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Journal of Environmental Economics and Management 46 (2003) 156–177

JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT

http://www.elsevier.com/locate/jeem

Property rights in a fishery: regulatory change and firm performance

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Received 19 March 2001; revised 4 March 2002

Abstract

A new method is introduced and applied to the British Columbia halibut fishery to analyze changes in productivity of firms harvesting a natural capital stock. The index-number technique decomposes the contributions of output prices, variable input prices, fixed inputs and productivity to firm profits, adjusted for changes in the natural capital stock. An application of the method is given using micro-level data from a common-pool resource. The indexes provide a ready-made comparison of all firms to the most profitable firm per unit of resource stock. Benchmarking with the decompositions also allows firms and regulators to improve overall industry performance by allowing them to analyze what components are contributing most to (relative) economic profits.

JEL classification: C43; D23; Q22

Keywords: Productivity; Profits; Index numbers; Regulations

1. Introduction

The welfare of firms in resource-based industries is dependent upon their profits that, in turn, depend on their productivity and the level of the natural capital stock. To help understand firm and industry behavior over time requires a decomposition into the effects of prices, firm capital

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0095-0696/03/$ - see front matter
doi:10.1016/S0095-0696(02)00027-X

stock, and productivity on profits, adjusted for changes in the natural capital stock. To assist in such analysis, the paper applies a new methodology to derive profit and productivity decomposition measures. The approach provides a useful method for assessing the effects of shifts in regulation, level shocks to the natural capital, price fluctuations and other factors on firm and industry performance.

The proposed productivity and profit decomposition uses only observed data (rather than estimated "benchmark frontiers") and is derived from theoretical results based on the relationship between the Törnqvist index and the translog profit function [15,20,41,42]. The method allows for intra-firm comparisons, but can be applied at the industry, regional or national level, and provides insights about firm performance and behavior that are unavailable from traditional productivity and efficiency measures based on frontier estimation [1,9,12,21,24,34,43].

The profit decompositions have a range of potential uses in natural resource and environmental management. For example, by decomposing profits or productivity into its contributing components the industry and regulators can identify the most important factors constraining economic performance. Further, benchmarking to the most profitable firm per resource stock allows individual firms to assess the factors preventing increased profits or productivity. Decompositions also permit a detailed analysis of whether regulatory change achieves the desired goals, such as increased productivity, by examining the existence of confounding effects, such as increases in input prices. Thus the method is a useful tool for identifying factors that limit profitability and productivity and for assessing the impact of regulatory changes in natural resource industries.

Section 2 presents the fundamentals of the method for decomposing profit ratios, and gives a justification to the proposed technique which is based on the economic approach to index numbers by exploiting exactness results between the Törnqvist index and the translog functional form. Comparisons are made with alternative decomposition techniques in Section 3. Section 4 describes the data used in the application and illustrates how to use profit decompositions to assess the effects of changes in regulations on firm performance. The results of the application of the index-number profit decomposition (INPD) are presented in Section 5. Interpretations of the profit decompositions are provided in Section 6 with an assessment of the effects of changes in regulations on the industry. The paper concludes with a review of the method, the results and its applicability to the study of economic performance.

2. Index-number profit decompositions

To derive the INPD, we first define the variable (or "restricted") non-zero profits of an arbitrary firm b, π^b, relative to the profits of another firm a, π^a:

$$\Gamma^{a,b} \equiv \pi^b/\pi^a. \tag{1}$$

If firm a has the highest profits in the sample of firms being examined, then its profits provide a natural denominator for comparisons. Such a comparison is particularly useful in natural resource industries, such as fisheries, where there may exist "highliners" who consistently earn profits far in excess of their fellow resource users.

An important question is why profits may be different for the firms. Let $P^{a,b}$ be a price index for the "netputs" (i.e., a price index for the outputs and variable inputs, where inputs are treated as negative outputs in order to simplify notation), and $Q^{a,b}$ is the corresponding quantity index. From the "weak factor reversal test" of Fisher [26], an important requirement for these indexes is the following:

$$\Gamma^{a,b} = P^{a,b} \cdot Q^{a,b}. \tag{2}$$

That is, a price index times the corresponding quantity index should equal the values index, i.e., the ratio of values. Because of our definition of the indexes in terms of "netputs" the value index here is a ratio of profits. Eq. (2) can be thought of as a "preservation of value" property—price times quantity should equal value in levels, and this should also be true in terms of price changes times quantity changes equaling value changes. If this condition is not satisfied by a particular choice of index number for $P^{a,b}$ and $Q^{a,b}$, then we can define either $P^{a,b}$ or $Q^{a,b}$ directly, and the other index is defined indirectly.[1] Consider the case where we define $P^{a,b}$ directly. Then we define $Q^{a,b}$ as follows, to ensure that (2) is satisfied:

$$Q^{a,b} = \Gamma^{a,b} / P^{a,b} \tag{3}$$

Hence, $Q^{a,b}$ is termed an "implicit" index, as it is implicitly defined once the "direct" index $P^{a,b}$ has been defined [2].

A productivity index between firms b and a can be defined as an output index divided by an input index, consistent with the usual calculation of total-factor productivity growth (i.e., output growth divided by input growth), as follows:

$$R^{a,b} \equiv Q^{a,b} / K^{a,b} = (\Gamma^{a,b} / P^{a,b}) / K^{a,b}, \tag{4}$$

where $K^{a,b}$ is a (quasi-) fixed input quantity index. Productivity in (4) is the difference in the implicit netput quantity index, $Q^{a,b}$, that cannot be explained by differences in fixed-input utilization, $K^{a,b}$. By rearranging Eq. (4), we obtain:

$$\Gamma^{a,b} = R^{a,b} \cdot P^{a,b} \cdot K^{a,b} \tag{5}$$

where the ratio of firms' profits can be decomposed into contributions from productivity ($R^{a,b}$), price ($P^{a,b}$) and fixed input ($K^{a,b}$) differences between the firms.

Any index number can be used for constructing the price and fixed-input indexes for use in (5). However, of all possible indexes, the Törnqvist [50] index has several advantages that recommend its use. Let $p^a \geqslant 0$ denote a price vector for firm a netput prices, so that $p^a = (p_1^a, \dots, p_N^a)$, where there are N variable netputs, denoted by $y^a = (y_1^a, \dots, y_N^a)$, and where $y_n^a > 0$ implies that the nth good is an output, while $y_n^a < 0$ implies that the nth good is a variable input. Similarly, let $r^a \geqslant 0$ be the price vector for firm a fixed-input prices, so that $r^a = (r_1^a, \dots, r_M^a)$, where there are M fixed inputs, denoted by $k^a = (k_1^a, \dots, k_M^a)$.

[1] Many commonly used indexes do not satisfy this weak factor reversal test. For example, the Laspeyres, Paasche and Törnqvist indexes do not satisfy this test, while Fisher's Ideal index does satisfy the test. See [2,17].

