Trip-Level Analysis of Efficiency Changes in Oregon's Deepwater Trawl Fishery

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Summary

In 2003, an industry-financed, government-administered buyback of trawl fishing permits and vessels took place on the US West Coast, resulting in the retirement of about one-third of the limited-entry trawl fleet. The lack of cost data in this fishery precludes an analysis of how the buyback has affected profitability, but changes in technical efficiency can provide some insight into the program's effects. This paper, the first of a planned series of analyses of the buyback's effect on technical efficiency in the trawl fleet, applies stochastic frontier analysis to assess whether technical efficiency changed perceptibly after 2003. We adopt a hierarchical modeling approach estimated with Markov Chain Monte Carlo methods, and present results from both Cobb-Douglas and translog specifications. The analysis is limited to 13 boats active in Oregon's deepwater 'DTS' fishery, which targets dover sole, thornyheads, and sablefish. The results suggest that the buyback has had little impact on trip-level technical efficiency in the study fishery. However, departures from the frontier are markedly bi-modal, indicating that a mixed-density approach to estimation may be more appropriate.

Keywords: Fishery Buyback, Technical Efficiency, Stochastic Production Frontier, Bayesian Inference, Markov Chain Monte Carlo

JEL Classification: Q2, L5, C1

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Introduction

The groundfish fishery of the US West Coast has been in crisis for several years. Due to the mingling of very depressed fish stocks with apparently healthy stocks, fishing regulations have become much more stringent over time. In 2003, an industry-financed buyback of fishing boats and limited-entry permits was carried out with the aims of reducing fishing pressure and increasing the profitability of boats that remained in the fishery. Assessing the effectiveness of the buyback in achieving these goals is important in its own right and also may shed some light on the relative benefits of further transition to a transferable quota system. However, an assessment of the buyback's economic benefits is difficult for several reasons: the large number of species landed by trawlers, the lack of cost data for the fleet, technological and regulatory change, and the effects of fluctuations in fish stocks and ocean conditions. In this paper, we examine the effect of the buyback on technical efficiency, which, while far from telling managers all they would want to know to assess the buyback's impact, is a useful metric for considering the effects of the program.

The US West Coast groundfish fishery is a biologically and institutionally complex multi-species fishery. More than 80 species are included in the regional groundfish management plan. Several different gear types and fishing strategies are routinely employed. Harvesting rights are divided among limited-entry, open access, tribal, and recreational sectors. Harvest management is accomplished with a mix of trip limits, cumulative monthly and bi-monthly limits, gear restrictions, and seasonal and area closures. These regulations have become progressively more complex over the past three decades. Groundfish landings by domestic fishing vessels increased dramatically following the expansion of the exclusive economic zone in 1976, but by the early 1980s concerns were being voiced about excessive fishing pressure on some fish stocks. Despite increasingly strict regulation of fishing, by 2000 the federal government had declared the fishery a disaster. The 2003 buyback retired 91 of 263 limited-entry trawl permits, with the aims of reducing fishing capacity, reducing fishing pressure, and restoring profitability.

This paper presents a preliminary attempt to gauge the economic effects of the buyback by examining its impact on technical efficiency at the trip level. Given the difficulty of assessing effects across the entire limited-entry groundfish fleet, our emphasis here is on developing a method and applying it to a small component of the fishery. Specifically, we propose a stochastic frontier analysis of boats that derive a large part of their income from the 'DTS' complex (Dover sole, thornyhead, and sablefish), a deepwater assemblage generally targeted by larger trawl vessels on the continental slope at depths in excess of 450 meters. We limit attention to the DTS complex because fishing at this depth takes place with a more uniform technology than does fishing nearer to shore, and also because the number of species caught is fairly small relative to shallower local waters. And while a multi-output distance function approach may seem more natural due to the diversity of species in the fishery, we opt, in this preliminary investigation, for the simpler and more conventional approach of aggregating catch across species. Presently, the problem of imposing curvature restrictions on the parameters underlying multi-output distance functions remains a significant challenge (see, for examples, Griffiths, O'Donnell and Tan Cruz, 2000; Dorfman and MacIntosh, 2001; and O'Donnell and Coelli, 2005). Based on two production function specifications, we estimate a composed-error stochastic production frontier to derive estimates of production function parameters and also the technical inefficiencies of boats in our sample. Comparing these inefficiencies provides a measure of the effect of the buyback on technical efficiency.

