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Productivity growth, catchability, stock assessments, and optimum renewable resource use

Dale Squires [a,*], Niels Vestergaard [b]

[a] U.S. National Marine Fisheries Service, 8604 La Jolla Shores Drive, La Jolla, California 92037, USA
[b] Department of Environmental and Business Economics, Centre for Fisheries & Aquaculture Management & Economics (FAME), University of Southern Denmark, Denmark

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Productivity growth substantially impacts rent-maximizing resource stocks, and can lead to an economic optimum that has overfished stocks: BMEY < BMSY. Bioeconomic models can give biased results and policy advice when not accounting for time-varying catchability—notably due to productivity growth—and density-dependent catchability, and not distinguishing between fishery-dependent and fishery-independent data and implications for catchability, modeling, and applicability of results. Productivity growth, as a component of time-varying catchability, also impacts stock assessments. CPUE standardization and productivity measurement both face an identification issue in disentangling changes in resource stocks from changes in productivity as well as endogenous regressors for which there are potential identification strategies. An empirical example illustrates BMEY < BMSY.

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1. Introduction

Growth in productivity or fishing power impacts the optimum exploitation of renewable resources such as marine capture fisheries.[1] This paper examines several of these key impacts upon bioeconomic models, population assessments, and the consequent policy recommendations.

First, the paper considers the effects of accounting for productivity growth in normative bioeconomic models. The bioeconomics literature, recently reviewed by [1–4], has largely overlooked the growing body of economic literature on the economics of productivity growth, reviewed by [5] in this volume. The bioeconomics literature recommends dynamic maximum economic yield (MEY) and biomass (or numbers of animals), denoted by B, of the resource stock (BMEY) corresponding to BMEY > BMSY (maximum sustainable yield resource stock), because a larger biomass lowers search and harvest costs that in turn raise economic rent [6–8]. In contrast, after incorporating productivity growth into bioeconomic models, BMEY < BMSY, because productivity growth lowers search and harvest costs on an on-going basis, and when coupled with discounting, there are weaker incentives to lower costs by keeping fish in the water [3].

The bioeconomics literature reaches additional conclusions that may not hold when incorporating productivity growth. The perceived crisis in global fisheries [7,9] is likely misstated in terms of economic rent, effective effort, and natural capital when productivity growth is accounted for in bioeconomic modeling [3]. Recommended optimum fleet sizes, nominal effort or physical capital levels, resource stock targets, and policy instruments simply do not match the more productive technology and its continual growth that are ongoing but are unaccounted for in current dynamic models. Rebuilding strategies [8] do not correspond to BMEY and impose unnecessary costs when accounting for productivity growth. The presence of productivity growth increases the risk of extinction, and more generally biodiversity loss, greater than considered by [1] and others. The bionomic (open-access) equilibrium of Gordon [10] may only exist, if at all, at levels much lower than currently held.

Second, the paper discusses how accounting for productivity growth and its measurement are closely related to issues that arise with catchability in population assessments and that also bear upon bioeconomic models.[2] The population assessment,

* Corresponding author.
E-mail addresses: dsquires@ucsd.edu (D. Squires), nv@sam.sdu.dk (N. Vestergaard).

[1] Productivity is an economic measure of total catch per unit of a single input (partial productivity) or per unit of all inputs (total factor productivity). Productivity is often called fishing power in the fisheries literature. Productivity (fishing power) growth is due to many factors, the most important of which is technological change.

[2] Catchability has several definitions [11]. One is the parameter that relates an index of relative abundance to population size (absolute abundance). Another is the proportionality parameter between fishing effort and fishing mortality or the portion of the stock captured by one unit of effort. The earliest known theoretically rigorous economics paper on time-varying and density-dependent catchability is [12]. Ekerhovd and Gordon [13] also raise the identification issue when using resource stock to evaluate catch-effort (or by extension productivity) relationships, and propose a specific identification strategy for VPA models. This paper builds upon both papers, as well as [11] and [3].

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bioeconomic, and fisheries productivity literatures grapple with, or should grapple with, catchability that is potentially time-varying and density-dependent and with the implications from using fishery-dependent and fishery-independent data.[3] Most importantly, stock assessments aim to remove the effect of productivity growth from stock estimates and economists want to remove the effect of stock changes from productivity growth. Both require an identification strategy to disentangle the two sources of change, often using the same fishery-dependent data. Productivity theory also provides a number of insights for standardization of catch and effort data.

Third, there is not an explicit, theoretically consistent mechanism to incorporate productivity growth into population assessments, and this paper discusses some possible approaches. Through the empirical example, the paper shows how to specify the catchability coefficient to account for growth in productivity or fishing power consistent with productivity theory. In this vein, catch per unit effort or CPUE, which is typically a partial rather than total factor productivity measure, may not accurately measure relative stock abundance and/or density, since not all economic inputs, and in many instances productivity growth, that affect fishing mortality are captured.