Using theses definitions, we can provide a general representation of a restricted profit function for a firm, π, as follows:

$$\pi(p,k) = \max_{y} \ \{p \cdot y\colon \ (y,k) \in T\}, \tag{6}$$

where T is the production possibility set for the firm. Hence, profit is maximized by the choice of y, subject to the constraint that k is exogenously given in each period. The conditions which define a restricted profit function with constant returns to scale are that it is (i) a non-negative function, (ii) positive homogeneous of degree one in p, (iii) convex and continuous in p for every fixed k, (iv) positive homogeneous of degree one in k, (v) non-decreasing in k for every fixed p, and (vi) concave and continuous in k for every fixed p.[2]

We consider the case where the log of π in (6) has the translog form [11,14,46], such that for firm $\imath = a, b$

$$\begin{aligned} \ln \pi^{\imath}(p,k) \ \equiv\ & \alpha_0^{\imath} + \sum_{i=1}^{N} \alpha_i^{\imath} \ln p_i + \sum_{l=1}^{M} \beta_l^{\imath} \ln k + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \alpha_{ij} \ln p_i \ln p_j \\ & + \frac{1}{2} \sum_{l=1}^{M} \sum_{m=1}^{M} \beta_{lm} \ln k_l \ln k_m + \sum_{i=1}^{N} \sum_{l=1}^{M} \delta_{il} \ln p_i \ln k_l, \end{aligned} \tag{7}$$

where $\alpha_{ij} = \alpha_{ji}$, for $i,j = 1, \dots, N,$, $\beta_{lm} = \beta_{ml}$, for $l, m = 1, \dots, M$ and the following restrictions hold so that the functional form in (7) exhibits constant returns to scale: $\sum \alpha_i^{\imath} = 1$, $\sum \beta_i^{\imath} = 1$, $\sum \alpha_{ij} = 0$, $\sum \beta_{lm} = 0$ and $\sum \delta_{il} = 0$. Note that only the second-order terms in (7) are restricted to be constant across firms.[3]

We define the following theoretical productivity index to capture the difference between firms a and b in terms of productivity:

$$R^{a,b} \equiv \left[\frac{\pi^b(p^a,k^a)}{\pi^a(p^a,k^a)} \frac{\pi^b(p^b,k^b)}{\pi^a(p^b,k^b)} \right]^{1/2}, \tag{8}$$

where the first ratio in the brackets is an index of productivity difference using firm a reference netput prices and capital (exogenous) quantities, and the second ratio is a competing index of productivity change which uses firm b reference netput prices and input quantities. Because it is unclear which of these two possible theoretical indexes is preferred, a geometric mean of the two is used in (8). The choice of the geometric mean also facilitates a useful theoretical result from index number theory.

Diewert and Morrison [20] exploited the translog identity of Caves et al. [7] to prove a relationship between the translog functional form and the Törnqvist [50] index formula and which they use for decomposing the growth in domestic product for a trading economy.[4] In the current context, we apply Theorem 1.

[2] See [13] for proofs.

[3] This translog profit function is "flexible" in the sense that is can approximate an arbitrary, twice continuously differentiable function to the second order [14, p. 113]. Hence, even if the actual profit function is not of the translog form, it is flexible enough to approximate it to a high order of approximation at one point at least. Many functional forms, such as the commonly-used Cobb–Douglas form, do not have even this rather minimal approximation property.

[4] For other applications and further details of the GDP approach, see [41,42].

Theorem 1. *If the functional form for a profit function*, π^ι, *is translog as defined by* (7) *for firms* $\iota = a, b$ *and there is competitive profit maximizing behavior by both firms, then the productivity index in* (8) *is exactly equal to a Törnqvist implicit netput quantity index*, $Q^{a,b} = \Gamma^{a,b}/P^{a,b}$, *divided by a Törnqvist direct input index*, $K^{a,b}$, *where* $\Gamma^{a,b} = \pi^b/\pi^a$ *and*

$$P^{a,b} \equiv \exp\left[\sum_{n=1}^{N} \frac{1}{2}(s_n^b + s_n^a)\ln(p_n^b/p_n^a)\right], \tag{9}$$

where $s_n = (p_n y_n)/(p \cdot y)$ *is the profit share of netput* n, *using the notation* $p \cdot y = \sum p_n y_n$, *and*

$$K^{a,b} \equiv \exp\left[\sum_{m=1}^{M} \frac{1}{2}(s_m^b + s_m^a)\ln(k_m^b/k_m^a)\right], \tag{10}$$

which is a Törnqvist quantity index, where $s_m = (r_m k_m)/(p \cdot y)$ *is the profit share of fixed input* m.

Proof. Consider a profit function $\pi^\iota(p^\iota, k^\iota)$, for any firm ι. If producers are competitively profit maximizing, then from Hotelling's Lemma,

$$y^\iota = \nabla_p \pi^\iota(p^\iota, k^\iota) \tag{11}$$

using vector notation, where ∇_p denotes the vector of first order derivatives with respect to each element of the price vector p. Following Diewert [14, p. 140], we have the following shadow pricing result, where the theoretical capital input price vector for firm ι, r^ι is now defined as a vector of ex post user costs of capital [20, p. 662]:

$$r^\iota = \nabla_k \pi^\iota(p^\iota, k^\iota). \tag{12}$$

Assuming constant returns to scale,

$$\pi^\iota(p, k) = p^\iota \cdot y^\iota = r^\iota \cdot k^\iota, \tag{13}$$

using the notation $p^\iota \cdot y^\iota = \sum p_n^\iota y_n^\iota$ and $r^\iota \cdot k^\iota = \sum r_m^\iota k_m^\iota$. For profit functions that are of the translog form, as in (7), the theoretical productivity index (8) can be re-expressed as follows, for $\iota = a, b$:

$$\begin{aligned}
R^{a,b} &= \left[\frac{\pi^b(p^a,k^a)}{\pi^a(p^a,k^a)}\frac{\pi^b(p^b,k^b)}{\pi^a(p^b,k^b)}\right]^{1/2} \\
&= \frac{\pi^b(p^b,k^b)}{\pi^a(p^a,k^a)}\left[\frac{\pi^b(p^a,k^a)}{\pi^b(p^b,k^b)}\frac{\pi^a(p^a,k^a)}{\pi^a(p^b,k^b)}\right]^{1/2} \\
&= \frac{p^b \cdot y^b}{p^a \cdot y^a}\exp\left\{\frac{1}{2}(\ln \pi^b(p^a,k^a) - \ln \pi^b(p^b,k^b)) + \frac{1}{2}(\ln \pi^a(p^a,k^a) - \ln \pi^a(p^b,k^b))\right\} \\
&= \frac{p^b \cdot y^b}{p^a \cdot y^a}\exp\left\{\frac{1}{2}[\nabla_{\ln p} \ln \pi^b(p^b,k^b) + \nabla_{\ln p} \ln \pi^a(p^a,k^a)] \cdot \ln\left(\frac{p^a}{p^b}\right)\right. \\
&\quad \left. + \frac{1}{2}[\nabla_{\ln k} \ln \pi^b(p^b,k^b) + \nabla_{\ln k} \ln \pi^a(p^a,k^a)] \cdot \ln\left(\frac{k^a}{k^b}\right)\right\}
\end{aligned} \tag{14}$$