In the remainder of the paper, we first present our econometric approach to estimating the stochastic production frontier. We then describe the study data and the prior information used in the empirical investigation. We then outline the main results. The final section offers a summary and conclusions, as well as notes on further work required to strengthen the preliminary analysis presented here.

Hierarchical Estimation of the Stochastic Production Frontier

The basis of our analysis is the composed-error model, first formalized by Aigner, Lovell and Schmidt (1977)[1]. This approach allows us to investigate catch as a function of inputs to production, random error, and inefficiency. Given data on output (here, catch per trip) and inputs to production, a stochastic production frontier may be specified as

(1) $y_i = \boldsymbol{x_i}'\boldsymbol{\beta} - z_i + u_i$

where y_i is the catch by unit i; $\boldsymbol{x_i}$ is a vector of inputs to production; $\boldsymbol{\beta}$ is a vector of parameters that, together with $\boldsymbol{x_i}$, defines the frontier; u_i is a normally distributed sampling error term; and z_i a term denoting the distance of y_i from the frontier, i.e., z_i is a measure of the inefficiency of unit i, which we will assume follows a truncated normal distribution. These are standard assumptions in the literature (see Kumbhakar and Lovell (2000) for a book-length treatment).

Because our unit of observation is the individual trip, we elaborate equation (1) to account for three dimensions of the sampling environment, namely the vessel, year, and trip for which catch is reported. We denote catch (in pounds) by vessel i in year j during trip k as y_{ijk} and exploit the availability of panel data by introducing a hierarchical structure in the parameters governing inefficiency. The idea of the hierarchical modelling structure is that observations within a sample may be probabilistically related at the unit or sub-unit level and that these relationships may be captured by representing model parameters themselves as draws from a distribution. Thus, we suppose that trips by boat i in year j have a particular efficiency level z_{ij} (assumed to be constant over trips for boat i in year j), but that there are both boat-specific and year-specific influences on the z_{ij}, which are embedded in the hierarchical structure and estimated simultaneously. A previous exercise in model selection (Tomberlin, Irz, and Holloway 2005) gives strongest support to a two-layer hierarchy based on the hypothesis that inter-boat differences are more important determinants of efficiency than are inter-annual differences. This hypothesis is embodied in a two-layer hierarchy of inefficiency parameters: the boat-year inefficiencies, z_{ij}, are drawn from a distribution $f^{TN}(z_{ij}|v_i, \eta_i^2)$ with a mean v_i specific to each boat, and these v_i are in turn drawn from a distribution $f^{TN}(v_i|\lambda, \omega^2)$. The regression equation has the general form

(2) $y_{ijk} = f(\mathbf{x}_{ijk};\boldsymbol{\beta}) - z_{ij} + u_{ijk}$,

where y_{ijk} denotes catch aboard boat i in year j on trip k; $f(\mathbf{x}_{ijk};\boldsymbol{\beta})$ specifies the functional form of the model in question; z_{ij} denotes the boat-year-specific inefficiency level; and u_{ijk} denotes a random error, which we assume is identically and independently normally distributed across trips, boats, and years. We consider results under two separate assumptions about functional form for $f(\mathbf{x}_{ijk};\boldsymbol{\beta})$. In the first analysis we assume that $f(\mathbf{x}_{ijk};\boldsymbol{\beta})$ has the Cobb-Douglas form and in the second we assume that it has the

[1] A review of recent developments in composed-error modeling is found in Murillo-Zamorano (2004).