This paper illustrates the impact of productivity growth, measured by an economic index number, upon MEY and BMEY for the US and Canada Pacific coast albacore (*Thunnus alalunga*) troll fishery. It employs a very simple bioeconomic model that accounts for productivity growth. It eschews a spatial bioeconomic model with density-dependent fish movement between spatially linked distinct populations or substocks, because supporting empirical biological evidence is absent for many fish species, and especially for northern albacore, which make ontogenetic migrations [14].[4]

Section 2 discusses the relationships between productivity measurement and catchability, population assessments, bioeconomic models, and the use of fishery-dependent and -independent data. Section 3 summarizes growth accounting and productivity, the Malmquist productivity measure, and bioeconomic models. Section 4 incorporates productivity growth into the Golden Rule of renewable resource economics. Section 5 provides empirical results and discusses policy implications. Section 6 concludes.

2. Catchability and fishery-dependent and -independent data

2.1. Issues in catchability

Several questions arise for productivity growth measures and bioeconomic models and their relationship to catchability and population assessments and the use of fishery-dependent and -independent data.[5] First, catchability, of which productivity is a part, may be density-dependent (elaborated upon below), so that bioeconomic models and population assessments may not fully and accurately track the entire population [11,12].[6]

Second, both productivity measures and stock assessments may use all or part of the same fishery-dependent data, potentially requiring an identification strategy to disentangle changes in resources stocks from changes in productivity. Third, productivity measures may use estimates of stock size from assessments that incorporate time-varying catchability. This can confound the productivity measures, since productivity measures are only one of several potential sources of time-varying catchability. Again, an identification strategy is required. Fourth, productivity measures can employ absolute resource stock measures or relative changes in stocks, where the latter are generally considered more reliable and the former are not always available (e.g., from yield-per-recruit analysis [15]). Fifth, catchability may be effort-dependent, in which catchability varies with the level or scale of effort and the crowding externality [12]. However, other than noting knowledge spillovers that depend upon the level of investment in physical capital, this fifth topic is left for future discussion.

Before proceeding to consider the first three questions in greater depth, note that CPUE, a widely used measure of relative stock abundance and/or of local density, is an average product of effort and a partial productivity measure, since only a single input is used, such as a measure of fishing time (days, sets). In contrast, total factor productivity (TFP) is measured using all inputs, since TFP is measured as a residual after accounting for changes in all inputs, including resource stocks [16]. CPUE, when a partial productivity measure, may not accurately measure relative stock abundance, since not all inputs that affect fishing mortality are captured.[7]

2.2. Density-dependent catchability

Productivity measures, bioeconomic models, and stock assessments are all potentially subject to density-dependent catchability of harvesting vessels. A stock is not evenly distributed and changes spatially and temporally as its abundance changes [11,12,18,19]. In addition, fisher search is non-random or there can be gear saturation or density-dependent gear avoidance behavior, all of which can affect catchability in fisheries and surveys. Fleet spatial expansion can also affect density-dependent catchability.

Density-dependent catchability has implications for use of fishery-dependent and fishery-independent data. Stock assessment from a restricted part of a stock's range requires the stock to decrease in the same proportion across the entire range in which it is fished, a linear relationship [11,18,19]. For CPUE to represent abundance, averaging catch rates for any time period over only areas fished requires assumptions about what catch rates would have been in areas that had not yet or were no longer fished [11,20]. Ignoring unfished areas and averaging only over areas fished (i.e., using fishery-dependent data) essentially assumes fleets behaved the same in both fished and unfished areas, and leads catchability and productivity measures to potentially exhibit "hyperstability" or "hyperdepletion." Density-dependent

[3] The most common source of fishery-dependent data is catch and effort information from commercial or recreational fishers. Surveys and life history studies provide some of the most important sources of fishery-independent data. Population assessments have long recognized these issues as is discussed herein.

[4] Source-sink larval or density-dependent fish movements between patches or meta-populations are not biologically supported spatial processes with albacore (and most other small and large pelagic species and some demersal species) [14]. Albacore broadcast spawn, and age 2–5 albacore migrate along the North Pacific Transition Zone.

[5] The discussion follows the bulk of the population dynamics literature and is couched in terms of surplus production models, in which catchability may be represented by a single coefficient. However, Eric Thunberg (personal communication) notes that in age-based or cohort models, catchability is represented as a vector. If selectivity is dome shaped, density-dependent growth may influence the number of ages that remain susceptible to the gear.

[6] An anonymous referee noted that the traditional view of density-dependent catchability posits that even if data are available for the whole population, the observed trend in the index does not track that of the population due to a nonlinear relationship between them. This is a different but related, problem to only having data for a portion of the population.

[7] Excluding the resource stock leaves a TFP residual that reflects changes in both productivity and the resource stock [16]. CPUE as a measure of abundance faces considerable problems [17]. Further, CPUE used as a measure of abundance in productivity and standardization studies creates an identification issue in regression models, such as general additive models or generalized linear models, to analyze and explain variations in stock abundance or to standardize effort. The identification issue arises when catch and/or effort are on both sides of the equation, leading to simultaneity bias, and when the regressor effort is a behavioral variable (a choice variable decided upon by fishers) and endogenous, potentially leading to biased and inconsistent parameter estimates

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