$$
\begin{aligned}
&= \frac{p^b \cdot y^b}{p^a \cdot y^a} \exp\left\{ \frac{1}{2} \sum_{n=1}^{N} \left[\frac{p_n^b y_n^b}{p^b \cdot y^b} + \frac{p_n^a y_n^a}{p^a \cdot y^a} \right] \ln\left(\frac{p^a}{p^b}\right) \right. \\
&\quad \left. + \frac{1}{2} \sum_{m=1}^{M} \left[\frac{r_m^b k_m^b}{p^b \cdot y^b} + \frac{r_m^a k_m^a}{p^a \cdot y^a} \right] \cdot \ln\left(\frac{k^a}{k^b}\right) \right\} \qquad (15) \\
&= \Gamma^{a,b} \exp\left\{ \sum_{n=1}^{N} \frac{1}{2} (s_n^b + s_n^a) \ln(p_n^a/p_n^b) + \sum_{m=1}^{M} \frac{1}{2} (s_m^b + s_m^a) \ln(k_m^a/k_m^b) \right\} \\
&= \Gamma^{a,b} \exp\left\{ -\sum_{n=1}^{N} \frac{1}{2} (s_n^b + s_n^a) \ln(p_n^b/p_n^a) - \sum_{m=1}^{M} \frac{1}{2} (s_m^b + s_m^a) \ln(k_m^b/k_m^a) \right\} \\
&= (\Gamma^{a,b}/P^{a,b})/K^{a,b}, \qquad (16)
\end{aligned}
$$

which is the productivity index (5), with $P^{a,b}$ as defined in (9) and $K^{a,b}$ as defined in (10), where Eq. (14) uses (13) and the "translog identity" of Caves et al. [7, p. 1412], that in turn uses the "quadratic identity" of Diewert [15, p. 118], and Eq. (15) uses (11)–(13). □

The total-factor productivity index, $R^{a,b}$ incorporates scale effects [7,25,47].[5] As is discussed in Section 5, $R^{a,b}$ can be thought of as an efficiency index for firm b compared with firm a. That is, if firm a is a firm of interest for firm b, then firm b is interested in determining the differences in profits between the firms that cannot be explained by prices faced and input quantities used.

In a similar fashion to the productivity index in (8), we can relate the Törnqvist indexes in (9) and (10) to the translog profit function defined in (7). Consider the following theoretical netput price index:

$$
P^{a,b} \equiv \left[\frac{\pi^a(p^b, k^a)}{\pi^a(p^a, k^a)} \frac{\pi^b(p^b, k^b)}{\pi^b(p^a, k^b)} \right]^{1/2}. \qquad (17)
$$

It can be shown that if π has the translog form in (7) for both firms, then the index in (17) is exactly equal to the Törnqvist price index in (9). It is also possible to consider the effect on profits of individual price differences, i.e., for good n, we consider the change in the price of good n while holding everything else constant:

$$
P_n^{a,b} \equiv \left[\frac{\pi^a(p_1^a, \ldots, p_n^b, \ldots, p_N^a, k^a)}{\pi^a(p^a, k^a)} \frac{\pi^b(p^b, k^b)}{\pi^b(p_1^b, \ldots, p_n^a, \ldots, p_N^b, k^b)} \right]^{1/2}. \qquad (18)
$$

Exploiting the same relationship with the translog functional form in (7), we can also obtain the following Törnqvist price change index for good n going from firm a to firm b prices, where s_n^a and s_n^b are negative if the good is a variable input:

$$
P_n^{a,b} \equiv \exp[\tfrac{1}{2}(s_n^b + s_n^a) \ln(p_n^b/p_n^a)]. \qquad (19)
$$

[5] It is not possible to separate out these effects unless further assumptions are made. We leave this for future research.

Using (19), we can derive the aggregate price index:

$$\prod_{n=1}^{N} P_n^{a,b} = P^{a,b}, \tag{20}$$

where $P^{a,b}$ is the aggregate Törnqvist price index in (9). Thus, it is possible to decompose the aggregate price index, $P^{a,b}$, into individual price indexes and also decompose $P^{a,b}$ to obtain price indexes for groups of goods and, thus, separate the effects of input and output price changes.

Further, consider the following theoretical input (capital) quantity index:

$$K^{a,b} \equiv \left[\frac{\pi^a(p^a, k^b)}{\pi^a(p^a, k^a)} \frac{\pi^b(p^b, k^b)}{\pi^b(p^b, k^a)}\right]^{1/2}. \tag{21}$$

If π has the translog form in (7) in each period, then the index in (21) is exactly equal to the capital quantity index in (10). In other words, we can analyze the effect on profits of differences in individual capital components, i.e., for good m, we consider the change in the quantity of good m while holding everything else constant:

$$K_m^{a,b} \equiv \left[\frac{\pi^a(p^a, k_1^a, \ldots, k_m^b, \ldots, k_M^a)}{\pi^a(p^a, k^a)} \frac{\pi^b(p^b, k^b)}{\pi^b(p^b, k_1^b, \ldots, k_m^a, \ldots, k_M^b)}\right]^{1/2}. \tag{22}$$

Exploiting the same relationship with the translog functional form in (7), as above, we can then derive the following Törnqvist capital change index for good m:

$$K_m^{a,b} \equiv \exp[\tfrac{1}{2}(s_m^b + s_m^a)\ln(k_m^b/k_m^a)]. \tag{23}$$

Using (23), we can derive the aggregate capital index:

$$\prod_{m=1}^{M} K_m^{a,b} = K^{a,b}, \tag{24}$$

where $K^{a,b}$ is the aggregate Törnqvist quantity index in (10). Hence, it is possible to decompose the aggregate capital index, $K^{a,b}$, into indexes for individual capital components as well as individual price effects.

Eqs. (5), (20) and (24) collectively represent a detailed decomposition of profits between firms a and b that can be applied in a wide range of applications. These equations may be referred to as index-number profit decompositions (INPDs).[6] From above, we see that the INPD can be derived from the "economic approach" to index numbers. That is, under certain assumptions, the indexes in the INPD can be derived from theoretical indexes which are well-founded in microeconomic theory.

It should be emphasized that the INPD represented by Eqs. (5), (20) and (24) can be motivated *without* making any behavioral assumptions or assumptions on the specific form of the technology. The use of the Törnqvist index in (5) can be justified by the axiomatic (or "test") approach to index numbers, as this index satisfies more reasonable axioms than most commonly used index numbers, such as the Laspeyres and Paasche indexes [18]. In addition, it can be shown

[6] Similar decompositions have been employed in different contexts. Fox, Kohli and Warren (2002) [30] use a similar technique to decompose estimates of the output gap while Lawrence et al. [44] decompose a single firm's profit growth.

that the Törnqvist index closely approximates the Fisher Ideal index, which satisfies even more axioms. This is a result in numerical analysis and does not depend on assumptions of optimizing behavior [16]. Thus strong reasons exist for the choice of the Törnqvist index over many other index-number formulae and, moreover, a justification exists from the axiomatic approach to index numbers for the INPD represented by Eqs. (5), (20) and (24).

3. Alternative decompositions

Some alternative decompositions for profit comparisons have been suggested by other authors. We describe some of the methods most closely related to our approach and note the relative advantages of our method.

The approach most closely related to ours is that of Humphrey and Pully [39]. Examining the impact of regulatory reform of the US banking industry in the 1980s, they propose a decomposition of profit growth for a bank into technology and "business environment" components. They estimate a profit function and use the estimated parameters of this profit function to calculate the separate profit components and present average results for small and large banks. In their approach, they do not solve the problem of the choice of weights in their indexes for technology and the business environment, and so present two versions of each with equally justifiable, but competing, results. Also, their method is not applied in a cross-sectional context and does not permit a detailed decomposition of a profit ratio like the INPD.