transcendental logarithmic form; in both cases, of course, it follows that y_{ijk} represents the natural logarithm of catch. In the Cobb-Douglas setting there are a total of four covariates, including the constant term; and in the translog setting there are a total of ten covariates. Our sample consists of 819 trips made by 13 boats over 5 years, although not all boats operated in each of the respective years (there are a total of 74 boat-years, to which the z_{ij} correspond). As indicated in the hierarchical setup, each z_{ij} is assumed to be drawn from one of the thirteen boat-level means, v_i, with corresponding variance η_i; and the thirteen v_i's, in turn, are drawn from the upper-level distribution with mean μ and variance ω^2. Figure 1 depicts the hierarchy. Here, we treat as latent or so-called 'missing data' the terms $\mathbf{z} \equiv (\mathbf{z}_1', \mathbf{z}_2', .., \mathbf{z}_N')'$, $\mathbf{z}_1 \equiv (z_{11}, z_{12}, .., z_{1T1})'$, $\mathbf{z}_2 \equiv (z_{21}, z_{22}, .., z_{2T2})'$, .., $\mathbf{z}_N \equiv (z_{N1}, z_{N2}, .., z_{NTN})'$, and $\mathbf{v} \equiv (v_1, v_2, .., v_N)'$; and primary interest centres on the locations and scales of the components of $\theta \equiv (\beta', \eta', \mu, \omega)$, where $\beta \equiv (\beta_1, \beta_2, .., \beta_K)'$ denotes the response of catch to the K covariates in each model and $\eta \equiv (\eta_1, \eta_2, .., \eta_N)'$ denotes the variance in the lower level of the hierarchy. Once a satisfactory prior is put in place we derive fully conditional posterior distributions for the components of θ and the components of the missing data vectors $\mathbf{v}$ and $\mathbf{z}$. Details are presented in Holloway *et al.* (2005).

Empirical Model and Results

To assess the impacts of the buyback on technical efficiency in our study sample, we wish to establish, primarily, whether the year-specific technical inefficiency distributions have moved by a significant amount over time. Regressors $\boldsymbol{x}_{ijk}$ in the model are crew size, horsepower, and total duration of tows per trip. We include observations on boats that made at least fifty DTS trips during 2000-2005, where a DTS trip is defined as a trip on which the DTS complex accounted for at least 90% of total catch volume for the trip. The analysis is thus limited to 819 trips by 13 boats during 2000-2005. Summary statistics are presented in Table 1, and a breakdown of trips by year is presented in Table 2.

While we have little information about the likely magnitudes of the components of θ, a proper prior is required for model comparison. We use the proper prior $\pi(\theta) \equiv \pi(\beta) \times \pi(\mu) \times \pi(\sigma) \times \pi(\omega) \times \prod_i \pi(\eta_i)$, and assume $\pi(\beta)$ is the K-dimensional Normal pdf with mean and variance $\mathbf{0}_\mathbf{N}$ and $\mathbf{I}_\mathbf{N} \times 10$, respectively; $\pi(\mu)$ is normal with zero mean and variance ten; and $\pi(\sigma)$, $\pi(\omega)$ and each component of the product $\prod_i \pi(\eta_i)$ is inverse-Gamma as in Zellner (1979), equation (A.37b), with degrees of freedom parameter $v = 1$ and scale parameter $s = 1$. These hyper-parameter values reflect weak prior information. Naturally, we wish to assess the extent to which the prior affects parameter estimates and the likelihood calculations. For this reason, we calculate three quantities that give some indication of the influence of the prior in these calculations, namely the maximum value of the likelihood function in the range of draws obtained from the Gibbs sample; the estimated value of the likelihood function in the Gibbs draws; and the estimated values and the numerical standard errors of the marginal likelihood values obtained by an extension (due to Chib, 1995) of the Gibbs sample used to estimate the posterior pdf's of the parameters.

