{B}}{pq\hat{B} - c + m\tilde{V} - m\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right)} + \frac{r}{n}\left(1-\frac{\hat{B}}{K}\right)\frac{pq\left(c - m\tilde{V} + m\frac{r}{nq}\right)}{\left[pq\hat{B} - c + m\tilde{V} - m\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right)\right]^2}\right\} d\hat{B} \\
& -\left\{\frac{r}{n}\left(1-\frac{\hat{B}}{K}\right)\frac{q\hat{B}\left(c - m\tilde{V} + m\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right)\right)}{\left[pq\hat{B} - c + m\tilde{V} - m\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right)\right]^2}\right\} dp \\
& -\left\{\frac{r}{n}\left(1-\frac{\hat{B}}{K}\right)\frac{pq\hat{B}m}{\left[pq\hat{B} - c + m\tilde{V} - m\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right)\right]^2}\right\} d\tilde{V}
\end{aligned}
$$

Under the assumption that it is costly to put forth effort for whatever size vessel, then

$$
\begin{aligned}
c - m\tilde{V} + m\frac{r}{nq} &> 0 \\
c - m\tilde{V} + m\frac{r}{nq}\left(1-\frac{\hat{B}}{K}\right) &> 0
\end{aligned}
$$

With the assumption of non-negative profits this means all terms in parentheses will be positive and hence

$$\frac{d\hat{B}}{dp} < 0 \quad and \quad \frac{d\hat{B}}{d\tilde{V}} < 0. \qquad \square$$