Kohli [41] has shown that a translog gross domestic product (GDP) function could be estimated, and the parameters could be used in a decomposition of the growth in GDP using the results of Diewert and Morrison [20]. Fox and Kohli [29] compared the index number approach and the theoretically equivalent (from the "economic approach" to index numbers) GDP growth decomposition approach and found that the results were similar to a high order of approximation.

Karagiannis and Mergos [40] use a profit-function framework to decompose total-factor productivity growth (TFP) into technical-change and returns-to-scale contributions. Unfortunately, as with the method of Humphrey and Pully [39], their decomposition is not unique, as they propose both input- and output-oriented decompositions. The orientation needs to be determined in order to separate out the contributing components of a constant returns to scale measure of TFP, and this choice is essentially arbitrary. Further, they do not derive a detailed decomposition of a profit ratio into components of interest, such as our method yields.[7]

Diewert [19] has also proposed a method for decomposing profit differences, rather than ratios, into contributing components. This approach draws on the old literature on index numbers in differences, and the Bennet [5] index (or "indicator") is found to have some nice properties (Diewert, 1998).[8] An adaptation of the approach to our context has some potential advantages over our method. In particular, its additive nature is very useful in many contexts. The Diewert

[7] The authors also claim that the rate of profit augmentation is a biased and incorrect measure of the TFP growth, but this is would require them to know the true TFP growth. They arbitrarily define the true TFP growth measure as the conventional Divisia index of TFP changes, which is clearly not the same as TFP estimates that are obtained from the profit augmentation approach (see, e.g., [22,27]).

[8] Following Diewert (1998) [51] index numbers in differences are termed "indicators" in order to distinguish them from standard index numbers that use ratios.

decomposition of a profit difference into price and quantity components (where the quantity component is set up to give ''an additive measure of overall efficiency change''), is interesting, but the individual components are difficult to interpret. For example, a price contribution to profits in dollars does not convey the relative importance of that price to relative profits. If we divide the price contribution by profits we can transform the contributions into percentage terms, but on the right-hand side of the decomposition we obtain a profit ratio (-1). Thus a problem with this Bennet indicator decomposition of a profit ratio is that it mixes multiplication and addition. Although it is the subject of ongoing research (e.g. [3,4]; Fox and Grifell-Tatjé, 2002 [28]), it seems that, at least for current purposes, the Bennet indicator approach does not work out as neatly as the Törnqvist index approach.

Grifell-Tatjé and Lovell [36] have also proposed a method for decomposing cost differences using the Bennet indicator and estimated frontiers. Their approach can be used in the profit decomposition case, in place of the less-attractive Laspeyres-type indicator used by Grifell-Tatjé and Lovell [35]. Balk [3], in a comment on their approach, proposes a decomposition which he describes as ''more meaningful'' [3, p. 6]. Regardless of how these decompositions are performed, they require the calculation of frontiers, which is not needed with the INPD.

Finally, we note some advantages of our method over approaches which require the estimation of benchmark frontiers. While frontier analysis is based on the observed data, benchmarking can involve comparing firms to parts of the estimated frontier between observations. This means that the shape of the constructed frontier is key for the analysis. In addition, it means that there can be serious ''dimensionality'' problems—with a small number of observations relative to the number of variables, it is possible for every firm to be on some part of the frontier. In our method, this dimensionality problem is avoided. The presentation of our method in this paper implies that price data are needed, and prices are not necessary for basic frontier analysis. However, in the absence of price data, weights can be chosen in their place and the same index numbers calculated, although with a different interpretation. It can be noted that some methods for modifying basic frontier analysis techniques, in order to overcome some of its limitations, also require the specification of weights (e.g., [10,23,31,49]).

4. Application of the INPD

The INPD is applied to the British Columbia (BC) halibut fishery to assess the effects on profits, efficiency and productivity of regulatory changes across firms and over time. The method is used to examine the effects of the introduction of individual harvesting rights into the fishery in 1991 by comparing firm-level differences in the periods 1988, 1991 and 1994.[9] Unlike other approaches, the INPD can decompose relative profits in terms of output and variable input prices, productivity and utilization of the fixed-input quantity.

Details of the industry are provided in [32]. In their study, they compared changes in efficiency between the periods 1988, 1991 and 1994 by estimating a stochastic frontier and deriving firm-level measures of economic, allocative and technical efficiency. They found that some measures of efficiency initially fell from 1988 to 1991, but increased from 1991 to 1994. They attribute the

[9] For a review of individual transferable quotas in fisheries see [33].

initial decline to deficiencies in the initial characteristics of the individual harvesting rights introduced in 1991, and temporary adjustments by fishers in the first year of the program.

The stochastic frontier approach cannot easily and neatly decompose profit changes into its component parts; productivity changes, input and output price changes and changes in reproducible capital. By contrast, the INPD allows for a comparison of the relative magnitude of the affect of each component on changes in profits. In other words, a profit decomposition identifies which components of profits, such as output prices, changed in response to regulations. For example, a shift to individual harvesting rights in 1991 made previous input restrictions on season length redundant and led to a 30-fold increase in the fishing season [32, p. 685]. The much longer fishing season, in turn, increased the landings of fresh fish, reduced spoilage and damage and contributed to higher output prices for fishers [6].

The data for the INPD were supplied by the Fisheries and Oceans Canada cost and earnings surveys from an independent random sample of 97, 163 and 54 halibut fishers in 1988, 1991, and 1994. The halibut fleet is defined as all longline vessels having a plurality of revenue from halibut, and the general fleet includes all licensed longline vessels that caught halibut.[10] A selection of 105 observations (43 observations for both 1988 and 1991, and 19 observations for 1994) was made from the data using the criteria that all vessels used bottom longline harvesting gear, caught halibut, and their reported revenues matched (within 10 percent) the independently obtained value of halibut landings recorded for each license holder. Summary statistics of the data are provided in Table 1.[11]

Input prices include home-port fuel prices and were obtained from Chevron Canada and Imperial Oil Canada. The price of labor is an opportunity cost and is derived from the expected weekly earnings in manufacturing that varies by region where the home ports of vessels are located. The measure of firm capital is vessel length and, along with the quantity and value of halibut caught by each fisher, was obtained from Fisheries and Oceans Canada. The output price faced by fishers is derived from the quantity and value data and varies by vessel based on the time of landings, where the fish were landed, and the size and quality of the fish harvested. A measure of the natural capital stock comes from the Pacific Halibut Commission given in [48]. The exploitable biomass is calculated from a separable catch-age model (CAGEAN) and is the biomass vulnerable to fishing. All prices are defined in Canadian dollars for 1994, and are calculated by inflating 1991 and 1988 values by the GDP implicit price index.

5. Firm-level profit decompositions

The INPD is applied by using firm-level data on halibut prices, fuel prices, price for labor and a firm-level capital measure represented by vessel length. Assuming competitive and profit

[10] A longline vessel is equipped with a length of line often several kilometers in length that includes short lengths of line to which baited hooks are attached. The fish are attracted to the hooks by bait and the line (with the fish) are hauled on board after a suitable period of time. Most longliners have automated systems for line hauling, hook cleaning and baiting.

[11] Further details about the data are provided in [32]. The sample used here differs slightly in that two further observations were excluded because of data inconsistencies. The sub-sample used to generate the INPD for the fleet included 13, 15 and 7 percent of all active vessels for the periods 1988, 1991 and 1994.