Estimation results, reported in Tables 3 and 4, are based on 10,000 'burn-in' Gibbs samples followed by a collection sample of the same size. The entire procedure takes about ten minutes to run on a standard computing platform. Table 3 presents estimation results from the Cobb-Douglas specification and Table 4 presents those from the translog specification. The main conclusions to be drawn from the tables are that few of the covariates are significant (i.e., have highest posterior density (HPD) intervals that do not include zero) and that there are some significant departures from the production frontier, *i.e.*, evidence of inefficiency in the sample. The results also serve to highlight the sensitivity of the DTS trawl data to changes in specification, a subject we are continuing to investigate. For example, readers should note the sizable differences in the estimates of the constants across models; differences in the magnitude of the tow-time coefficients across specifications; and differences across the boat inefficiency scores between specifications. We are continuing to investigate why inclusion of the cross-product terms has such an influence on some parameter estimates.

Figures 2 and 3 present plots of the distributions of the Gibbs sample for the boat-year inefficiency terms, grouped by year, for each of the two specifications. Within each figure, the modes of the six distributions are very similar, indicating that *within each specification*, the inefficiency levels in the fleet have changed little, if any, over time. While there is a slight suggestion that the curve for 2005 shows improved efficiency in that year relative to earlier years, we conclude that there is little evidence that the buyback has had a discernible impact on the overall level of trip-level technical efficiency in the fishery. The bimodal appearance of the figures does however strongly suggest that a mixture model may be a more appropriate framework for analysis for these data. Thus, our preliminary finding that there has been little if any change in the technical efficiency of the DTS fleet over time requires further testing, which we intend to pursue through the application of a mixture model of the multi-output distance function, estimated subject to the full set of monotonicity and curvature conditions (Fare and Primont 1995).

Conclusions

This paper has presented a stochastic production frontier for assessing the effect of a permit buyback on technical efficiency in a fishery, and described estimation of this frontier by Bayesian hierarchical methods. We applied this framework to a small sample of boats that participate in the deepwater DTS fishery off the coast of Oregon. Our results suggest that there has been little, if any, change in trip-level technical efficiency in the wake of the 2003 buyback.

These results are necessarily tentative. Our decision to limit the study to only 13 boats means that there may be significant information that our prelimary analysis ignores. Similarly, only two years of post-buyback data are available, and it is possible that some effects of the buyback involve significant lags. Including more boats and trips will pose significant conceptual and computational challenges because the number of species caught and activities undertaken by a broader segment of the groundfish trawl fleet will be much higher. Even for the DTS fishery, a multi-output model, properly constrained, would be preferable. Another important point is that this fishery is restricted by cumulative trip limits defined over one- or two-month periods. Further analysis may well reveal that the buyback has had significant efficiency effects at this longer time scale, i.e., while individual trips may not have become more efficient, the ability to make more trips during a two-month period may result in greater efficiency overall.

Beyond expanding the data and exploring the appropriate unit of observation for the analysis, further work on the effects of the buyback would benefit from several conceptual extensions to the approach presented here. We have not yet incorporated exogenous factors such as ocean conditions and fish stocks, though these are clearly important. We also intend to elaborate the model to account for productivity changes, since changes in the location and shape of the production frontier itself are almost certainly part of the buyback story. We will also consider possible mixing over two or more types of vessels within the data set, as suggested by the bimodality of the inefficiency measures. And we will implement fully the curvature and monotonicity restrictions implied by economic theory and assess the sensitivity of any conclusions made to these restrictions using formal model-comparison methodology that has only recently become available (Chib 1995; Chib and Jeliazkov 2001).

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Table 1: Summary Statistics on 819 Trips by 13 Boats, 2000-2005

	Mean	Std. Dev.	Minimum	Maximum
Number of Crew	3	0.50	2	5
Horsepower	405	108	190	638
Total Tow Time (hrs)	25	19	0.5	96
DTS Catch (lbs)	7933	6395	77	34,467
DTS Share of Trip Catch	0.97	0.03	0.90	1.00

Table 2: Trips per Year in Data Set

Year	Trips Used in Estimation
2000	184
2001	156
2002	119
2003	119
2004	117
2005	124
Total trips	**819**