Table 1
Summary statistics: data on the British Columbia Halibut longline fishery

	Mean	Standard deviation	Minimum	Maximum
All years				
Revenue	88,727	69,983	12,474	346,900
Landings	34,108	29,036	5180	162,100
Price	2.79	0.73	1.75	4.51
Crew	3.74	1.47	2	9
Crew-weeks	3.27	1.63	1	10
Labor price	560	34.02	508	620
Fuel quantity	7043	9585	381	72,845
Fuel price	0.34	0.06	0.23	0.43
Vessel length	1367	339	904	2479
1988				
Revenue	109,548	73,595	12,474	346,900
Landings	52,856	33,598	6725	162,100
Price	2.02	0.15	1.75	2.33
Crew	4.51	1.56	2	9
Crew-weeks	3.14	1.15	1	7
Labor price	522	10.62	508	549
Fuel quantity	8441	13,325	1056	72,845
Fuel price	0.40	0.02	0.38	0.43
Vessel length	1447	359	904	2479
1991				
Revenue	48,673	29,507	14,855	150,880
Landings	15,591	9046	5180	46,389
Price	3.08	0.21	2.65	3.48
Crew	2.95	1.00	2	7
Crew-weeks	2.91	1.81	1	10
Labor price	582	11.32	555	596
Fuel quantity	4097	2275	381	13,158
Fuel price	0.27	0.02	0.23	0.29
Vessel length	1241	257	913	2018
1994				
Revenue	132,257	82,213	18,662	309,520
Landings	33,583	19,682	5253	68,566
Price	3.85	0.30	3.41	4.51
Crew	3.79	1.27	2	6
Crew-weeks	4.37	1.74	2	10
Labor price	597	12.45	582	620
Fuel quantity	10,546	7759	1791	30,703
Fuel price	0.33	0.00	0.33	0.34
Vessel length	1473	378	1014	2269

Note: Values are in $1994 Canadian dollars and are per vessel. Crew size includes the captain. Weeks fished pertain to weeks actively fishing halibut. Halibut landings are in pounds and the price is per pound. Fuel quantity is in liters and vessel length is in centimeters. The price of labor is the opportunity cost of labor per person per week. There are 43 observations for 1988 and 1991, and 19 observations for 1994.

maximizing behavior and constant returns to scale, then for each firm $p \cdot y - rk = 0$, or $p \cdot y = rk = \pi$, where p is output price, y is output, k is capital, r is the rate of return on reproducible capital and π is firm profit. Under these assumptions, the share of capital in profit is equal to one and the capital quantity index in (10) simplifies to

$$K^{a,b} = k^b/k^a. \tag{25}$$

In the BC halibut fishery, the variable inputs are fuel (F) and labor (L) and from equations (5), (20) and (24), our decomposition of the profit ratio between firm a and firm b ($b = 1, \ldots, 105$), $\Gamma^{a,b}$ is

$$\Gamma^{a,b} = R^{a,b} \cdot PH^{a,b} \cdot PL^{a,b} \cdot PF^{a,b} \cdot K^{a,b}. \tag{26}$$

Hence, the profit of firm b relative to firm a can be decomposed to identify the sources of the difference between the firms' profits. In this decomposition, given in Eq. (26), differences in profit can be explained by differences in productivity, $R^{a,b}$, the price of halibut faced by the firms, $PH^{a,b}$, the price of labor, $PL^{a,b}$, the price of fuel faced by the firms, $PF^{a,b}$, and the vessel length, $K^{a,b}$. The decompositions are, in general, not pure difference indexes, but represent contributions of the components to the profit ratio.

For common-pool resources, an important issue to consider is the affect of the natural capital stock on profits and productivity. To account for changes due to the stock over the three sample periods, a harvest-adjusted natural capital stock index equal to the ratio of the natural capital stock (measured in metric tons) to the total allowable harvest for the fleet (TAC) (also measured in metric tons), is defined by (27).

$$stock^t \equiv biomass^t/TAC^t, \tag{27}$$

for $t = 1988, 1991, 1994$.

The natural capital stock index represents the available biomass per unit of the allowable harvest (total allowable catch). Thus, for a stock-flow production technology, an increase (decrease) in the biomass, holding the TAC fixed and all other factors constant, should make it easier (harder) for fishers to catch the allowable harvest and tend to increase (decrease) profits. Using the stock index, a resource adjusted measure of efficiency between firms a and b can be defined as

$$\begin{aligned}\Gamma_s^{a,b} &\equiv (\pi^b/stock^b)/(\pi^a/stock^a) \\ &= (\pi^a/\pi^b) \cdot (stock^a/stock^b) = \Gamma^{a,b} \cdot (stock^a/stock^b) \qquad (28) \\ &= R^{a,b} \cdot PH^{a,b} \cdot PL^{a,b} \cdot PF^{a,b} \cdot K^{a,b} \cdot (stock^a/stock^b), \qquad (29)\end{aligned}$$

where $stock^a$ is the value of the harvest-adjusted natural capital $stock^t$ in (27) for the year in which the reference firm a is observed, and similarly for $stock^b$. If firms a and b are observed in the same period then Eqs. (29) and (26) are identical (i.e., $\Gamma^{a,b} = \Gamma_s^{a,b}$). Thus Γ_s can be decomposed into the contribution of the natural capital stock and the components of Γ, as given in (26). Γ_s may be interpreted as a measure of efficiency as it represents the restricted or variable profits achieved given an exogenously determined input, or the natural capital stock per unit of allowable catch.

Its decomposition into its component parts provides insights into what factors are responsible for changes in efficiency, and the possible causes of inefficiency across firms.[12]

For comparative purposes, a reference firm (a) must be chosen as the benchmark in the INPD given in (29). The choice of the reference firm is important because of transitivity. In other words, a different reference firm may result in different relative rankings between firms. This potential problem is not unique to the INPD, and typically researchers use multilateral index numbers [8,38,45]. In these multilateral approaches, comparisons are often made to an "average" country/firm as the denominator. However in the current context, and more generally, a composite or average firm is of little interest as an assessment of firm performance relative to the most profitable firm is more insightful. In other words, firm-level comparisons to the best performing firm, in terms of profits, helps identify what factors may be limiting increases in profit in the rest of the industry.[13] Thus, a natural denominator or reference is the firm that maximizes profit per unit of the harvest-adjusted natural-capital stock, as defined by (29). This reference firm is observation 15 from a total of 19 observations in 1994, or observation 101 out of the pooled sample of 105 observations for all sample periods.

An examination of the harvest-adjusted natural-capital stock (27) reveals $stock^{1988} = (438.76/12.8) = 34.28$ for 1988, $stock^{1991} = (425.06/7.145) = 59.49$ for 1991, and $stock^{1994} = (282.59/8.967) = 31.5$ for 1994. Thus, over all periods, it was easiest to catch the TAC in 1991. That is, the harvest constraint was likely to be most binding for the industry in 1991 when the biomass per unit of TAC was greatest. Given that the reference firm a is observation 15 in 1994, comparisons among firms for the same period are independent of the stock index. For the other two periods, 1988 and 1991, from Eq. (29) we see that adjustment by the stock variable is the same as multiplying both sides of the INPD (26) by the same constant ($stock^{1994}/stock^{1988} \approx 0.919$ for 1988, $stock^{1994}/stock^{1991} \approx 0.530$ for 1991, and $stock^{1994}/stock^{1994} = 1$ for 1994) to obtain a natural capital stock or resource adjusted profit ratio, $\Gamma_s^{a,b}$.

The results of the INPD are presented in Tables 2–4 for years 1988, 1991 and 1994. Geometric means of the index numbers are given in Table 5. To assist in the evaluation of the INPD, the pooled index series are plotted in Fig. 1, where the observations for each of the three years are separated by vertical dotted lines. When comparing the index values, if an index takes a value greater (less) than one, it contributes by expanding (contracting) the profit ratio, Γ. For the reference firm, observation 15 in 1994, its index values are unity and the index values for all other firms are relative to this firm. For example, from Table 2, and without adjusting for the natural capital stock, observation 43 has a higher profit than the reference firm, but lower restricted profit after adjusting for the stock variable. In other words, observation 43 has a value of Γ which is greater than one (1.060), but a value of Γ_s which is less than one (0.975).

For the decompositions, a value greater than one for the input indexes (PL, PF and K) does *not* mean that price of the input is higher than for the reference firm. Instead, it implies that the *contribution* of the price of the input to the profit ratio is greater than it is for the reference firm. A

[12] In principle, similar decompositions are possible using estimated "benchmark" data.

[13] In addition, using an average firm constructed using symmetric weights gives small firms the same weight as large firms. For example, in constructing an average industry price using a symmetric mean would give the same weight to the prices faced by small firms as by large firms [8]. This problem is well known in the literature on multilateral comparisons.

Table 2
Decomposition of profit ratios (Γ), 1988

Obs.	Profit	Γ_s	Γ	R	PH	PF	PL	K
1	36,647	0.112	0.122	0.576	0.413	0.996	1.003	0.511
2	220,915	0.673	0.732	2.878	0.454	0.987	1.005	0.566
3	9746	0.030	0.032	0.152	0.359	0.982	1.025	0.587
4	24,643	0.075	0.082	0.367	0.366	0.985	1.010	0.610
5	47,108	0.144	0.156	0.662	0.383	0.996	1.006	0.614
6	41,271	0.126	0.137	0.570	0.386	0.994	1.009	0.620
7	24,392	0.074	0.081	0.336	0.371	0.997	1.004	0.649
8	21,124	0.064	0.070	0.268	0.398	0.992	1.012	0.654
9	52,944	0.161	0.176	0.586	0.458	0.998	1.003	0.654
10	21,682	0.066	0.072	0.281	0.390	0.996	1.006	0.654
11	80,099	0.244	0.266	0.988	0.402	0.996	1.012	0.663
12	94,875	0.289	0.315	1.024	0.447	0.996	1.010	0.682
13	20,113	0.061	0.067	0.248	0.392	0.987	1.013	0.685
14	70,725	0.216	0.235	0.870	0.393	0.991	1.004	0.689
15	38,076	0.116	0.126	0.430	0.425	0.996	1.005	0.689
16	110,685	0.337	0.367	1.262	0.415	0.998	1.005	0.699
17	44,208	0.135	0.147	0.463	0.444	0.993	1.015	0.706
18	112,014	0.341	0.371	1.180	0.441	0.998	1.003	0.713
19	144,313	0.440	0.478	1.367	0.483	0.998	1.007	0.720
20	36,879	0.112	0.122	0.423	0.399	0.993	1.011	0.722
21	141,533	0.431	0.469	1.569	0.413	0.997	1.005	0.722
22	114,851	0.350	0.381	1.246	0.421	0.996	1.007	0.723
23	108,003	0.329	0.358	1.054	0.462	0.997	1.005	0.733
24	100,789	0.307	0.334	0.972	0.454	0.998	1.005	0.755
25	133,247	0.406	0.442	1.117	0.507	0.998	1.006	0.777
26	126,752	0.386	0.420	1.169	0.425	0.998	1.004	0.844
27	164,951	0.503	0.547	1.493	0.430	0.995	1.005	0.851
28	53,144	0.162	0.176	0.510	0.400	0.995	1.005	0.866
29	134,791	0.411	0.447	1.119	0.445	0.996	1.005	0.895
30	228,375	0.696	0.757	1.639	0.505	0.998	1.005	0.912
31	142,163	0.433	0.471	1.058	0.477	0.997	1.006	0.931
32	164,709	0.502	0.546	1.234	0.467	0.997	1.004	0.946
33	66,349	0.202	0.220	0.491	0.465	0.991	1.009	0.964
34	86,073	0.262	0.285	0.678	0.435	0.998	1.006	0.964
35	159,838	0.487	0.530	1.168	0.452	0.997	1.006	1.002
36	35,303	0.108	0.117	0.273	0.415	0.993	1.011	1.028
37	233,703	0.712	0.775	1.622	0.461	0.997	1.005	1.034
38	148,642	0.453	0.493	0.894	0.491	0.998	1.005	1.119
39	166,143	0.506	0.551	1.159	0.422	0.997	1.008	1.121
40	187,672	0.572	0.622	1.175	0.469	0.996	1.007	1.125
41	74,333	0.227	0.246	0.519	0.412	0.995	1.006	1.154
42	124,089	0.378	0.411	0.793	0.427	0.994	1.008	1.212
43	319,704	0.975	1.060	1.667	0.455	0.992	1.006	1.401

Table 3
Decomposition of profit ratios (Γ), 1991

Obs.	Profit	Γ_s	Γ	R	PH	PF	PL	K
1	19,975	0.035	0.066	0.206	0.622	1.007	0.997	0.516
2	16,620	0.029	0.055	0.172	0.616	1.008	0.998	0.518
3	29,471	0.052	0.098	0.283	0.611	1.003	0.999	0.563
4	26,881	0.047	0.089	0.241	0.649	1.003	1.001	0.568
5	24,933	0.044	0.083	0.225	0.644	1.004	0.999	0.568
6	17,916	0.031	0.059	0.182	0.573	1.002	0.999	0.568
7	24,730	0.043	0.082	0.237	0.605	1.006	1.001	0.569
8	17,486	0.031	0.058	0.163	0.617	1.003	0.998	0.576
9	18,804	0.033	0.062	0.174	0.604	1.011	0.998	0.587
10	13,432	0.024	0.045	0.108	0.692	1.009	1.002	0.590
11	18,888	0.033	0.063	0.168	0.623	1.006	0.998	0.594
12	13,373	0.023	0.044	0.125	0.591	1.004	0.998	0.601
13	23,522	0.041	0.078	0.203	0.628	1.008	1.001	0.606
14	31,434	0.055	0.104	0.257	0.657	1.002	1.001	0.616
15	42,880	0.075	0.142	0.335	0.681	1.004	1.001	0.620
16	36,501	0.064	0.121	0.279	0.681	1.004	1.003	0.632
17	27,447	0.048	0.091	0.191	0.744	1.003	1.002	0.638
18	46,124	0.081	0.153	0.334	0.713	1.002	1.001	0.640
19	47,289	0.083	0.157	0.339	0.712	1.007	1.003	0.643
20	52,498	0.092	0.174	0.367	0.723	1.006	1.000	0.652
21	42,582	0.075	0.141	0.331	0.646	1.002	0.999	0.660
22	30,690	0.054	0.102	0.223	0.684	1.002	0.999	0.666
23	28,371	0.050	0.094	0.243	0.570	1.008	1.001	0.675
24	23,500	0.041	0.078	0.162	0.702	1.003	0.999	0.685
25	60,796	0.107	0.202	0.443	0.659	1.004	1.000	0.688
26	58,979	0.104	0.196	0.384	0.737	1.002	1.001	0.688
27	31,657	0.056	0.105	0.216	0.691	1.002	1.001	0.699
28	52,457	0.092	0.174	0.391	0.628	1.002	1.001	0.706
29	56,882	0.100	0.189	0.389	0.670	1.002	1.000	0.722
30	80,947	0.142	0.268	0.557	0.651	1.008	1.000	0.734
31	33,381	0.059	0.111	0.211	0.710	1.004	0.998	0.739
32	39,169	0.069	0.130	0.249	0.702	1.002	1.001	0.740
33	48,306	0.085	0.160	0.300	0.719	1.003	0.998	0.741
34	67,688	0.119	0.224	0.417	0.698	1.002	1.001	0.769
35	55,851	0.098	0.185	0.326	0.708	1.002	0.999	0.802
36	71,062	0.125	0.236	0.388	0.743	1.010	1.001	0.808
37	73,436	0.129	0.243	0.435	0.686	1.001	1.001	0.814
38	84,393	0.148	0.280	0.426	0.763	1.002	1.002	0.858
39	75,461	0.133	0.250	0.471	0.615	1.002	1.001	0.861
40	99,517	0.175	0.330	0.469	0.734	1.002	1.001	0.954
41	43,650	0.077	0.145	0.212	0.676	1.005	1.003	1.005
42	144,332	0.254	0.479	0.598	0.712	1.002	1.002	1.119
43	118,302	0.208	0.392	0.504	0.680	1.002	1.001	1.140