Table 3: Estimation Results

	Cobb-Douglas			Translog		
	95% lower HPD	Mean	95% upper HPD	95% lower HPD	Mean	95% upper HPD
β_{crew}	-0.16	0.31	0.77	-4.77	2.68	10.26
$\beta_{horsepower}$	-1.05	-0.12	0.82	-4.21	2.20	8.69
$\beta_{tow\text{-}time}$	0.67	0.73	0.79	-1.26	0.18	1.62
β_{crew^2}				-4.39	-0.63	3.22
$\beta_{horsepower^2}$				-1.63	-0.40	0.81
$\beta_{tow\text{-}time^2}$				-0.16	-0.05	0.06
$\beta_{crew*horsepower}$				-1.92	-0.36	1.16
$\beta_{crew*tow\text{-}time}$				-0.24	0.13	0.51
$\beta_{horsepower*tow\text{-}time}$				-0.18	0.09	0.36
$\beta_{constant}$	5.67	11.81	17.67	-15.77	2.63	20.61
σ	0.68	0.72	0.75	0.68	0.72	0.75
η_1	0.39	0.72	1.36	0.39	0.71	1.34
η_2	0.33	0.62	1.21	0.34	0.63	1.24
η_3	0.30	0.55	1.04	0.30	0.55	1.04
η_4	0.28	0.50	0.95	0.28	0.51	0.96
η_5	0.34	0.69	1.51	0.34	0.69	1.47

η_6	0.29	0.53	0.99	0.29	0.53	1.01
η_7	0.31	0.57	1.07	0.31	0.57	1.09
η_8	0.32	0.64	1.40	0.31	0.64	1.40
η_9	0.31	0.56	1.09	0.31	0.56	1.09
η_{10}	0.30	0.55	1.05	0.30	0.55	1.04
η_{11}	0.31	0.56	1.08	0.31	0.57	1.07
η_{12}	0.32	0.58	1.09	0.32	0.58	1.10
η_{13}	0.32	0.60	1.15	0.32	0.60	1.14
v_1	2.88	4.90	6.87	0.78	2.43	4.39
v_2	3.17	5.19	7.15	1.15	2.79	4.66
v_3	2.67	4.67	6.59	0.56	2.19	4.14
v_4	2.93	4.90	6.82	0.89	2.47	4.33
v_5	2.89	4.92	6.89	0.79	2.47	4.39
v_6	2.87	4.87	6.80	0.72	2.37	4.33
v_7	2.88	4.87	6.79	0.80	2.41	4.32
v_8	2.99	5.02	6.99	0.92	2.59	4.50
v_9	2.52	4.64	6.66	0.57	2.19	4.10
v_{10}	2.95	4.94	6.88	0.92	2.52	4.38
v_{11}	3.04	5.09	7.07	0.80	2.51	4.58
v_{12}	2.74	4.73	6.66	0.67	2.29	4.16
v_{13}	2.92	4.93	6.86	0.89	2.50	4.37
ω	0.28	0.46	0.79	0.28	0.47	0.80
μ	2.85	4.90	6.86	0.78	2.44	4.38
Mean z_{ij} *in 2000*	2.77	4.84	6.81	0.65	2.38	4.34
Mean z_{ij} *in 2001*	2.91	5.02	7.05	0.78	2.56	4.59
Mean z_{ij} *in 2002*	2.82	4.94	6.98	0.71	2.47	4.49
Mean z_{ij} *in 2003*	2.77	4.91	7.04	0.66	2.45	4.52
Mean z_{ij} *in 2004*	2.79	4.94	7.05	0.68	2.48	4.54
Mean z_{ij} *in 2005*	2.55	4.74	6.89	0.45	2.28	4.43
Maximized Log-Likelihood		-869.67			-867.62	
Estimated Log-Likelihood		-886.08			-884.62	
Marginalized Log-Likelihood		-927.79			-941.10	
Numerical Standard Error		0.02			0.02	