Table 4
Decomposition of profit ratios (Γ), 1994

Obs.	Profit	Γ_s	Γ	R	PH	PF	PL	K
1	48,302	0.160	0.160	0.362	0.777	1.000	0.995	0.573
2	74,907	0.248	0.248	0.497	0.815	1.000	0.997	0.616
3	49,087	0.163	0.163	0.344	0.745	0.999	0.997	0.637
4	45,990	0.152	0.152	0.306	0.774	0.999	0.999	0.646
5	158,406	0.525	0.525	0.932	0.867	1.000	0.999	0.651
6	36,729	0.122	0.122	0.224	0.825	0.999	0.997	0.663
7	16,821	0.056	0.056	0.100	0.774	0.999	0.990	0.726
8	103,993	0.345	0.345	0.519	0.912	0.999	1.000	0.729
9	60,479	0.201	0.201	0.350	0.775	1.000	0.998	0.740
10	86,540	0.287	0.287	0.424	0.895	1.000	0.999	0.756
11	138,343	0.459	0.459	0.692	0.859	1.000	0.999	0.772
12	199,279	0.661	0.661	1.001	0.850	1.000	0.999	0.777
13	195,089	0.647	0.647	0.804	0.893	1.000	1.000	0.901
14	224,863	0.746	0.746	0.961	0.814	1.000	1.000	0.954
15	301,597	1.000	1.000	1.000	1.000	1.000	1.000	1.000
16	91,222	0.302	0.302	0.332	0.883	0.999	1.000	1.033
17	152,742	0.506	0.506	0.537	0.816	0.999	1.000	1.156
18	197,772	0.656	0.656	0.556	0.986	1.000	1.000	1.197
19	221,740	0.735	0.735	0.694	0.827	0.999	1.000	1.282

Table 5
Decomposition of profit ratios (Γ), means

Obs.	No.	Profit	Γ_s	Γ	R	PH	PF	PL	K
All years	105	84,220	0.152	0.204	0.467	0.581	0.999	1.003	0.752
Small	56	51,530	0.095	0.135	0.363	0.573	1.000	1.002	0.647
Large	40	137,341	0.328	0.401	0.702	0.594	0.999	1.003	0.959
1988	43	103,898	0.242	0.264	0.770	0.429	0.995	1.007	0.795
Small	24	702,98	0.162	0.176	0.644	0.412	0.994	1.008	0.661
Large	19	142,539	0.386	0.420	0.947	0.450	0.996	1.006	0.983
1991	43	45,851	0.068	0.128	0.277	0.667	1.004	1.000	0.688
Small	33	34,482	0.061	0.114	0.263	0.659	1.004	1.000	0.637
Large	10	83,369	0.139	0.262	0.411	0.700	1.003	1.001	0.904
1994	19	126,521	0.331	0.331	0.486	0.844	1.000	0.998	0.808
Small	9	66,079	0.184	0.184	0.346	0.806	1.000	0.997	0.662
Large	10	180,919	0.561	0.561	0.660	0.880	1.000	1.000	0.967

Note: The arithmetic mean is used to average over the profit values, while the geometric mean is used to average over the indexes. The full sample mean for the vessel length index (K) is used to split up observations into "small" and "large" vessels. Small vessels are defined as those being shorter than the sample average ($K < 0.752$), and large vessels are defined as being longer than the sample average ($K > 0.752$). "No." denotes the number of vessels in each year/size category.

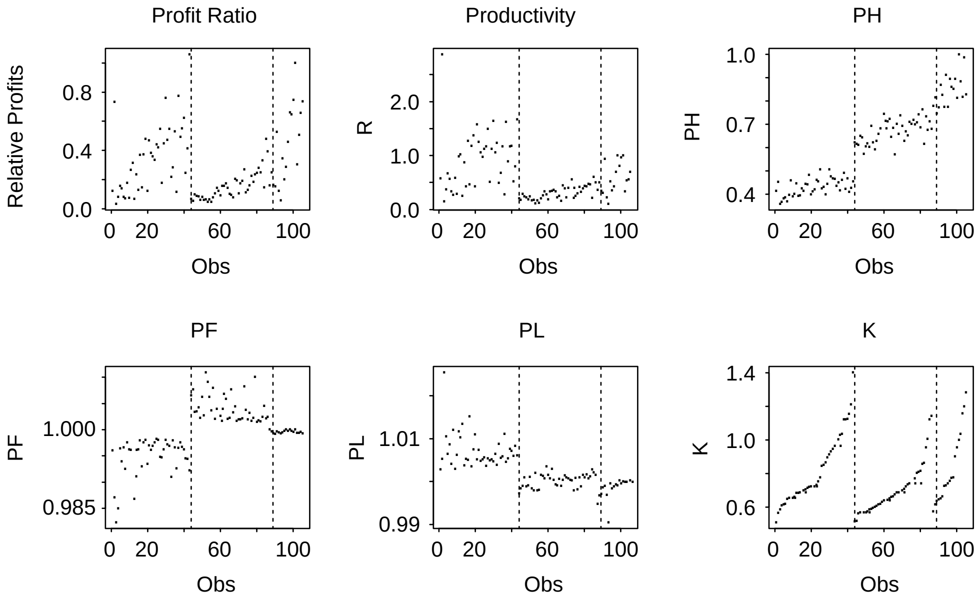

Fig. 1. Profit-ratio decomposition.

higher contribution of the fuel price to profit, for example, may indicate that the price of fuel is lower for the observation in question than that for the reference firm because higher fuel prices imply lower profits. If fuel prices are identical for the observation in question and another (but not the reference firm), a PF measure of greater than one implies that fuel costs represent a smaller share of profits for the given observation than the other firm. A similar interpretation applies for PL, the opportunity cost of labor.

6. Profit decompositions and regulatory change

Table 5 and Fig. 1 reveal important changes in the profits and decompositions across the 3 years of the sample. In particular, Table 5 shows that considerable variation exists across the three periods in terms of productivity (R) and the output price (PH). The results indicate that the average contribution of productivity to relative profits was highest in 1988 (0.770) and lowest in 1991 (0.277), with a considerable recovery in 1994 (0.486).[14] Thus the initial allocation of individual harvesting rights in 1991 is associated with a decline in the contribution of productivity to relative profits. A possible explanation for such an outcome is the adjustments required by firms in 1991 in response to a completely different regulatory system. The subsequent increase in the contribution of productivity to profit performance from 1991 to 1994 was associated with the trading of the individual harvesting rights that was allowed in 1993. Transferability would have

[14] Using the geometric mean for averaging over the indexes results in the means in Table 5 maintaining the relationship in (26).

permitted firms with relatively higher levels of productivity to increase their share of the harvest by buying harvesting rights from relatively less productive firms who exited from the fishery.

The profit decompositions may be compared to the estimates of changes in efficiency estimated with a production frontier for the same industry and periods. In the frontier analysis, short-run technical cost efficiency significantly declined for both small and large vessels over the period 1988–1991 and increased from 1991–1994 for both vessel classes, but the change was only statistically significant for small vessels [32]. These changes were accompanied by a 28 percent decline in the number of active vessels in the industry between 1988 and 1994. Thus although the INPD and frontier estimates of changes in the fishery were obtained by very different methodologies, they provide comparable results with initial declines in performance from 1988 to 1991, but subsequent gains from 1991 to 1994. The advantage of the INPD, and unlike the frontier approach, is that it allows us to examine the relative importance of changes in prices (inputs and outputs), capital and productivity on profitability across vessels and time periods.

The decompositions summarized in Table 5 show that the most striking change in the profit decompositions over all vessels occurred with respect to the output price (PH). The increase in the price of halibut is directly attributable to the change in regulations as previously fishers landed a frozen product caught in a total fishing season of a few days. By contrast, under the individual quota system the season length increased from 6 days in 1990 to 214 days in 1991. This had two effects. First, it allowed fishers to land and market fresh halibut which commands a much higher price than the frozen product, which represented most of the sales prior to the introduction of harvesting rights. Second, the increased season length reduced congestion externalities and provided fishers with much more time to bring their harvest on board and to avoid bruising and damaging of the product and increase the price received [32]. Further, these output price increases occurred only for the BC halibut fishery and not in the Alaska halibut fishery which, at the time, still operated as a “derby” fishery [37]. Overall, the INPD results indicate that the upward shift in output prices had a large and positive impact on the restricted profits of firms.

Given that all other firms have a PH value less than unity, high output prices explain why the reference firm had the greatest profits per unit of the resource stock. A comparison of the mean value of the PH decomposition in Table 5 reveals that, for the firms in the sample, increases in the price of halibut was the single biggest factor in improving firm performance from 1988 to 1994. Indeed, without the increases in the output prices attributable to the introduction of private harvesting rights, average firm performance would have not increased over the 1988–1994 period.

A comparison of the other profit decompositions for the fuel input price (PF), labor input price (PL) and the firm-level capital stock (K) reveal little change in the average performance over the three periods. Nevertheless, a relatively lower average fuel price in 1991 is reflected in higher values for PF, or a greater contribution of fuel to the profits in 1991 relative to the reference firm in 1994. Similarly, the lower average price of labor in 1988 is reflected by the price of labor making positive contributions in 1988 to increasing profits relative to the reference firm that is observed in 1994. Thus, for this industry, it would seem that the greatest benefits associated with a shift to individual harvesting rights in 1991 has been an increase in the output price, directly attributable to a much longer fishing season.

Another comparison of interest is the effect of vessel size on profits and productivity. Fig. 1 provides three sets of observations for each of the three observation periods 1988, 1991 and 1994. For each period, observations are ranked in increasing order of vessel size. Interestingly, a positive relationship appears to exist between vessel size and relative profits for all three periods, and between vessel size and the output price for the period 1994.[15] It would suggest that increased vessel size is associated with improved economic performance. This finding complements the results of [32] who find that if fishers were able to freely adjust their vessel size, they could substantially increase their long-run technical cost efficiency. If improved performance is associated with increased vessel size, it suggests that on-going restrictions on vessel size in fisheries in which halibut fishers are active participants may be preventing the full economic gains from individual harvesting rights.

Overall, the index decompositions provide a breakdown of the relative importance of regulations on firm performance. For example, the INPDs indicate that some of the greatest gains associated with privatization of the commons may arise on the revenue side rather than on the costs or input dimension. The results also suggest that regulatory change can lead to significant productivity shocks among firms, but that firms can adjust rapidly to such shifts. In addition, the indexes provide a ready-made comparison of all firms relative to the most profitable firm per unit of resource stock. In turn, this provides useful information for benchmarking across firms at a point in time. Such pairings of firms to the reference or benchmark indicate what components are contributing most to changes in profits, and suggest what may be done to improve overall industry performance.

7. Concluding remarks

The paper proposes a new method for assessing firm-level economic performance and evaluating changes in industries over time. The method explicitly accounts for changes in the natural capital stock and decomposes contributions to profits in terms of productivity, variable input prices, output prices, and reproducible capital. A decomposition, with this level of detail and information, cannot easily and neatly be obtained using standard efficiency and productivity analysis techniques. Moreover, standard efficiency-analysis techniques typically estimate multi-dimensional ‘‘benchmark frontiers,’’ whereas only observed data are used in the proposed profit-decomposition technique. Further, the method can be justified from either the axiomatic approach to evaluating index numbers, which makes no behavioral assumptions or assumptions on the specific form of technology, or it can be justified from microeconomic theory through the economic approach to index numbers.

The index-number profit decomposition has a wide number of potential applications in measuring firm, industry and regulatory performance. Using the approach with data from the British Columbia halibut fishery, the decompositions indicate that the major benefit from a shift to individual harvesting rights in the industry in 1991 was an increase in output prices. Further, the results indicate a positive relationship between relative profits in the industry and vessel size following the introduction of individual harvesting rights. This suggests that vessel size restrictions imposed upon fishers may be preventing the full gains in economic performance associated with the introduction of individual harvesting rights.

[15] Non-parametric tests are required to determine the significance of such a relationship. Unfortunately, such tests are not suitable in the current context because of the small number of observations.

More generally, the application suggests that the method could be used in many different industries for assessing economic performance and evaluating the effects of regulatory change. For instance, by decomposing profit into the contributions of inputs and outputs, firms and regulators can identify the most important factors constraining improved performance and can analyze what may be contributing to regulatory success or failure. Further, benchmarking across firms, and by decompositions, can assist individual firms understand what may be preventing them from increased profitability. Ultimately, profit and productivity decompositions should prove useful to firms and regulators who want better decision-making and improved management and industry performance.

Acknowledgments

The authors gratefully acknowledge helpful comments from two anonymous referees, Antonio Alvarez, Erwin Diewert, Ulrich Kohli, Diane Dupont, Daniel Gordon, and seminar participants at the University of Oviedo, University of Geneva, Universitat de les Illes Balears, University of Lund, and the 2000 New Zealand Econometrics Study Group, Winter Meeting, University of Canterbury.

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