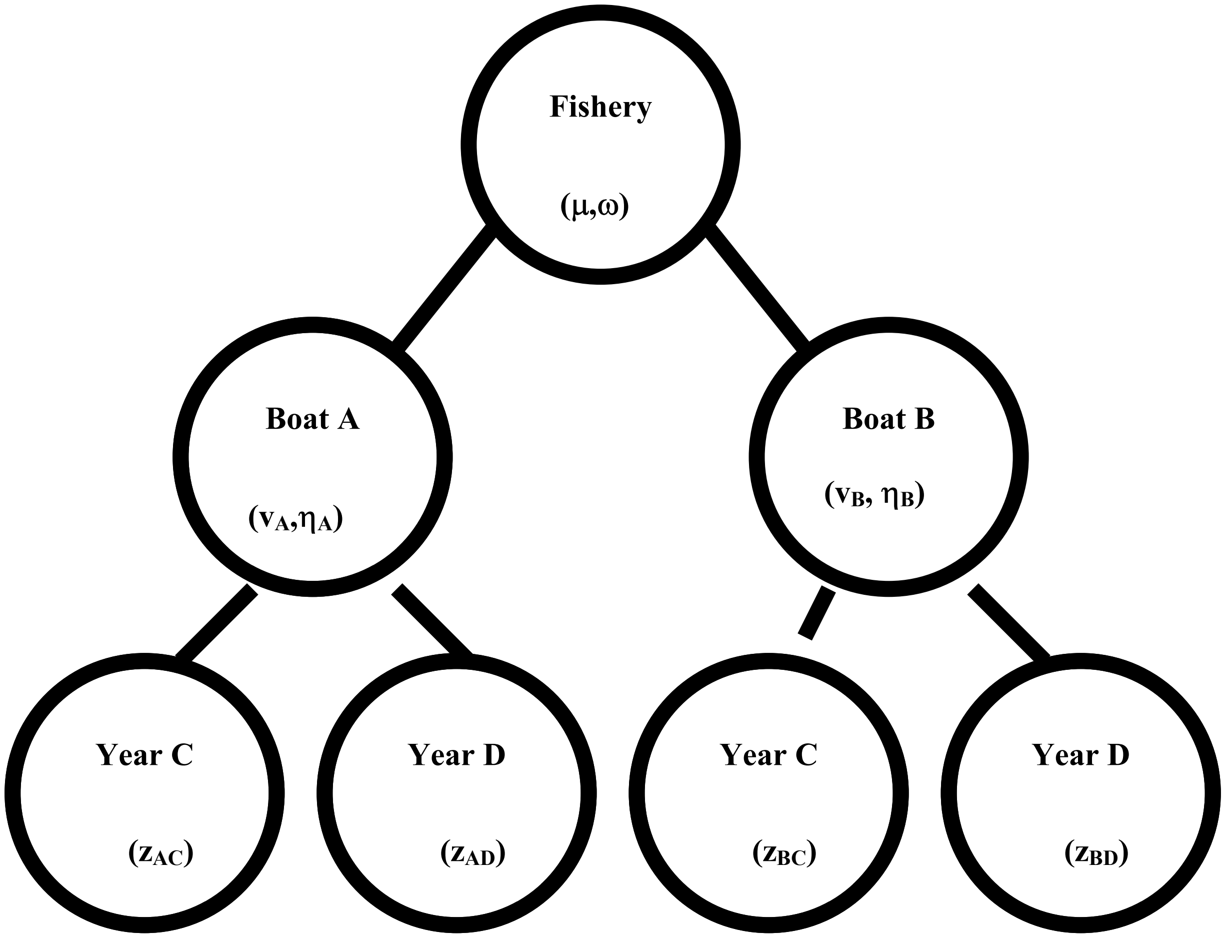

Figure 1. A Two-Layer Hierarchy of Boat Efficiency

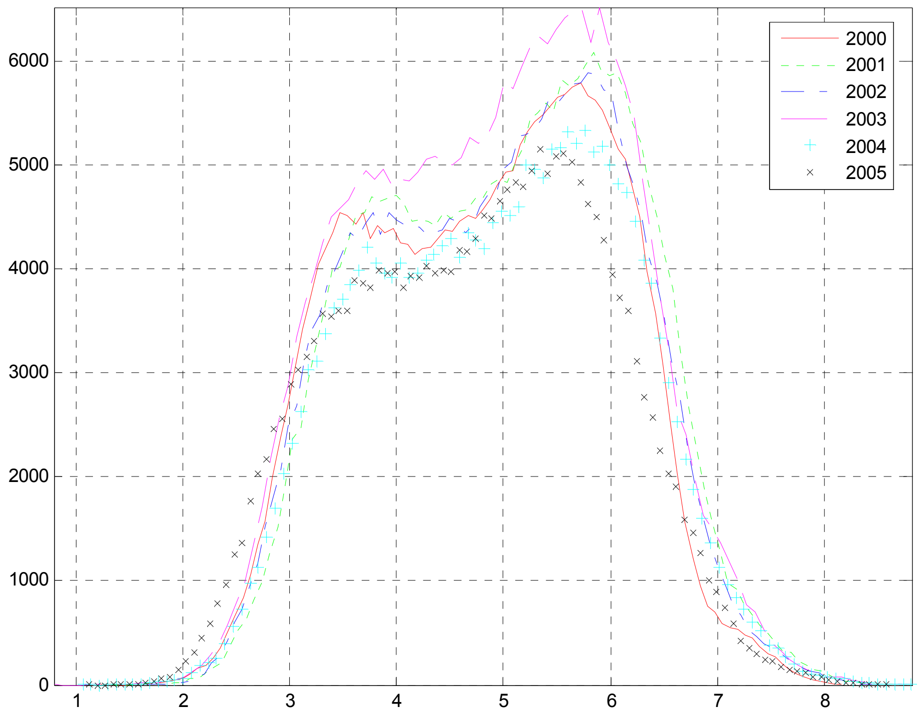

Figure 2: Distribution of Gibbs samples for inefficiency terms z_{ij} by year, assuming a Cobb-Douglas production function.

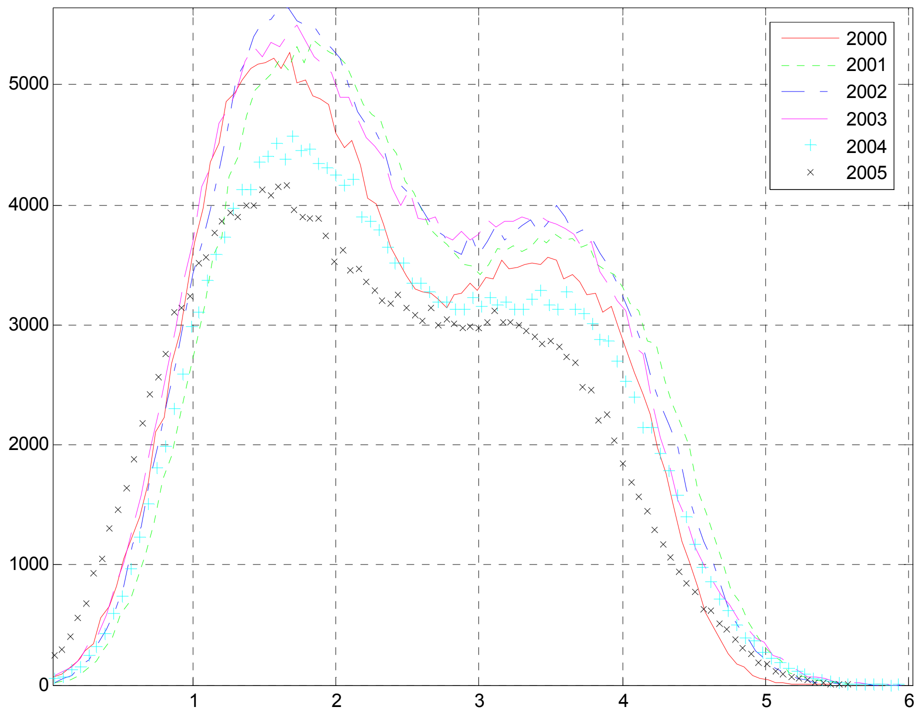

Figure 3: Distribution of Gibbs samples for inefficiency terms z_{ij} by year, assuming a translog production function.

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